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ASBESTOS SUBSTITUTE PERFORMANCE ANALYSIS

Revised Final Report

February 1982

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SECTION 1

INTRODUCTION

Asbestos is a generic term for a number of naturally occurring hydrated silicate minerals that, when crushed or processed, separate into flexible fibers made up of fibrils. There are six common asbestos forms: chrysotile (or "white asbestos"), anthophylite, amosite, crocidolite (or "blue asbestos"), tremolite/actinolite. Chrysotile asbestos is the form most commonly used, since it is in ample supply. It accounts for about 95 percent of all the asbestos commercially consumed.[1] In addition to the different forms of asbestos, there are varying grades, as well. Chrysotile asbestos is graded according to the length of its raw fiber. The fibers are distinguished by separation into eight groups numbered 1 through 8. Group 1 contains relatively long fibers (up to 6 inches in length), while successive groups contain progressively shorter fibers. The length of the fiber as well as the form of the asbestos determine the specific properties of the asbestos and therefore the uses to which the fibers are put. All forms of asbestos exhibit properties which make them useful in the production of industrial, commercial and consumer goods. Specifically, asbestos fibers are strong, durable, resilient, chemically and thermally stable, and resistant to heat, corrosion, rot, vermin and chemicals. This diversity of properties has led to the widespread use of asbestos in select mass-produced consumer items. Today, an average United States resident could expect to find asbestos around his home in such products as: floor tile, house siding, automobile brakes, appliance insulation, roofing sealants, municipal water supply pipe, sewer mains and fireproofing for the family wood stove. In all, approximately 1.6 kg (3.6 lbs) of asbestos are used in the country annually (1980) for every man, woman and child.*

Asbestos use is typically reported by major product categories. These categories and their relative asbestos consumption rates are as follows:

Product category	Metric tons consumed, 1980	Percent of U.S. consumption
Asbestos paper	90,020	25.1
Friction products	43,700	12.2
Asbestos-cement pipe	144,000	40.2
Asbestos-cement sheet	7,900	2.2
Floor tile	36,080	10.1
Gaskets and packing	12,300	3.4
Paints, coatings and Sealants	10,900	3.0
Plastics	1,500	0.4
Textiles	1,900	0.5
Miscellaneous	10,400	2.9
Total	358,700	100

*Assumes 1980 U.S. population of 210 million.

These data were extracted from the Bureau of Mines asbestos consumption figures for 1980.[1] It should be noted that 1978 figures were 619,400 metric tons total[1] consumption, or a 42 percent decrease in asbestos consumed during this 2-year period. Individual product categories differ slightly from those reported by the Bureau of Mines. For this report, the paper category includes paper products, thermal and electrical insulation, and roofing felt. In addition, that portion of the flooring products asbestos consumption which is attributable to flooring felt (approximately 60 percent),[2] has also been defined here as "paper products." These changes were made to consolidate the presentation and group together all products which are manufactured by conventional paper-making equipment.

Public health concerns over excessive exposure to asbestos fibers and increasing regulation of the handling and use of raw asbestos have prompted manufacturers to seek substitutes for asbestos containing products. These substitutes take the form of fiber replacement in the original asbestos product or a completely new asbestos-free alternative. This report details the status of these substitutes.

A section of this report is dedicated to each major product category. Each section considers both the asbestos product and the potential substitutes. For both the substitute and the asbestos product, the following items are addressed:

- Special qualities required,
- Product composition,
- Uses and applications, and
- Product manufacturing summary, including a description of the manufacturing process, plant locations, and production volumes.

In addition, each section lists:

- Methodology, including search strategy and a summary of contacts,
- Cost comparison (asbestos and nonasbestos) product,
- Current trends,
- Conclusion, and
- References.

Substitutes are grouped into both fiber and product descriptions for each category. Sections which discuss multiple asbestos-containing products first address each product, its manufacturing description, and its substitutes independently. The cost comparison information, trends, and conclusions for all products is kept apart and discussed at the end of the section.

When available, the cost data are reported in 1980 dollars. These data should be used for comparison purposes only, as actual costs are dependent upon a variety of locally influenced factors. Every effort has been made to include the major asbestos product substitutes that are commercially available. However, due to constant changes in this area, the list of substitutes for any section may not be exhaustive. Nonetheless, this report covers, in detail, the current status of asbestos product substitutes.

REFERENCES

1. Clifton, R. A. U.S. Bureau of Mines, Mineral Industry Surveys. Asbestos in 1978. August 22, 1979, and Clifton, R. A., Preprint from the 1980 Bureau of Mines Minerals Yearbook. Asbestos, p. 4.

2. The Resilient Floor Covering Institute. Comments on the Advanced Notice of Proposed Rulemaking on the Commercial and Industrial Use of Asbestos Fibers. Submitted to the U.S. EPA, Washington, D.C. February 18, 1980.

SECTION 2

PAPER PRODUCTS

INTRODUCTION

Asbestos Paper Products are many and varied but may be defined in terms of nine general categories, listed in order of descending annual (1980) consumption rates:

- Flooring felt
- Roofing felt
- Beater-add gaskets
- Pipeline wrap
- Millboard and rollboard
- Specialty papers
- Commercial papers
- Electrical insulation
- Beverage and pharmaceutical filters

U.S. Bureau of Mines estimates indicate that, as a whole, asbestos paper products consumed 90,020 metric tons of asbestos in 1980. This represents 25 percent of all asbestos consumed in the United States for this year.[1] Each category within the general paper products scope is covered separately in this section; commercial papers include general insulation, muffler paper, and corrugated paper; specialty papers covers cooling tower fill, transmission paper, chlorine electrolytic diaphragms and decorative laminates. The only available estimate on relative asbestos use in the paper products category* is presented in Table 1.

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*Note: the breakdown of descending annual consumption rates given on this page is derived from this table.

TABLE 1. ESTIMATED CURRENT[Δ] ANNUAL CONSUMPTION OF ASBESTOS FIBER IN PAPER PRODUCTS[2]

Category	Metric tons consumed	Percent of consumption
Flooring felt	40,500	45
Roofing felt	29,700	33
Beater-add gaskets	8,100	9
Pipeline wrap	5,040	5.6
Millboard	2,700	3.0
Electrical insulation	360	0.4
Commercial paper		
General insulation	1,170	1.3
Muffler paper	--	NA
Corrugated paper	--	NA
Specialty papers		
Cooling tower	810	0.9
Transmission paper	360	0.4
Chlorine electrolytic diaphragms	990	1.1
Decorative laminates	--	NA
Beverage and pharmaceutical filters	30	0.03
Total paper products	90,020*	100

NA = Not available but considered small.

*Total should be increased slightly to include subcategories without figures.

ΔBased on data from a 1979 report (Gordon & Riddle), a 1976 A. D. Little report, industry contact in 1979, and 1980 Bureau of Mines figures. Assumptions include the postulation that the percentage breakdown for consumption remained approximately the same for 1980.

This table has been revised from original 1979 format, to agree with the noted downward trend in asbestos consumption. In 1979, for example, flooring felt accounted for 118,000 metric tons of asbestos, roofing felt for 82,000 and total consumption for the paper products category rested at 260,000 metric tons. One year later, Bureau of Mines figures report total paper consumption* at only 90,020 metric tons, with flooring felt decreased to 40,500 mt and roofing to 29,700 mt. This table carries the same percentages of use into 1980, as data on varied percentages does not currently exist. However, figures should be used accordingly.

Asbestos consumption appears to be declining for several reasons. One is a noted downturn in the U.S. economy as a whole. This has led to a building slump which further reduces the need for asbestos materials. In addition, competition from the expanding substitutes market cannot be ignored.

Within this section each individual category is broken down into:

- Asbestos product
  - Special qualities--product composition
  - Uses and applications
  - Manufacturing summary--process, name and number of manufacturers, and production volumes
- Substitute product
  - Methodology--search strategy and summary of contacts
  - Special qualities--product composition
  - Uses and applications
  - Manufacturing summary--process, name and number of manufacturers and production volumes

In addition, an overall cost comparison, current trends, and conclusion are presented at the end of the section.

FLOORING FELT

Asbestos Product

Special Qualities--
Asbestos is used in flooring felts to add dimensional stability and other important properties necessary in flooring such as high moisture, rot, and

*Figures arrived at by product mix of BOM figures by GCA.

heat resistance. These qualities have allowed asbestos to successfully compete with previously successful flooring felt materials—organic and jute felt--such that asbestos has now largely replaced them as a backing material.

It should be understood that this category covers the asbestos paper product, felt, which, in the past was used extensively, by itself, as an underlay for other flooring surfaces but now is used mostly in a combined form as flooring carrier to vinyl-asbestos sheet flooring. This sheet flooring product is covered under the Floor Tile section of this report as substitutes to the floor tile and sheet products are similar.

Product Composition--

Asbestos flooring felts are composed of about 85 percent asbestos and 15 percent latex binder.[3] The latex binder is normally a styrene-butadiene type, although acrylic latexes have been used in the past.[4] Chrysotile asbestos is used with the shorter fibers, grades 5 through 7 predominating. These grades are normally obtained from Canada although limited quantities are available domestically. The domestic grades are mostly used, however, to make vinyl-asbestos floor tiles in which the asbestos fibers are used as a reinforcing agent for the vinyl and not as a backing (see Floor Tile section).

Uses and Applications--

Most asbestos flooring felt is sold commercially and is used in residential applications. Due to its special qualities, asbestos felt backing is used with vinyl sheet flooring as a general floor surfacing medium. Asbestos backing is particularly useful in prolonging floor life when moisture from below the surface is a problem.

A small quantity of flooring felt is produced for use without vinyl coating.[4] The rolls are made in smaller sizes than the rolls intended for vinyl coating. This uncoated asbestos flooring felt is directly bonded (with adhesives mopped on) to the floor deck at the job site and the final flooring, which may be vinyl tiles, sheet vinyl, or carpeting is applied on top of the felt. This particular use of asbestos felt is normally associated with concrete bases where moisture exists. The asbestos paper helps to transfer the water to the walls. The use of asbestos flooring felt without a vinyl coating represents only a small fraction of its total use. However, it appears that this use is becoming more popular.[6]

Asbestos Product Manufacturing Summary--

Manufacturing process--Asbestos flooring felt is formed on conventional papermaking machines with the end product in latex coated rolls. The felt is then manufactured into a final consumer product by coating one side of the felt with a resilient vinyl type surfacing, typically a plastisol or an organisol. Plastisols are dispersions of homopolymers and vinyl acetate copoymers of vinyl chloride in conventional polyvinyl chloride plasticizers; an organisol is a plastisol containing a volatile diluent that lowers viscosity.[4] These vinyl surfaces are applied to the asbestos felt by various extrusion coating, laminating, and spread coating methods.

The basic operations steps in coating asbestos flooring felt with vinyl include the following. The base asbestos felt roll is unwound and fed continuously into the coating machinery. The vinyl surface is placed onto the asbestos felt by the coaters; this process may also include various printing techniques to enhance the appearance of the final flooring surface. The vinyl plastisol, which is surface applied, can be colored by various additives or techniques. Vinyl-coated felt is passed through a fusion oven because plastisols cannot air dry; they require fusion temperatures of at least 121°C for the copolymers, and 149°C for the homopolymers. Most of the heat from the laminate is removed by chill rolls made of chrome-plated steel within which high-velocity water is circulated. The sheet surface may be further decorated by various chemical or printing methods before or after cooling. The vinyl sheet structure is then edge-trimmed by razor, score, or shear cutting and wound into a roll which is sold to customers, primarily in the construction and floor-laying industry.

Name and number of manufacturers--Two major producers of asbestos flooring felt are listed below:

Manufacturer*	Location
Armstrong Cork	Fulton, New York
Congoleum Industries	Cedarhurst, Maryland

Armstrong Cork ships its product to their Lancaster, Pennsylvania, factory for vinyl coating. The bulk of Congoleum's felt is sent to other Congoleum plants for coating, although some is sold to a number of independent flooring companies.

Brown Company of Berlin, New Hampshire, made asbestos flooring felt in the past, but terminated their production a few years ago.[4]** GAF Corporation formerly manufactured asbestos flooring felt in Erie, Pennsylvania, but announced a commitment to end sales of asbestos paper products effective April 1, 1980.[8] This has been confirmed by April 1981 phone contact.[9]

Production volumes--Asbestos flooring felt is currently estimated to consume about 40,500 metric tons, or approximately 45 percent of the asbestos used in this product category each year placing it topmost among paper products in annual fiber consumption.

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*Nicolet Industries' plant at Norristown, PA, once manufactured asbestos flooring felt but is now closed. New owners have bought out Nicolet and are apparently working mainly on the production of nonasbestos products such as sheet packing, millboard and monolithic products.[7]

**From this phone contact, it can be assumed that this means 1975-1976.

Substitute Product

Methodology--

Search strategy--Information about asbestos flooring felt was obtained through both a literature search and phone contact with industry representatives.

Summary of contacts--The following companies were contacted in the process of researching this section of the report. Attempts were made to reach other industry representatives, such as GAF, Erie, Pennsylvania, and Fabri-Glass Incorporated, Moline, Illinois, but were unsuccessful.

- Mr. M. Schaum, Congoleum Incorporated, Cedarhurst, Maryland, August 1979
- Mr. H. Davies, Nicolet Industries, Norristown, Pennsylvania, July 1979
- Mr. E. Morse, Brown Company, Berlin, New Hampshire, July 1979

Special Qualities--

The advantage of asbestos-backed vinyl, as mentioned previously, lies in its dimensional stability and moisture resistance. Dimensional stability refers to the ability of the flooring to stretch and contract with temperature changes and "settling" of the floor deck. The flooring should be able to withstand these conditions without cracking, warping, or otherwise deteriorating.

The recent development of backless vinyls is putting market pressure upon asbestos-backed vinyl. "Backless" sheet vinyl is actually a sheet flooring with a special vinyl backing; this special backing has excellent elastic properties which allow the flooring to stretch and contract under the most severe applications. Also, this backless vinyl is easier and faster to install than asbestos-backed vinyl. It requires a minimum of adhesive deck bonding, usually only around the edges, and can be stapled into place.

Foam-cushioned backings, formed by attaching a cellulose foam layer to sheet vinyl surfacing, are also actively competing with asbestos backings. Here again, the backing has very good dimensional stability and moisture resitance. Also produced is a flooring system "sandwich" consisting of a vinyl surface, a foam cushion midsection, and an elastic vinyl backing. Backless vinyl and foam-cushioned backings appear to be good, commercially available alternatives to asbestos-backed vinyl flooring.

Lextar reports that they have a very active program to replace asbestos felt in roll vinyl flooring and have designed a performance effective felt for this purpose. Information on the composition and potential cost of this product may be found in subsequent sections.[10]

The choice between carpeting and wood floors is usually made by customer preference. Linoleum is rarely used at this time; there are no domestic producers of linoleum, only importers. Residential customers also have the option of buying the successful "place and press" vinyl tile squares instead of a system which may include asbestos-backed vinyl.

An alternative such as organic floor backing has proven unacceptable where moisture is present, and cannot be recommended for on or below grade use.

Product Composition--

Industry sources have begun research on other fibrous materials that could replace asbestos; potential substitutes that have been studied include fiberglass, cellulose, Nomex, and other polymeric fibers. At present, none of these have been found to be an acceptable substitute for asbestos, and therefore there do not appear to be any commercially available substitutes for asbestos-backed flooring vinyl at this time. However, Lextar of Wilmington, Delaware, reports active research towards production of flooring felt composed of their Pulpex fiber, glass fiber, fillers, and binder resins.[10]

Uses and Applications--

As previously discussed, asbestos substitute materials are used as flooring coverings, replacing the need for asbestos felt backing in vinyl floors, either by providing a complete covering in and of itself as in carpeting, wood floors, and vinyl tile squares ("place and press") or by providing another type of backing as in foam-cushioned backings and even backless sheet vinyl. These floor coverings all display various properties which must be considered and weighed by the customer before final product selection.

Substitute Product Manufacturing Summary--

<u>Name and number of manufacturers</u>--Substitutes to flooring felt include the various types of flooring systems commercially available. Fiber substitutes are not a viable option at this time; however, companies such as Lextar, a Hercules/Solvay Company, are performing extensive research in this area. Such options as carpeting, backless vinyl flooring, foam cushioned-backed vinyls, wood, vinyl-asbestos floor tiles, and linoleum all act as readily available substitutes to asbestos flooring felt. The consumer choice between these products and asbestos for flooring rests on personal tastes, availability, ease and type of application, cost, etc. There are many different manufacturers of these competitive products.

<u>Production volumes</u>--The production volumes of each of the substitute products were not available at this time. For widely used floor coverings such as carpeting and wood floors, the production volumes are expected to be high. In contrast, production volumes of the newer replacement products are only sufficient for testing purposes at this date.

ROOFING FELT

Asbestos Product

Special Qualities--

Asbestos is used in roofing felts because of its dimensional stability and resistance to rot, fire, and heat. Rot resistance is particularly important due to roofing felt's use on flat or nearly flat roofs with poor drainage. Given the rapid heating and cooling of roof surfaces some cracking may occur, allowing for water penetration, particularly in damper climates or in areas where snow, subject to periodic melting, has accumulated on the rooftop. Asbestos felt resists cracking, perhaps better than any competing product.

Asbestos roofing is considered by many roofers to have an exceedingly long life. Some contractors contacted estimated that it would last indefinitely.[11,12] To date, it has been in use for over 100 years with many individual applications lasting up to 40 years.[13]

Product composition--

Asbestos roofing felts are composed principally of asbestos fibers (85 to 87 percent).[3] Other materials, such as wet and dry strength polymers, kraft fibers, fiberglass, and mineral wool, are also often used as fillers. Sheets are saturated with coal tar or asphalt. The paper is made in either single or multilayered grades and may have fiberglass filaments or wire strands embedded between paper layers for reinforcement. Usually grade 6 or 7 chrysotile fiber imported from Canada is used in roofing felt.

Uses and Applications--

Two types of built-up roofs are used on flat surfaces. The most common system, sometimes called a hot roof, involves the application of several plys or layers of roofing felt alternating with asphalt or tar, often with a top layer of gravel imbedded in the asphalt. The layers used may be organic, fiberglass or asbestos felts. The second system is a cold roof not requiring the application of hot tar or asphalt. Another, newer system of roofing, which has been marketed in the United States for only 3 to 4 years, is a single-ply membrane made of rubberized asphalt, PVC, or butyl rubber. Gravel may be applied on the top surface as a ballast.

Asbestos roofing is primarily used for built-up roofing and as an under layer for other roofing products. Roofing, the top cover of building structures, includes the roof deck, insulation (if any), and the overall weather protection surface. Asbestos roofing felts go back to the 1870s and the orginal product line produced by H. W. Johns.[13] In 1968 the American Society for Testing and Materials issued a recommendation for the use of asbestos felt on built-up roofs[3] which helped asbestos felts penetrate the roofing market. However, the growth of asbestos roofing felts has tapered off and is expected to continue to decline due to competition from substitute materials.[14]

Built-up roofing is commonly prepared at the job site by cutting lengths from product rolls to the required sizes and shapes. "Built-up" refers to the practice of layering paper lengths on top of each other while hot roofing tar is mopped between layers for adhesion and/or additional weather protection. Built-up roofing is attached to the roof deck by adhesive tars or by nailing if the roof deck can accept nails. There are three basic types of built-up roofing: gravel surface, smooth-surface, and mineral surface.[15] Gravel surface roofs and smooth-surface roofs are constructed similarly except in the final surfacing; instead of the light mopping of asphalt used in smooth-surface roofs, for gravel roofs a flood coat of hot asphalt is applied and covered with aggregate gravel which serves more for appearance than for actual protection. In mineral surface roofs, roofing paper is sealed with weather grade asphalt embedded with opaque, noncombustible mineral granules resulting in a roof in a choice of colors. In all built-up asbestos roofing, saturated roofing felt is further coated with asphalt and tar during installation, minimizing any potential fiber release during the roofing life cycle.

As an under layer for other roofing products, asbestos roofing paper is attached to the roof deck, again by tar adhesives or by nailing. It is then covered by shingles, cement sheets or other forms of common roofing. Asbestos paper, used as an underlayer, is generally applied in industrial and commercial roofing rather than for residential use.[13]

According to various industry sales persons, at least 60 percent of asbestos roofing is applied during reroofing jobs while the remainder is applied to new construction. In reroofing, removal of the old roof is contingent upon several factors: the type and condition of the old roof and customer perference. Aggregate roofs, such as gravel surface, must normally be removed because they lack a smooth surface onto which the new roofing can be attached. A badly damaged or warped roof must be removed for the same reasons and because of the possibility that the roof deck itself has been damaged and requires repair. On roofing jobs where the new roof may be built over the old roof, the customer may want the old roof removed to reduce roof weight. Conversely, the customer may not want the old roofing removed due to added costs of disposal.

Asbestos Product Manufacturing Summary--

Manufacturing process--Roofing paper is a felted asbestos sheet manufactured with varying formulations on conventional papermaking machines, then converted into roofing felt by saturation with asphalt or coal tar. The felt is pulled through a bath of hot asphalt or coal tar until it is thoroughly saturated. After saturation, the paper passes over a series of hot rollers to set the asphalt or coal tar into the paper. It may, on occasion, be coated with extra surface layers of asphalt. The felt's thickness or grade and the amount of asphalt coating required depend upon the product's intended use. After saturation and coating, the paper passes over a series of cooling rollers that reduce the paper temperature and provide a smooth surface finish. Paper given extra coats of asphalt must be treated to prevent adhesion between layers when the paper is rolled. The felt is then air-dried, rolled and packaged for marketing.

Name and number of manufacturers--There are two major domestic manufacturers of asbestos roofing felt, as seen in Table 2. In the past, GAF and Johns-Manville also manufactured roofing felt, but this product line has been discontinued.[9,17]* Plants listed make base felt which is later saturated with asphalt. Saturation plants are not necessarily located at the sites where the base felts are made; manufacturers of base felts may have a number of saturation plants.

TABLE 2. MANUFACTURERS OF ASBESTOS ROOFING FELT

Manufacturer	
Celotex Corporation A subsidiary of Jim Walters Co.	Lockland, OH Linden, NJ
Johns-Manville Corp.	*
Nicolet Industries	Ambler, PA

Production volumes--Production of asbestos roofing felt in 1980 was estimated at 29,700 metric tons, or 33 percent of the asbestos paper market. Table 3 gives estimated company production and market shares for 1975. Johns-Manville Corporation and GAF Corporation, which together produced two-thirds of the asbestos roofing felt in 1975 will no longer produce asbestos paper products after 1980[8,16,18] (however, as stated previously, J/M will continue to saturate asbestos felt).

TABLE 3. ASBESTOS ROOFING COMPANY PRODUCTION AND MARKET SHARES (1975)[3]

Company	Estimated production (metric tons)	Market share (percent)
Johns-Manville Corporation	80,000	67
Celotex Corporation	17,200	14
Nicolet Industries	12,500	10
GAF Corporation	10,300	9
	120,000	100

*Johns-Manville does not produce asbestos roofing felt in the U.S.; it is produced in a Kinsey Falls, Montreal, J/M plant. However, J/M does saturate asbestos felts (from Canada) with asphalt at the following U.S. locations: Manville, NJ; Waukeegan, IL; Pittsburg, CA; Los Angeles, CA; Savannah, GA.[16]

Substitute Products

Methodology--

Search strategy--The methodology utilized to research substitutes for asbestos roofing felt consisted of both primary and secondary data collection. In primary data collection, major manufacturers, distributors, and roofing contractors dealing with organic, fiberglass, and single-ply membrane roofing systems were contacted by phone. Manufacturers were a primary source of technical data on roofing systems including the composition, qualities, and performance of roofing felts, single-ply materials, historical trends, market characteristics, and material costs. Roofing contractors within the Boston area were contacted to determine regional costs, construction practices, market demand, and perceived health problems associated with various roofing felts. A building distributor was called to cross-check regional trends of demand for these products and to identify contractors using organic, asbestos, and fiberglass felts.

Summary of contacts--The following individuals were contacted by phone to obtain information for this section.

- Mr. Charles McLaughlin, Estimator, Card M. Roofing, Somerville, MA
- Mr. Andy Noble, Assistant Sales Manager, Koppers Company, Eastern Division, W. Orange, NJ
- Mr. Greg Perkins, R-625 Products Marketing Manager, Owens-Corning Company, Toledo, OH
- Representative, Water Guidance Systems, Brainford, CT
- Representative, Carlisle Tire and Rubber Division of Carlisle Corporation, Carlisle, MA
- Mr. Bob McIntyre, Gates Engineering Company, Wilmingon, DE
- Salesman, Bradeo Supply Corporation, Woburn, MA
- Mr. S. Mullincamp, Research Director for Roofing Products, Owens-Corning Company, Granville, OH
- Sales Manager, Asbestos Roofing Felts, Johns-Manville Corporation, Manville, NJ
- Estimator, Gilbert and Becker Roofing, Dorchester, MA
- Estimator, McGrath Roofing Company, Dorchester, MA
- Dr. Philip Enterline, University of Pittsburgh, Pittsburgh, PA

- Mr. A. Padavani, Johns-Manville Corporation, Denver, CO
- Mr. Jim Contorno, Bird & Son Co., Chicago, IL
- Mr. Henry Molvt, Koppers Company, West Orange, NJ
- Ms. Jayne Porter, Monier Company, Orange, CA
- Mr. Henry Chess, PPG Industries, Pittsburgh, PA
- Mrs. McKinney, Reichold Chemical Co., Irwindale, CA

Special Qualities--

Alternatives to asbestos roofing felt include organic felt, fiberglass felt and a rubberized single-ply membrane roofing system. A well-installed, built-up roof with an organic felt, good insulation and proper expansion joints may last 20 years or more. As single-ply membrane systems are new to the market their durability is not yet assured.

Organic felts, fiberglass felts and asbestos felts are all saturated with coal tar or asphalt before use. Fiberglass felt is stronger, more durable, longer wearing and more heat resistant than organic felt, but according to some, because the material is so new, conversion will require both manufacturing experience and applicator training.[19]

Single-ply membrane roofing is applied to the roof deck cold, an important attribute when city ordinances or other considerations prohibit hot tar. Some central business districts have ordinances to prevent installation of built-up roofing due to the dangers associated with tar kettles. At 343°C to 399°C the tar or asphalt mixture will burn and has, in some cases, exploded causing damage to property and pedestrians. In these instances only the newest of the systems (the single-ply membrane system) could be applied because it does not require hot tar or asphalt.

Johns-Manville produces the Glas Ply built-up roofing system, a specially constructed three-ply membrane with exceptional uniformity and natural venting characteristics. The asphalt-impregnated fiberglass ply felts meet the 200 psi (at -18°C) tensile strength preliminary performance criteria recommended by the National Bureau of Standards. It requires less mopping asphalt than other systems because more asphalt is impregnated during manufacturing. The material is compatible with asbestos base felts and Johns-Manville Asbestile® flashing system. Uniform porosity allows deep penetration of asphalt leading to improved interply adhesion.[20]

Product Composition--

Organic felt is made primarily from cellulose fibers on papermaking machines and, as with all roofing felts, is saturated with coal tar or asphalt.

Fiberglass roofing felt is made of glass or refractory silicate mixed with binder. The exact composition is not available.[21] There are three basic manufacturing processes. Owens-Corning invented the continuous filament process in 1964. The other processes involve shorter fibers; one uses a steam blown process and the other employs a wet slurry process similar to the basic papermaking process.

Single-ply membrane roofing is a laminate of a modified bitumen or rubber and plastic or PVC. Typical is Koppers KMM System, a 160-mil, five-layer laminate composed of a thick plastic core protected on each surface by a layer of modified bitumen and an outer film of polyethylene. Such a membrane is loosely laid (i.e., without layers of tar) with a covering of loose gravel or with a base surface where protection from the elements is afforded by other means. The edges of the membrane are sealed together through the application of heat, essentially ironing them together, or through the application of a cold adhesive.

Uses and Applications--

Organic felts have been used in the United States in built-up roofing systems for 25 years. Fiberglass roofing, although invented more than 15 years ago, has only recently has been accepted for widespread use. The rubberized single-ply membrane roofing system has been used in the United States for only 5 to 6 years but has been employed in Europe for 20 to 25 years.

Although in terms of strength and durability organic felt rates lowest of the three felts, it is still the most widely used. Of the small sample of roofing contractors contacted, it was estimated that 80 to 90 percent of their built-up roofs utilized organic felts. Four or five other roofing companies contacted used organic felts exclusively. The primary reasons for this include the fact that organic felt is the lowest cost system and has been on the market longest. Its qualities are well known.

Currently there are at least four companies manufacturing single-ply membrane roofing systems.[22-24] One of the chief advantages of this system, as mentioned earlier, is that it can be applied to the roof deck cold and thus avoids the need for hot tar or asphalt. Due to the dangers associated with hot tar roofs in central business districts, some cities have considered prohibiting the use of hot tar, encouraging the use of cold membrane systems.

Tile roof, becoming more common in the west and southwest, can be installed when the roof surface is pitched but is unsuitable for flat, built-up roofs. Where tiles are used there is no need for any type of underlay.

Substitute Product Manufacturing Summary--

Name and number of manufacturers--At present, the fiberglass roofing felt market is dominated by Owens-Corning. Other companies such as PPG Industries and Reichold Chemical Company manufacture the basic fiberglass strand and sell this to the paper manufacturers. Most of the producers of asbestos roofing felt have diversified to manufacture competing nonasbestos products along with their original output. Both Johns-Manville and Celotex produce organic felts, with Johns-Manville being one of the biggest manufacturers. Bird & Son of Chicago, Illinois, Koppers Company in West Orange, New Jersey, and CertainTeed Corporation also make organic roofing felts. The three major companies produce both types of felt products, depending on market conditions and consumer demand.[25]

Single-ply membrane roofing is made by Carlisle Tire and Rubber Company, a Division of Carlisle Corporation in Carlisle, Massachusetts; Water Guidance Systems, a subsidiary of Plymouth Rubber Company in Brainford, Connecticut; Koppers Company, Eastern Division, West Orange, New Jersey; and Gates Engineering Company, Wilmington, Delaware.

Production volumes--Owens-Corning is the largest producer of the nation's fiberglass roofing felt. When the conpany's organic felt sales are included, it is responsible for a good portion of the total roofing felt market.[26]* Owens-Corning has presented a continuous filament Permaply product called R-265 which was developed in 1964.[21] Several other companies apparently imitate this product with their own.

BEATER-ADD GASKETS

Asbestos Product

This subsection considers beater-add gaskets, so named because of the process used in their manufacture--asbestos fibers and binders are added in the beaters of the papermaking process. Other types of asbestos gaskets, such as compressed sheet gaskets, are not paper products and are discussed elsewhere, in the Packing and Gaskets segment of this report.

Special Qualities--

Asbestos is used in beater-add gaskets because of its unique combination of qualities. It is not only heat resistant, resilient, and strong, but is also chemically inert, which is important for many chemical applications. Metal sheathed or jacketed gaskets take particular advantage of the resilience of asbestos.** No other material currently available possesses all of these characteristics for beater-add gasket applications. However, Rogers[27] reports that there are several commerically viable substitutes for asbestos gasket papers available at the current time (see the Substitutes section), both through their company and the other companies listed in the Substitute Product Name and Number of Manufacturers section; other comments to the Draft version of this report such as those from Victor Products Division of the Dana Corporation substantiate this finding.

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*Due to the competitive nature of this industry, phone contact with Owens-Corning (11-17-81) indicated that the company prefers not to relate production volume percentages. Therefore, adjectives are used to describe production versus specific percentages.

**Information from unpublished OSHA document on asbestos.

Product Composition--

Beater-add gasket papers are composed of 60 to 80 percent asbestos fibers and 20 to 40 percent binders, usually latex. The latex polymer used determines the material's suitability for use in water, aqueous solutions, oils, fuels, or chemical environments. Polymers used as binders in addition to latex include natural rubber, various synthetic rubbers, neoprene, nitrile, and other elastomers.

Nearly all domestic beater-add gaskets are formulated with various grades of chrysotile asbestos although in the past, small amounts of crocidolite asbestos were used on customer request since crocidolite is preferable to chrysotile in applications involving strong mineral acids and alkalis. At present, no domestic manufacturers report using crocidolite asbestos in gasket paper.

Uses and Applications--

Gaskets are installed to obtain tight, nonleaking connections in piping and other joints. Asbestos gaskets are used mainly by the automotive industry in a variety of applications, including heat gaskets, carburetor gaskets, manifold gaskets, and oil and transmission gaskets. In addition, asbestos gaskets are widely used in other transportation applications, such as trains, airplanes, and ships. Further, they are used in industrial and commercial equipment of all varieties, including heat exchangers, boilers, furnaces, and pipe connections. The chemical industry uses asbestos gaskets extensively for piping, reactors, and equipment connections because of the high chemical inertness of asbestos. Chrysotile gaskets are used when hostile environments require glass reactors and piping; the gaskets are sometimes jacketed with a polytetrafluoroethylene (teflon) sheath. A small number of crocidolite gaskets have been made in the past, primarily for use in the chemical industry because crocidolite, or blue asbestos, is even more inert to certain chemicals than chrysotile. Blue asbestos gasket paper has also been used as a layering material in sulfuric acid towers; chrysotile asbestos is no longer believed to be used in this application.

Asbestos Product Manufacturing Summary--

Manufacturing process--Beater-add gaskets are manufactured on papermaking machines as described previously and are considered paper products. "Beater-add" gaskets are so named due to the fact that the binder is added during the beater process in the production stages. Compressed sheet gaskets are covered in the Gaskets and Packings section of this report.

Beater-add asbestos gasket paper is usually produced in a sheet or a sheet roll that can vary in thickness from that of very thin paper to that of millboard. The manufacturing process is similar to that of all asbestos paper products. Gaskets fall into a product category (along with insulation paper, flooring carrier, commercial and specialty papers, and electrical insulation paper) requiring no further processing after the original paper forming process other than cutting to size.

While some manufacturing plants making beater-add gasket paper may convert this intermediate product into a final product, most production is sold to fabricators who make the final gasket. Gasket fabrication takes many forms. Die-cutting is normally the first step. Here the gasket sheet is machine cut to customer specified sizes and dimensions. However, die-cut gaskets may be further processed by reinforcing the gasket with wire insertions or by sheathing the paper with various metals, foils, plastics, or cloth. Specific fabrication is, of course, dependent upon the final use.

Name and number of manufacturers--Domestic manufacturers of beater-add gasket paper are listed in Table 4. Most gasket paper produced is sold to fabricators who make the final consumer product. The 1978 edition of the Thomas Register lists almost 200 fabricators of asbestos gaskets, but this includes fabricators working with compressed sheet gaskets in addition to those working with beater-add gaskets.

TABLE 4. MANUFACTURERS OF ASBESTOS BEATER-ADD BASKET PAPER

Armstrong Cork	Fulton, NY
Hollingsworth & Vose	E. Walpole, MA
Boise Cascade	Beaver Falls, NY
Colonial Fiber Company*	Covington, TN
Nicolet Industries	Norristown, PA
Johns-Manville	Manville, NJ[29]
Rogers Corp.	Rogers, CT[30]†

*Manufacturers asbestos gasket paper, but not the final product.[28]

†Some lines have been discontinued; plans are to convert to nonasbestos in the near future (Telecon, April 1981).

Production volumes--Annual asbestos fiber consumption in beater-add gasketing was approximately 9 percent of the paper total, making it the third largest use of asbestos in the paper products group. Only flooring felt and roofing felt use more asbestos. Demand for asbestos gasket paper was expected to increase in the future, but, due to the downsizing of automotive engines, there may be a downturn in the use of asbestos gasket paper rather than growth. The annual growth rate through the 1970s was developed through technological change to asbestos paper gaskets from metallic gaskets. This technological change is complete and cannot be counted on to bring about further growth.[13,31] Although a recent study[3] expects an upward trend to continue, industry sources anticipate slightly lower growth (assuming the market to be free of competition from substitute products). The growth rate for asbestos gasket paper in the late 1970's was one of the highest of all asbestos products.

Substitute Products

Methodology--

Search strategy--The search stategy used in compiling gasket information included a literature review and telephone contacts with several leading producers of substitute products.

Summary of contacts--The following companies were contacted by phone for this subsection.

- Mr. Bill Brunner, Customer Service Manager, Chicago Gasket Co., Chicago, IL
- Mr. Barry Reznic, Applicatons Engineer, Cotromics Corp., Brooklyn, NY
- Sales personnel, Carborundum Corporation, Niagara Falls, NY

Special Qualities--

Alternatives to asbestos gaskets are made by the paper process with asbestos being replaced by some type of mineral filler and/or fiber and/or a high temperature-resistant organic fiber.[27] Three basic alternatives to asbestos beater-add gaskets exist: ceramic paper, teflon, and all-metal products. Silicone rubber is also a potential substitute as it is serviceable to 316°C; however, its applications are limited because it cannot be used in the presence of certain oils and fluids. It should also be noted that many facings may be made using the beater-add (Fourdrinier) process, with other materials used in conjunction with this to produce a final gasket product which, metal reinforced, etc., may be found in the Gaskets and Packings section of this report. Specifically, this includes information on recent developments in this field by Victor Products, a division of Dana Corporation.

Ceramic paper has the heat resistance of asbestos, but is not particularly resilient and is deteriorated by oil,[32] effectively eliminating it from possible use in automobile gaskets. Ceramic paper does have good resistance to some chemicals and in some high temperature applications has even been shown to outlast asbestos paper as a layering paper in sulfuric acid production.[33] Fiberfrax paper, composed of ceramic fibers, inert fillers, and organic bonding agents can be used as a direct substitute for some asbestos gaskets.[34]

Teflon is not a resilient, rubbery material as is asbestos; rather it is plastic, tending to deform and flow under loads. Due to its nonsticking properties, teflon is difficult to retain in joints so it is commonly used with an asbestos paper filler.

As with teflon, all-metal gaskets are not resilient, but are usable in limited applications. Because of the lack of resilience, all-metal gaskets cannot be substituted directly in most automotive applications.

Reports currently indicate that test results show asbestos-free materials work very adequately in asbestos gasket applications and compare favorably with the asbestos-based product. Alternative materials that are commercially reliable are being approved by OEM manufacturers and are equal in service life to asbestos beater-add gaskets.[31]

Product Composition--

The substitutes for asbestos gaskets discussed include ceramics, teflon, and metals. Teflon material is used especially by the chemical industry. The Teflon Envelope Gasket manufactured by the Chicago Gasket Company is composed of fluorocarbon resins.[35] For metal gaskets, a surface-to-surface seal is accomplished by a ribbing in the metal surface which creates an airtight connection when sealed. Ceramic papers, such as those produced by Cotromics Corporation, are based on aluminum oxide,[33] but exact formulas are an industry secret. Fiberfrax paper is composed of ceramic fiber, inert fillers, and organic bonding agents.

Rogers is reported to have offered the first nonasbestos gasket paper to the market in January 1979. This grade was NOBESTOS D-7102, designed as a nonasbestos substitute for Rogers GP/duroid 3102. In June 1979, a second grade was introduced, NOBESTOS D-7280, designed as a substitute for Rogers GP/duroid 3280. At present, Rogers has a total of ten grades of NOBESTOS gasket materials, four of which (7101, 7201, 7301, 7701) are designed to replace compressed asbestos (see also Gaskets and Packings section).[27]

Hollingsworth and Vose reports similar developments in the nonasbestos beater-add gasket field. This company has developed and supplied a wide variety of nonasbestos beater-add papers to all of its gasket manufacturing customers. In the Hollingsworth and Vose product, asbestos is replaced with other materials which completely meet the physical requirements for gasket papers. At this time, Hollingsworth and Vose (H & V) is commerically producing a variety of gasket materials as asbestos substitutes, along with exploration on applications of these products in other fields. The U.S. Patent Office has recently granted a patent to H & V covering the technology used to produce these alternative products.[36]

Substitute Product Manufacturing Summary--

Name and number of manufacturers--There are several manufacturers of nonasbestos gaskets made from ceramic fiber papers, teflon, and metal. Three prominent manufacturers of these products were contacted: Cotromics Corporation of Brooklyn, NY; Carborundum Corporation of Niagara Falls, NY; and Chicago Gasket Company of Chicago, IL. The Cotromics Corporation product is called simply "ceramic paper," Carborundum's is called "Fiberfrax," and Chicago Gasket's is called "Teflon Envelope Gasket." In addition, Rogers Corporation provided comments to this report along with information on their product. Other reported producers of nonasbestos beater-add gaskets are: Garlock, Armstrong-Cork, Nicolet, Hollingsworth and Vose, and Johns-Manville.[27] Also, Victor Products Div. of the Dana Corp. in Lisle, IL, makes asbestos-free gaskets.[37]

Production volume--Production voluems are thought to be small, but increasing. This will be subject to a greater increase as substitute products gain market hold. Company representatives[33,35] were not willing to reveal present production volumes.

PIPELINE WRAP

Asbestos Product

Special Qualities--

Asbestos paper has been successful as pipeline wrap due to the ability of asbestos to resist soil chemicals, rotting, and decay, while maintaining dimensional stability throughout its lifetime. These qualities are very important for underground pipeline wrap, as well as for the few times that asbestos pipe wrap may be applied above ground.

Product Composition--

Asbestos pipe wrapping papers contain a minimum of 85 percent asbestos, are commonly reinforced with parallel strands of fiberglass for strength, and are saturated with either coal tar or asphalt. They also may contain cellulose and starch binders.

Uses and applications--

Asbestos pipe wrap protects underground pipelines from corrosion. The wrapping paper is normally attached to the outside circumference of the pipe by machine winding. On occasion, it is attached via hand winding during special field fabrication of damage repairs. The wrap can be attached or bonded to the pipe surface by special adhesive coatings or by hot enamels that are coated onto one side of the paper. The coatings or enamels also aid in the corrosion protection of the pipe.

The oil and gas industry is the largest user of asbestos pipe wrap for their underground piping networks. The chemical industry also uses pipe wrap in underground protection of hot water and steam piping (conventional organic-Kraft-wraps rot away quickly in this function). Above-ground applications are minimial--special piping in cooling towers is one such use.

Asbestos Product Manufacturing Summary--

Manufacturing process--Asbestos pipe wrap is manufactured in similar fashion to asbestos roofing paper. For pipe wrap, the felt is commonly reinforced with parallel strands of fiberglass and saturated with either coal tar or asphalt. The final product is normally a roll containing less tar and coating than conventional asbestos roofing paper.

Pipe wrap is sold directly to pipeline construction companies such as Williams and Mapco, and to pipe coating yards.[3]

Name and number of manufacturers--Manufacturers of asbestos pipe wrap and their plant locations are listed below. Nicolet is reported to produce pipe wrap in much larger quantities than is Celotex.[3]

Manufacturer	Location
Nicolet Industries	Amber, PA
Celotex[38]	Lockland, OH
Johns-Manville[29]	Waukegan, IL

Production volumes--Asbestos pipe wrap consumed 5.6 percent of asbestos fiber used in paper products in 1979, placing it between millboard and gasket use among the asbestos paper subcategories for that year. Exact production volumes of individual manufacturers are not known.

Substitute Products

Methodology--

Search strategy--Industry contacts and an extensive literature search were the two main approaches used to obtain information.

Summary of contacts--Below is a list of contacts made for this paper category.

- Mr. Tony Silva, Johns-Manville Corporation, Denver, CO
- Mr. Bentle, New England Tape Company, Hudson, MA
- Mr. Bob Smith, Pyramid Plastics, Incorporated, Hope, AR
- Mr. Richard Dokmo, Tapecoat Company, Evanston, IL
- Mr. William Tinsley, Maror-Kelly Company, Houston, TX
- Mr. Terry Wright, D. E. Stearns Company, Houston, TX
- Mr. Chuck Lang, H. C. Price Company, Fairless Hills, PA
- Mr. Bill Power, PolyKen Pipeline Coating, Divison of Kendall Company, Boston, MA

Special Qualities--

Saturated fiberglass is becoming more and more competitive with asbestos in pipe protection because it has many of the characteristic advantages of asbestos. A comparison of the pipeline protection of fiberglass and asbestos is very similar to the discussion of fiberglass roofing felt versus asbestos roofing felt. Fiberglass is more dimensionally stable, rot resistant, and stronger than organic materials, yet asbestos still enjoys slight advantages in these qualities. Asbestos also has a better fire rating than fiberglass. Fiberglass has the advantage of requiring less asphalt saturation than asbestos and, given the escalating cost of petroleum products, this may eventually mean a lower cost.

In addition to fiber replacement in pipeline wrap, there are a variety of asbestos-free coating materials which are potential substitutes. These coating materials, which are discussed in Section 8, include:

- Enamels
- Extruded plastics--polyethylene and polypropylene

- Fusion bonded thermosetting powder resins
- Liquid epoxy and phenolics
- Tapes
- Wax coatings
- Polyurethane foam insulations
- Concrete

Several of these materials have been on the market for years while others have been introduced fairly recently. Although wax coatings, polyurethane foam insulations and concrete may be used only in special situations, other coatings such as extruded plastics provide excellent moisture, rot, and chemical resistance as well as strength and therefore can be used in most general applications.

Another potential substitute in this area is Fibercoat® by Textured Products, Inc., which lists pipe coverings as a potential application; in fact this company reports that they have had major indications for Fibercoat use in the duct and pipe installation industry.[39] Information on this product may be found under "Electrical Insulation."

Plastic tapes, although not adapted for use as pipeline wrap to date, display excellent moisture resistance. However, some can be attacked by various soil chemicals (depending upon application). Research in this area may be applicable in the future if the use of plastic in pipe wraps looks viable as an alternative; plastic has been used in this area in the past.

Product Composition--

Alternative systems include saturated fiberglass, plastic coatings, and extruded epoxys and resins. More specific compositions are not available at this time.

Uses and Applications--

Saturated fiberglass is used for the same applications as asbestos pipe wrap. Plastic tapes have been used in pipeline protection for more than 20 years,[3] although by themselves, they would probably not be a total substitute for asbestos pipe papers because they can be attacked by various soil chemicals in some instances and can crack or warp in others. Piping layered with an extruded coating of epoxy resin has only recently become commercially available. It must be time-proven during actual use if potential users are to be convinced of its advertised properties.

Substitute Product Manufacturing Summary--

Name and number of manufacturers--Alternatives to asbestos pipe wrap include saturated fiberglass, extruded epoxy resins, and, possibly in the future, a type of plastic tape wrap. Plastic coatings are now available.

Saturated fiberglass is made by Johns-Manville corporation, which headquarters at Denver, Colorado. Pyramid Plastics Incorporated in Arkansas produces extruded epoxy resin coatings, and the New England Tape Company makes plastic tapes, but to date, these are not applicable to pipeline use; instead they are for coating smaller tubes and yarns. It is believed that plastic tape coatings are available through other sources, such as PolyKen Pipeline Coating Company, a Division of Kendall Company in Boston, MA.[3]

MILLBOARD AND ROLLBOARD

Asbestos Product

Special Qualities--

Due to the presence of asbestos fibers in millboard, it, like all asbestos paper products, provides protection from fire, heat, and corrosion as well as resistance to rot. In structure and texture, most millboard is similar to a heavy cardboard. Asbestos millboard can be cut or drilled and nailed or screwed to a supporting structure.

Millboard varieties differ in their ability to withstand elevated temperatures--standard millboard is good to 427°C and high quality millboard is rated to 538°C. Above 566°C even high quality millboard becomes brittle. The chrysotile fibers used to impart resilience, strength and heat resistance suffer of major loss of strength in the region of 302°C to 496°C. It is rare that a continuous working temperature in excess of 566°C can be withstood even in unstressed situations.

Differences between grades are due largely to the different fibers used; longer, higher quality fibers can resist higher temperatures. Also, high quality millboard uses a calcium silicate binder as opposed to the starch binder used in less expensive boards.[40] However, premium grade millboards capable of withstanding higher temperatures attain increased thermal resistance at the expense of reduced strength.

As evidenced in numerous thermal insulation applications, millboard has a long service life. For example, once installed behind or beneath a wood stove for heat and flame protection, millboard is expected to last indefinitely. Similarly, in industrial uses, such as linings for refractory brick in furnace floors, long lasting thermal insulation is required, so millboard is frequently used.

Rollboard differs from millboard in that it is thin enough to be rolled to its thickness. It is usually sold in flat sheets.[13] Both millboard and rollboard contain a starch binder. Rollboard, being thin, is flexible, but has a lower upper temperature limit of 177°C.

Insulating board, a high temperature resistant millboard manufactured with amosite rather than chrysotile fibers has better board integrity and lower shrinkage when exposed to fire. The boards are light weight, acid resistant and easily machined.

Product Composition--

Asbestos millboard is composed primarily of asbestos fibers; asbestos content ranges from 68 to 95 percent by weight, with 70 percent considered typical.[41,42] Group 5 chrysotile fibers are preferred. Binders, which may be starches, elastomers, or silicates or, less frequently, glue, cement and gypsum, usually account for 3 to 25 percent by weight. Mineral wool, fiberglass, and cellulose are commonly used as filler.

Insulating board is a similar paper product consisting of asbestos with a calcium silicate (lime/silica) binder. In this product, amosite is used instead of chrysotile because it provides a higher degree of reinforcement at low board densities and has favorable drainage properties.

Uses and Applications--

Asbestos millboard is rot-resistant, will stand up to many corrosive gases and liquids, and is fire and temperature resistant. This makes millboard particularly important as a lining in floors, partitions, ceilings, and fire doors, and as an insulating barrier in stoves, ovens, and heated appliances. It has important uses in metal and chemical industries as well. Table 5 illustrates industry applications; each use is discussed in more detail in the paragraphs that follow.

Asbestos Product Manufacturing Summary--

Manufacturing Process--Millboard is considered an asbestos paper product because it is manufactured in essentially the same process as paper, using a wet cylinder paper machine usually equipped with one or two cylinder screens, conveying felts, pressure rolls and a cylinder mold. While paper produced on a cylinder machine is made as a continuous sheet, millboard is not. A cylinder rotating in a vat of slurry picks up a thin coating of fiber which is removed from the cylinder and drawn through a press for partial dewatering. The sheet is wound continuously onto a cylinder mold, a drum about 4 feet wide and usually about 4 feet in circumference. The cylinder mold rotates, collecting layers of fibers until the desired thickness is obtained. The cylinder is then momentarily stopped as workers cut the built-up layer of material lengthwise, removing one thick sheet of damp millboard. Once the sheet is removed the cylinder starts rotating to build up another sheet. The wet millboard, containing about 50 percent water, is air-dried or moved into an autoclave or oven for rapid curing. Finished millboard usually contains 5 to 6 percent water.[41]

Millboard is produced in a standard size in the United States, 42 x 48 inches, and ranges in thickness from 1/32-3/4-inch. The most popular thicknesses are 1/4- and 1/2-inch. Thicker sheets are produced by laminating sheets together. Rollboard is a lamination of two 1/6-inch or thinner sheets.

Name and number of manufacturers--Celotex, Johns-Manville (Waukeegan, IL), and Quin-T Corp. (Tilton, NH) manufacture asbestos millboard.[29,43,44] GAF discontinued production of asbestos paper and rollboard as of April 1, 1980.[8,18,45] Nicolet has closed their Norristown, PA plant but may still manufacture millboard elsewhere.[7,43] Asbestos millboard products are considered to be a mature or aging product group; sales growth is expected to be slow to nonexistent.[3]

TABLE 5. INDUSTRIAL, COMMERCIAL AND RESIDENTIAL USE OF ASBESTOS MILLBOARD AND INDIVIDUAL APPLICATIONS[2]

User	Individual application
Industrial	
General	In boilers, as gaskets, which may be metal reinforced, as flame and heat barriers, as slip-planes for furnace linings, as rolls or discs to convey a material from one point in the manufacturing process to another.
Electrical	Thermal protection in large circuit breakers
Appliance	Fire-proofing agent for commercial and home security boxes, safes, and files
Aluminum	Pouring trough cover and trough liner
Marine, shipyard, aircraft	Liner for container that catches hot metal from cutting operations
Foundry	Trough liner and iron trough cover
Steel	Backup insulation for furnace lining
Metallurgical	Used between the hot mandrel and the bearing shell in molten babbitt operation
Ceramic	Low mass kiln cars
Glass	As insulation in glass tank crowns, melter, refiner, sidewalls, etc.
Commercial	
Metal-clad doors	Between outside metal and wood core
Office partitions	Between metal sheets, valued as a fireproofing and sound deadening material. Very large potential market
Soldering fixtures and soldering blocks	
Spark and glare shields in welding shops	
Fireproof wallboard	
Washers in electrical apparatus	
Linings for safes, dry-cleaning machines, incinerators, heater rooms	
Garage paneling	
Residential	
Linings for home safes, stoves, heaters and electric switch boxes	
Tent shields	
Stove pipe rings	
Stove mats, table pads*	
Perfume rings for oil lamps	

*Millboard is no longer used in toasters as element boards for wire insulation. It has been replaced by reconstituted mica.

Production volumes--The current level of asbestos millboard production is estimated to be about 3 percent of paper products asbestos use. Research Triangle Institute has estimated annual 1979 use for millboard to total 1500 tons (1360 metric tons);[46] 1980 figures used here indicate that this figure may be 2700 metric tons.[1]

Substitute Products

Methodology--

Search strategy--Data on asbestos and substitute millboard were gathered through contacts with a number of companies that provided useful data on product specifications, uses, prices, and market trends. In addition, secondary sources provided information on general product trends and substitute materials. An extensive literature search was also conducted.

Summary of contacts--The following individuals and companies were contacted in the course of researching asbestos millboard.

- Mr. Carl Weber, Market Manager, Industrial Products Division, Johns-Manville Sales Corp., Denver, CO
- Mr. Gary Morganson, Customer Services, Insulation Division, Carborundum Corp., Niagara Falls, NY
- Ms. Carol Stein, Sales Representative, Pars Manufacturing Co., Ambler, PA
- Mr. Edmund Fenner, Director, Environmental Services, Johns-Manville Corp., Denver, CO
- Mr. William F. Kiser, Marketing Manager, Ceraform Products, Johns-Manville Corp., Manville, NJ
- Mr. Peter Heckman, Nicolet, Ambler, PA
- Mr. Neil Newell, Pyrotex, Carlisle, PA

Special Qualities--

The principal substitutes for asbestos millboard and rollboard are fiberglass, mineral wool, and ceramic boards. When considering the substitutes to asbestos millboard, it should be kept in mind that direct comparisons are difficult, since the substitute specifications do not always mesh exactly with the particular asbestos product specifications for a given use in terms of temperature, resistance to corrosion, etc; they may instead not match up to the asbestos product, or, in some cases, surpass the asbestos product. For example, even though Carborundum's Fiberfrax boards can be seen as an asbestos substitute, in actuality they can outperform asbestos at temperatures above 538°C and thus fill a need that asbestos cannot. All of the Fiberfrax millboards (trade-named "Duraboard," GH Boards," and "Hot Board") have low thermal shock and chemical corrosion. GH Board and Duraboard can withstand continuous temperatures of 1260°C without shrinking; Hot Board is good to 1093°C.[47]

Pars Manufacturing Company also makes a nonasbestos product called No. 9 millboard. This is good to 850°F, which is comparable to asbestos millboard. Industry sources have indicated that this product is comparable in many other respects to asbestos millboard, but more specific data are not available.[48]

Johns-Manville Corp. produces a substitute to asbestos millboard named Ceraform 102 Board which has a continuous use limit of 1260°C. Other Ceraform boards are Types 103, 126, 130, 141, and 143. In addition to the differences in the binder used, the other products may be stronger than Type 102 or have other specialized characteristics that make them suitable for specific applications such as in molten metal containment.[49] Ceraform board applications overlap with the uses of the asbestos millboard but also fulfill more diverse higher temperature uses for which asbestos millboard is not suitable. Johns-Manville has designed a Ceraform type board that is suitable for temperatures up to 816°C to 871°C. Ceraform 102 possesses low heat storage, is corrosion resistant and has excellent thermal shock resistance, much as the Carborundum Fiberfrax products.[49]

Babcock and Wilcox manufacture a ceramic substitute for asbestos in millboard, Kaowool. For applications where thermal conditions are not severe enough to warrant ceramic fibers, several types of mineral block and slab products are available.[50] Ceramic board uses overlap with those of asbestos but may also be used in higher temperature range applications for which asbestos is unsuitable.

Nicolet of Ambler, PA, is marketing two nonasbestos products, both under the name of Millboard. Details on their qualities are not known.[51]

Pyrotex of Carlisle, PA, is also manufacturing asbestos-free millboard, but details on this product were not available.[52]

Ceramic fiberboards mentioned here cannot substitute for asbestos millboard in most gasket applications. They are not resilient enough and also are deteriorated by oils.

Alumina-silicate boards, made by Pars Manufacturing Company and Carborundum, are available in thicknesses of up to 50 mm. If purchased with a special high temperature silica binder, these boards may be used successfully in applications such as process rollers for plate glass manufacture as a direct substitute for asbestos millboard.

Vermiculite may be a substitute in insulation boards, as it has both insulation and protection properties. Usually it is combined with glass fiber to achiever greater structural integrity.

Another possible replacement for areas such as duct insulation is Fibercoat® by Textured Products, described in "Electrical Insulation."

Janos Industrial Insulation Corporation calls its asbestos millboard replacement NuBoard. It will not burn and is resistant to temperatures up to 982°C, depending upon application.[53]

Victor Products Division of Dana Corporation markets a Mineral Board, which, when used with overlaps, flanges, and grommets to enclose the board, is resistant to fluids as well as heat and pressure. Typical applications include cylinder heads, manifolds, and other areas where pressure resistance is required.[54]

Product Composition--

The substitute product "Fiberfrax," by Carborundum, is composed of alumina-silicate (ceramic) fiber and inorganic binders. The Pars Manufacturing Company's nonasbestos "No. 9 millboard," is made of an alumina-slicate high temperature refractory material.[48] More specific data on these products are not available.

Johns-Manville's Ceraform 102 Board is similar to the other substitutes, composed primarily of a refractor fiber consisting of silica and alumina with a small amount of organic material. Ceraform boards are vacuum formed from a slurry of raw materials and dried to a predetermined hardness. Organic materials present in the Type 102 board burn out at 260°C, but a more expensive board containing only inorganic binders and suitable for temperatures up to 816°C to 871°C is available for applications where this may present a problem.

The mineral board produced by Victor Products contains mostly inorganic materials with minimal organics present. It is white in color.[54]

Vermiculite encompasses a group of hydrated alumina silicates resembling mica in appearance. Bulk material costs are low, but costs rise after vermiculite undergoes exfoliation, an expansion that occurs upon heating. Exfoliated granules may be delaminated to form vermiculite plates for insulation boards or alkali-resistant glass fibers may be added in a lime-silica matrix to combine the insulation and fire protection properties of vermiculite with the structural integrity of glass fibers. Perlite, similar to vermiculite, may also be used as a substitute for this application. It is a naturally occuring noncrystalline silicate of volcanic origin.

Information on the composition of both the Pyrotex and the Nicolet products was not available to the writers at the time of issue of this report.

Uses and Applications--

Carborundum's Fiberfrax is used in a variety of ways to substitute for asbestos paper products including millboard, rollboard, commercial paper, textiles, and insulation fibers (covered in other sections). Various boards differ in density, thicknesses, hardness, and strength; uses of these products vary according to the need for strength and hardness.[55,56] Fiberfrax board is currently being used in place of asbestos millboard in the following applications:

- Thermal protection in large circuit breakers
- Fireproofing agent for commercial and home security boxes, safes, and files
- Molten aluminum pouring trough covers and liners
- Liners for catching hot metals being cut in shipyards
- Trough covers and liners in the steel and foundry industries
- Backup insulation for furnace linings
- Heat shields for personnel protection
- Rigid, high-temperature gaskets
- High-temperature baffles and muffles
- Chimney and furnace linings
- Hot gas duct linings
- Expansion joint material

Pars Manufacturing Company's No. 9 millboard has uses similar to asbestos millboard. The Johns-Manville product, Ceraform 102 Board, is similar to Fiberfrax. Typical applications include furnace and kiln linings and as backup insulation.[49]

Special applications for the Pyrotex and Nicolet products are unknown at this time.

Substitute Product Manufacturing Summary--

Name and number of manufacturers--Several companies have developed substitutes for asbestos millboard and similar asbestos paper products. Examples are ceramic fiberboards by Carborundum Company and ceramic board with Kaowool by Babcock and Wilcox. Johns-Manville[40,57] and Pars Manufacturing[48] also have nonasbestos millboards. The Johns-Manville product is trade named "Ceraform 102 Board." Nicolet has also developed nonasbestos millboard substitutes as well as the Pyrotex Company of Carlisle, Pennsylvania. In addiiton, Janos Industrial Insulation Corp. of Moonachie, NJ, makes NuBoard as an asbestos millboard replacement, and Victor Products Division of Data Corporation makes a mineral board replacement.

Production volume--Nonasbestos substitutes for asbestos millboard are being used in place of asbestos millboard in some applications. As there are many individual uses, each with individual requirements, the current production volume of substitute products could not be quantified at this time, although it is expected to grow.

SPECIALTY PAPERS

Asbestos Product

Special Qualities--

There are six major classes of asbestos specialty papers:

- Cooling tower fill
- Transmission paper
- Beverage and pharmaceutical filters*
- Electrolytic diaphragms
- Decorative and industrial laminates
- Metal linings

These classes were chosen after extensive discussions with industry representatives; although other types of specialty papers may be produced, the quantity of asbestos used in their manufacture is minimal.

Asbestos is used in specialty papers primarily due to its chemical and heat resistant properties.

Asbestos is used in cooling tower fill for its heat and chemical resistance. In applications where high heat resistance is necessary, asbestos paper will continue to be used, because of its proven durability and heat resistant qualities. Extensive government testing at governmental facilities at Oak Ridge[58] found asbestos fill (Asbedek) superior in performance to alternatives.

Asbestos is used in transmission papers for its excellent friction characteristics and oil resistance as, during use, the paper-lined disks are normally coated with transmission oil. Asbestos has been found to be durable in this application.

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*Covered separately in last Paper Products section.

For beverage and pharmaceutical filters, asbestos represents a mineral medium that does not degrade or otherwise affect liquid quality while acting as a suitable filter. In the electrolytic diaphragm, it provides strength and the appropriate properties needed for manufacturing this product. In the electrolytic process, cathode surfaces are generally lined with a layer of asbestos either in the form of paper or as vacuum-deposited fibers.[59] The asbestos maintains the caustic strength and minimizes the diffusional migration of hydroxyl ions. All diaphragms gradually clog with residual impurities in the brine and particles of graphite from the anode, and therefore must be renewed at regular intervals (approximately every 100 days).[60]

High-pressure industrial laminates are a significantly more durable form of the decorative product. Asbestos is no longer being used in any significant quantity in making decorative laminates.[61] Asbestos paper was used to produce a speical fire-retardant decorative laminate; fire retardant laminates are used for interior surfacing and paneling in public buidings, buses, railcars, and ships requiring a Class 1 fire-resitant rating.[62] Decorative laminates are thin, rigid sheet materials that have been resin saturated to press the layers together. They are faced with decorative colors or patterns and characterized by showing resistance to damage from scuffing or scratching.[61] Industrial laminates are sheets produced from asbestos electrical paper fused at high temperatures. Asbestos electrical paper is used here to allow for effective insulation and to protect the conductor from fire.

Asbestos is used in metal lining paper to provide corrosion-resistance and strength.

Product Composition--

The base for cooling tower fill consists of a blend of two grades of chrysotile asbestos bound with DuPont neoprene latex; the content is 90 to 91 percent asbestos and 9 to 10 percent binder.[63] Baltimore Air Coil asbestos fill (MNA) is composed of a base asbestos paper saturated with melamine, a thermosetting resin.[63]

Asbestos transmission paper is a latex-bound product currently made with chrysotile asbestos. Although it has been reported in a survey of consumers that this paper was made with crocidolite (blue) asbestos,[64] it is currently believed to be made solely with chrysotile asbestos due to supply and health problems associated with crocidolite.[65]

Electrolytic diaphragms are made from mixing asbestos fibers and water to form a slurry. Decorative laminates are produced by impregnating asbestos electrical paper with thermosetting resins and then fusing multiple layers together at high temperature and pressure. They are made up of asbestos paper which contains asbestos and a phenolic or melamine resin and is formed in thin, rigid sheets and then colored or patterned accordingly. Industrial laminates consist basically of asbestos fibers, combined to make electrical paper with thermosetting resins added.

Metal lining paper is manufactured like commercial asbestos paper except that the metal lining paper contains a higher percentage of binder and a small percentage of clay.

Uses and Applications--

The major use of asbestos fill in cooling towers is in applications where high heat resistance is necessary. One such application is in gaseous diffusion as performed at the governmental facilities in Oak Ridge. The Munters Corporation produces a fill, "Asbesdek," used mainly in mechanical draft towers.

Automobiles equipped with automatic transmission get their drive from metal transmission disks covered with a super-tough asbestos paper.[64] Four, six, and eight cylinder autos with power shift contain from 8 to 12 of these paper-lined disks.

Asbestos beverage filter paper is used by beer, wine and liquor distilling industries to remove microorganisms and fine solids from the liquid medium. Pharmaceutical and cosmetic industries use the paper as well.

Asbestos is used as a diaphragm in production of chlorine via brine electrolysis. Asbestos paper sheets were used in diaphragm cells through the 1930s and 1940s but now almost all diaphragm cells made with asbestos use a slurry[66] of water mixed with asbestos, rather than as a paper. The slurry is vacuum-deposited onto a cathode pole, and the diaphragm is built-up inside the electrolysis cell.

Decorative laminates can be bonded to plywood, fiberboard, or metals and can be sawed, drilled or sanded with conventional woodworking equipment. Decorative laminates appear generally in wall or ceiling paneling, desk tops, counter tops, and worktable tops. Asbestos is only one of many materials from which decorative laminates can be made; the bulk of decorative laminates are made with kraft papers. Industrial laminates are used for telephone switchboard construction, television circuit boards, and other electronic applications. Tube and rod laminate can also be used as core or winding barriers for such equipment. The sheets can also be stamped or fabricated into specialty spacers or washers.

Metal lining paper is used as a corrosion-resistant liner for both metal sidings and culvert pipe. Culvert pipe is in turn used for landfill drainage and water treatment applications.

Asbestos Product Manufacturing Summary--

Manufacturing process--A wet cooling tower dissipates heat from water by maximizing the water-air interface, either with splash-type fill or with film-type fill. Splash-type fill which can consist of asbestos paper, polyvinyl or polypropylene plastics, cellulose, asbestos-cement sheets, aluminum or steel creates small liquid droplets which drip down onto another surface, splash, and reform.[63] Film-type fill, made of similar materials, spreads the water over large areas in a thin film, exposing it to the air.

The Munters process for fill production impregnates fluted sheets of asbestos paper with about 20 percent of a saturant formulated on a chlorinated rubber base. The fluted sheets are bonded together with neoprene latex to form packs with 3/4-inch deep neoprene reinforced edges. The maximum size of individual packs is 12 x 12 x 72 inches.[63] The cooling tower fill made by Munters is trade named "Asbesdek" and looks like a stack of corrugated sheets.

Baltimore Air Coil manufactures asbestos fill (MNA) for use mainly in air-conditioned buildings, machinery, and computers. The base asbestos paper is saturated with the thermosetting resin Melamine.[63]

In transmission paper, the base paper is saturated with phenolic resins to create a very hard and resilient product in a saturation process similar to that described for cooling tower fill. The saturated and hardened paper product is then cut to the required size.

Beverage and pharmaceutical paper is made on conventional papermaking euqipment; metal lining paper is manufactured similarly to commercial paper discussed previously.

Currently, almost all commerical asbestos diaphragm cells use a slurry instead of the paper sheets mentioned previously. The slurry is made by mixing fibers with water, then vacuum depositing the slurry through a perforated plate onto the cathode pole. Happ (Hasker asbestos Plus Polymer) diaphragms are basically the same but add a fluoropolymer resin to the slurry to help diaphragm bonding while reducing voltage load. The use of paper sheets has diminished because the voltage load is significantly higher with paper as opposed to vacuum deposited slurry.

Decorative laminate sheet is formed by saturating successive layers of paper with either a phenolic or melamine resin. The layers are then pressed and cured. Industrial laminates are made by impregnating asbestos electrical paper with thermosetting resins and then fusing multiple layers together at high temperature and pressure.

Name and number of manufacturers--There are reported to be approximately 11 domestic manufacturers of asbestos specialty papers. Munters Corporation of Fort Myers, FL, and Baltimore Air Coil of Baltimore, MD, are secondary manufacturers of cooling tower fill but the base asbestos paper stock is manufactured by Nicolet in Ambler, PA, and GAF Corporation in Erie, PA. A large amount of asbestos transmission paper is sold to the Delco-Moran Division of General Motors for fabrication. Johns-Manville was to have discontinued manufacturing of specialty asbestos paper in April 1980.[67,68] Westinghouse's Decorative Micarty Division markets decorative laminates, but reports that asbestos is no longer used in any significant quantity.[61] The manufacturers of individual asbestos specialty products may be found in Table 6. In addition to the manufacturers listed, Johns-Manville makes specialty papers in Manville, NJ, and Waukegan, IL; and Lydall (Colonial Fiber) produces them in Covington, TN, and Rochester, NH. J/M and Nicolet produce asbestos paper which is sent to secondary processors for further fabrication.

TABLE 6. MANUFACTURERS OF ASBESTOS SPECIALTY PAPER

Type of specialty paper	Manufacturer
Cooling tower fill	Munters Corp., FL*[69] Baltimore Air Coil, MD*
Transmission paper	NA
Electrolytic diaphragms	NA
Decorative laminates	Westinghouse - Decorative Micarty Div.**
Industrial laminates	NA
Metal lining paper	Jim Walter - Armco Steel Co. of Ohio$^{\Delta}$ (Celotex), Linden, NJ and Lockland, OH GAF, H. H. Robertson Co.$^{\Delta}$ Erie, PA

NA = Not available.

*Secondary processors.

**No longer produced in any significant quantity--in fact, reports indicate that asbestos is no longer used in this product at this location.[70]

$^{\Delta}$The first company listed manufactures the base felt and sells this product to the second company which uses it to line pipes.

Production volumes--The major use of asbestos fill has been in general cooling tower applications; however, the asbestos fill is becoming too expensive compared to readily available plastic fills and the volume of asbestos paper used for cooling tower fill is decreasing.[58] It has been estimated that several thousand tons of asbestos fiber were formerly consumed annually to make cooling tower fill.[3] Currently about 810 metric tons are used in cooling tower applications.

Other specialty paper products use much less asbestos. In 1980, an estimated 360 metric tons of asbestos fiber were consumed in the production of automatic transmission paper (updated from 1977 estimate referenced).[65] This figure was probably only 360 metric tons in 1980 (see Table 1). As indicated, decorative laminates made with asbestos are no longer produced in any significant volume. The specialty grade of asbestos paper manufactured for use as a diaphragm in electrolytic cells uses minor quantities of asbestos.[71] While no production volumes for this specialty item are available, it is estimated that less than 990 metric tons of asbestos are used annually (1981 data) About 0.54 kg of asbestos is consumed during electrolytic cell operations to produce 0.9 metric tons of chlorine.[59] Annual production of chlorine is on the order of 9 million metric tons[72] and about 70 percent of the American chlorine is produced by the diaphragm cell process,[73] indicating that approximately 38 thousand metric tons of asbestos were estimated to be consumed annually in electrolytic cells (1977). Almost all of this asbestos is in the form of slurry, not paper.

In sum, with estimated tower fill consumption of about 810 metric tons/yr, transmission paper use of 360 metric tons, electrolytic diaphragms requiring approximately 990 metric tons, decorative laminates and other miscellaneous categories with no available figures, but considered small by industry sources, the most recent estimate of total consumption of specialty papers would be about 2106 metric tons annually.[1]

Substitute Product

Methodology--

Search strategy--A combination of a literature review and a telephone survey of industry representatives was used to gather data on asbestos specialty papers and their potential substitutes.

Summary of contacts--

- Mr. J. Skold, Munters Corp., Fort Myers, FL, August 1979
- Mr. M. Lai, Hooker Chemical Co., Niagara Falls, NY, August 1979
- Mr. B. Pedersen, Sales, E.I. DuPont de Nemours, Co., Wilmington, DE, March 1980
- Mr. D. Cannady, Decorative Mircarty Division Manager, Westinghouse, Corporation, Hampton, SC, August 1979

- Mr. J. F. Reis, Johns-Manville Corporation, Denver, CO
- Mr. E. M. Fenner, Johns-Manville Corporation, Denver, CO, July 1979
- H. H. Roberston Co., sales personnel

Special Qualities of Product--

Substitutes for specialty papers include:

Specialty paper	Substitute product
cooling tower fill	polyvinyl and polypropylene plastics cellulose aluminum steel
transmission paper	none, but research and development currently underway in this area
beverage and pharmaceutical filters	cellulose and glass fibers (see next section for detail)
electrolytic diaphragms	Nafion membrane cell PTFE
laminates	chemically treated papers glass and ceramic papers kraft papers
metal linings paper	Veriscore

Asbestos-cement sheet use as cooling tower fill is rapidly decreasing due to its potential for wear and fiber release under extreme conditions. A wide variety of substitute materials are currently available for cooling tower fill including polyvinyl and polypropylene plastics, cellulose, aluminum, and steel.[58,63] Metal substitutes are more durable; fire resistant metal laminates are economical and are now on the marketplace. Fill substitutes must be chemical resistant as well as flame resistant.

Tests have shown it to be difficult to find a material capable of substituting for asbestos in diaphragms for brine electrolysis which can perform as well. At present, an asbestos diaphragm has a useful life of 6 or 7 years.[74] Electrolytic diaphragm substitutes have been tested by Hooker Chemical in Tacoma, Washington, and by Diamond Shamrock Chemical in Muscle Shoals, Alabama,[75] and show the new membrane cell to have a number of advantages over the asbestos diaphragm. It produces a stronger caustic solution, reducing evaporation required to make a concentrate, lowers the salt content of the caustic and the chlorine produced contains no hydrogen impurities. However, the membrane cell developed by DuPont is not as efficient electrically as asbestos diaphragms. This ion exchange method has shown less energy efficiency than the percolating diaphragm method used in the past. For example, Hooker's electrolytic cell with membrane consumes 3110 kWh/metric ton of chlorine produced compared with 2780 kWh/metric ton for asbestos.[66] Membrane materials are not interchangeable with asbestos diaphragms. Such modification would be feasible only when a new plant is being built or an entire plant is being reworked. Similarly, mercury cells which eliminate asbestos diaphragms entirely are available, but are not interchangeable with existing electrolytic diaphragm cells.[76] About 0.5 percent of chlorine is thought to be produced by ion exchange and 19.5 percent by a mercury-amalgam method.

Product Composition--

For most applications any of the materials mentioned for cooling tower fill substitutes are adequate. An alternative to asbestos electrolytic diaphragms is DuPont's Nafion membrane mentioned previously. It consists of a film of perfluorosulfonic acid resin (copolymer of tetrafluoroethylene) and another monomer to which negative sulfonic acid groups are attached. Promising results have also been obtained with a 2-layer diaphragm polypropylene (PTFE). This cell has a resistance inside the electrolysis cell which is comparable to that of asbestos. Tests carried out over a period of 1100 hours did not show significant deterioration.

As for metal linings, H. H. Robertson Co. has produced "Veriscore," which is manufactured in the same manner as their Galbestos sheet-siding which contains asbestos paper, except that the asbestos paper lining is replaced with a 3 mil thick layer of epoxy resin. Various types of specially painted sheets can also be used as a siding substitute for Galbestos.

Economical, fire-resistant laminates that use chemically treated papers as a laminated substrate and/or laminating resins containing flame-retardant chemicals are available. Also, glass and ceramic paper substrates are used when the extra cost is acceptable. For decorative laminates, asbestos papers have been replaced by Kraft papers.

The fiber size distribution of specialty paper substitutes varies from product to product. Most substitutes mentioned, such as the Nafion membrane, aluminum tower fill and glass paper substrates do not contain fibers. Specific fiber sizes for substitutes containing fibers were not available.

Uses and Applications--

Nonasbestos cooling tower fill is a direct substitute of the asbestos product. New diaphragm products substitute for asbestos products, and supply some advantages such as a stronger caustic solution for producing concentrate to offset the disadvantage of higher energy costs. Metal lining substitute products enjoy uses similar to their asbestos counterparts, as do decorative laminates. No substitutes for asbestos transmission paper appear to be available.

Substitute Product Manufacturing Summary--

Name and number of manufacturers--Two manufacturers of nonasbestos substitutes are listed in Table 7. An alternative to asbestos diaphragms in eletrolytic cells is a membrane cell formed from DuPont's Nafion membrane[60,75] which has been developed and demonstrated by Hooker Chemical Company.

TABLE 7. MANUFACTURERS OF NONASBESTOS SPECIALTY PAPERS

Asbestos product	Substitute	Manufacturer
diaphragm	membrane cell-Nafion	DuPont de Nemours & Co./ Hooker Chemical Co.
metal lining paper	Versicore	H. H. Robertson Co.

The H. H. Robertson Company has developed and markets "Veriscore" as a substitute for their asbestos-containing Galbestos sheet siding.

Data on manufacturers of nonasbestos transmission paper and cooling fills are not available.

Production volume--Little information is available on the production volumes of substitute products for specialty paper.

COMMERCIAL PAPERS

Included under this heading are the following types of products

- general insulation paper
- muffler paper
- corrugated paper

Only small amounts of asbestos muffler paper are now thought to be produced and asbestos corrugated paper is no longer believed to be manufactured.

Asbestos Product

Special Qualities--

Asbestos is used in commercial papers because of its resistance to fire and corrosion. It provides commercial papers with the strength and durability needed for numerous applications.

Commercial asbestos paper exhibits fine durability properties, allowing it to meet Federal Specifications requirements. For example, commercial grade paper is good for temperatures up to 316°C or 427°C where loss of strength is not critical. Nonburn paper is suitable for continuous service at temperatures of 316°C, and doublex asbestos paper has high wet strength and a slightly elevated temperature limit of 427°C (or 649°C where some embrittlement and loss of strength is not critical).

Nearly all of the current production of commercial asbestos paper falls into the subclass of general insulation papers. Types of insulation available include:

- Commercial Grades: A medium length fiber paper with minimum 95 percent fiber content. Available in 10, 12, 16, 32, and 64 lb/100 sq. ft. weights in widths of 18, 36, and 72 inches in 25, 50 and 100 lb rolls. Suitable for most general purposes in industry. Good for temperatures up to 316°C or 427°C where loss of strength is not critical. Meets Federal Specification HH-P-1784.

- Nonburn Paper: A medium length fiber paper with high fiber content. Available in a weight of 4 lb/100 sq.ft., 36 inches wide in 50 and 100 lb rolls. Suitable for continuous service at temperatures of 316°C.

- Long Fiber Paper: Made with a high-grade, long asbestos fiber; minimum fiber content 98 percent on 6 lb and heavier papers. For use as a thermal insulation, gasketing, and base sheet for saturating.

- Doublex Asbestos Paper: Completely inorganic; will not burn, char, or smoke. Has high wet strength. Available in a weight of 10 lb/100 sq. ft., 36 inches wide in 50 or 100 lb rolls. Developed for use as a neon sign pattern paper. Also used as liner for foundry funnels and pouring gates. Temperature limit 427°C or 649°C where some embrittlement and loss of strength is not critical.

Product Composition--

The commercial asbestos paper category encompasses a broad range of papers that differ primarily in weight and thickness. The product is normally composed of 95 to 98 weight percent asbestos fiber and 2 to 5 percent starch binder.[3] Short and medium grades of chrysotile are used.

Muffler paper contains a very high percentage of asbestos fiber and only a small percentage of starch binder. The surface of the product is waffled or indented.

Corrugated asbestos paper is a commercial paper product corrugated and cemented to a flat paper backing, sometimes laminated with aluminum foil. Corrugated paper is manufactured with a high chrysotile asbestos content and a starch binder.

Uses and Applications--

The principal use of commercial asbestos paper is to provide maximum insulation against fire, heat and corrosion with minimum product thickness. Commercial papers fall into three subclasses based on use: (1) general insulation papers, (2) muffler paper, and (3) corrugated paper.

General asbestos insulation papers have the following major uses in steel and aluminum factories:

- Thermal insulation in annealing furnaces
- Trough lining for smelting process
- Refractory lining
- Expansion joints between brick layers of furnace
- Backing insulation
- Insulation to catch molten metal drippings and hot metal

In foundries, asbestos paper is used as mold liners, as refractory liners, and as expansion joint material on induction coil heaters. In the glass/ceramic industry, commercial paper is used for kiln insulation, linings, and as a separator for hot and cold flat glass sheets. GAF Corporation makes a grade of commercial paper that is laminated to steel decks for fireproofing.[77] Johns-Manville sells commerical paper to a large electric parts and appliance manufacturer for electrical insulation not requiring the high purity of asbestos electrical insulation. Commercial paper is used for dielectric and thermal protection of transformers for fluorescent tubes[56] and in mercury vapor lamp housings.

Muffler paper is used by the automotive industry primarily in the construction of catalytic converters for exhaust emission control systems. The paper is applied as a wrap between the inner and outer skins of the converter or muffler for two reasons: First, it maintains the high temperatures required for pollution control within the converter reaction chamber; second, it insulates the outer skin, preventing it from becoming too hot. In a less common application, muffler paper is used as a heat shield between the muffler and the automobile body.[3]

Corrugated asbestos paper is used as a thermal insulator for pipe coverings, block insulation, and specialty panelings. Applications of corrugated asbestos paper include appliance insulation up to 149°C, hot-water and low-pressure steam pipe insulation, process line insulation, and panel insulation, such as paneling in elevators.[5,71,78]

It should be noted that a large portion of the commercial paper produced is sold to distributors and/or converters who, in turn, sell to their customers. Thus, due to the large number of people involved in the production and conversion process, it is nearly impossible to identify all of the specific end uses which might arise.

Asbestos Product Manufacturing Summary--

Manufacturing process--General asbestos insulation and muffler paper are manufactured on conventional papermaking machines producing sheet rolls or tapes as end products. The manufacturing operation for corrugated paper also employs conventional papermaking equipment but adds a corrugation machine to produce the desired corrugated molding of the paper suface.

Name and number of manufacturers--Commercial paper is manufactured in the United States by Nicolet (Ambler and Norristown, PA) and Celotex (Lockland OH, and Linden, NJ). GAF and Johns-Manville were due to discontinue the manufacture of commercial paper in 1980.[8,18] Commercial asbestos paper is normally sold by the manufacturer to independent distributors, converters and some original equipment manufacturers. There are about 300 distributors and/or converter companies in the U.S.[3] Two of the larger distributor-converters are Grant Wilson (Chicago, IL) and Janos Industrial and Insulation (Moonachie, NJ). Original equipment manufacturers include General Electric, Ford, and Caloric.[79]

Muffler paper is made by Celotex in Lockland, OH. At present only small quantities are being manufactured, primarily for export.[5,71] Corrugated paper was formerly produced by Johns-Manville Corporation and Nicolet Industries but is not being manufactured at present, apparently due to the availability of reasonably priced substitutes and customer desires to avoid products containing asbestos.

Production volumes--As noted above, it is believed that corrugated paper is no longer produced[5,71] and asbestos muffler paper is only produced in small amounts.

In 1975, 3500 tons of asbestos were used to manufacture asbestos muffler paper, making it the fastest growing segment of the asbestos paper industry at that time. It is also estimated that about 3500 tons of asbestos went into corrugated asbestos paper.[3] By 1977, corrugated asbestos paper demand had declined to 2500 tons.[80] Presently, the entire category of general commercial insulation papers are believed to consume 1170 tons annually; individual muffler and corrugated paper production figures are not available, but production volumes are believed to be minimal.

Substitute Products

Methodology--

Search strategy--Information on asbestos commercial papers was gained both from contact with industry representatives and literature review.

Summary of contacts--

- Mr. E. Cavicchio, GAF Corporation, Erie, PA, August 1979
- Mr. B. Reznick, Cotronics Corporation, Brooklyn, NY, March 1980
- Representative, Johns-Manville Corporation, Denver, CO, March 1980
- Representative, Celotex Corporation, Linden, NJ, March 1980

Special Qualities--

Substitutes which may be used in place of asbestos commercial paper include ceramic, cellulose and fiberglass products. Applications vary, and those products demonstrating high temperature resistance appear to lack the ability to couple this with sustained strength. Ceramic paper can be used at higher temperatures than asbestos; it can withstand a continuous temperature of 1260°C. At 1760°C it will melt.[81] However, it has not been proven to be as strong or resilient as asbestos paper. Cellulose and fiberglass papers generally lack the heat resistance and dimensional stability required for heat and flame resistance.

A Johns-Manville product, called Cerafiber, may be used for general insulating, and flameproofing applications to 1316°C. These low-density papers do not store heat and thus may be heated or cooled almost instantaneously. In addition, they possess unusually low thermal conductivitiy, can be safely cycled from cryogenic temperatures to their highest operating temperature, and offer outstanding tensile strength, flexibility, and resiliency. They can be easily die-cut, rolled, folded, bent, or wrapped.[82]

In addition, Fibercoat® by Textured Products, Inc. is suggested as a possible alternative for some commercial papers, including aircraft engine exhaust system wrap and furnace linings.[39] Detailed information on Fibercoat may be found in the secton titled "Electrical Insulation."

Product Composition--

Substitutes may be made from ceramics, cellulose or fiberglass. Cotronics' ceramic paper is made from high purity refractory fibers.[81] Despite the widespread public belief that ceramic products are hard and brittle, these ceramic papers can be cut with scissors, folded, wrapped, rolled and formed into free standing shapes. The J/M product is also made from pure refractory fibers; the binder content varies from 5-6 percent depending upon the type of paper.[82]

Uses and Applications--

Commercial asbestos paper is primarily used as a general insulation for heat and flame applications. For many of these applications, ceramic paper could be substituted for asbestos paper, but the cost would be greater.

Specifically, ceramic paper can be substituted for asbestos papers in the following applications:[56,83] (1) liners, covers, and insulation for the aluminum and steel industry; (2) molds, liners, and insulation in foundries; (3) similar applications in the glass making industry; (4) fire protection barriers; and (5) welding insulation. Domestically, ceramic paper has already replaced asbestos paper in mufflers and catalytic converters.[5,71] It is being used in kiln and furnace construction, high temperature filters, lab ovens, arcing prevention, high temperature gaskets, instant crucibles, acoustical insulation (inside mufflers), expansion joints, casting alloys, lamphouse insulation, and chromatography. Glass, ceramic, chemical, electrical, metal, optics, welding, and instrumentation applications have all been developed.[50]

Ceramic materials display advantages over asbestos commercial papers, primarily an ability to withstand a greater temperature range and a lack of any identified negative health effects. Yet they also have disadvantages including greater cost, and second, less dimensional stability.

Substitute Product Manufacturing Summary--

Name and number of manufacturers--At present, the only commercially available alternatives to commercial asbestos paper are ceramic mineral fiber papers and glass papers. The ceramic papers are marketed by such companies as Carborundum Corporation (Niagara Falls, NY), Cotronics Corporation (Brooklyn, NY), and Johns-Manville (Denver, CO). The J/M product comes in rolls of 12 in., 24 in., and 36 in.[28]

Production volume--The exact production volume of products substituting for asbestos commercial paper is not known. However, it is known that ceramic paper has already replaced asbestos paper in many muffler and catalytic converter applications domestically.[5,7,8]

ELECTRICAL INSULATION

Asbestos Product

Special Qualities--

Asbestos is used in electrical paper insulation because of its high thermal and electrical resistance, which permits the paper to act effectively as an insulator and protects the conductor from fire. However, despite the special properties of asbestos utilized in electrical insulation, it appears that substitutes are now available which retain these properties while reducing the associated risk of asbestos fiber exposure to employees.

Product Composition--

The composition of absestos electrical insulation paper varies with the intended application but generally contains chrysotile asbestos fibers and cellulose bound with latex polymers. Small amounts of amosite and tremolite are also used occasionally. Quin-T's high purity asbestos paper uses chrysotile fibers obtained from Johns-Manville, chemically treated to remove impurities (trace elements).[71]

Electrical insulation is frequently impregnated with solid resins to increase dielectric strength, improve mechanical properties and provide moisture-proofing characteristics offsetting the hygroscopic property of asbestos fiber. Depending upon the expected temperature of service, resin-bonded papers or boards may use phenol, formaldehyde, polyvinyl acetal, epoxy, or silicone resins. Glass or other fibers may also be present.[50]

Uses and Applications--

Asbestos is widely used in the electrical industry in the form of paper, tape, cloth, and board. It may be applied as a felted material or as a filter for natural and synthetic insulating resins. The largest use of asbestos electrical paper is as insulation for dry transformers, for layer insulation, and cross-over insulation.[84,85] Asbestos paper tapes are used as a general wire wrap, as turn insulation for various industrial equipment, and to a much lesser extent, in appliances. Electrical equipment subjected continuously to high temperatures is the most typical use of asbestos paper insulation. For example, electrolifting magnets used in steel mills to pick up and move billets have asbestos paper as turn insulation[84] and steel mill drive motors have asbestos insulation. Asbestos materials are not suited for high-voltage insulation nor for high-frequency insulation, due to a high dielectric loss even when dry. Therefore, their main electrical use is in low-voltage, high temperature situations, and for confinement of arcs.[50]

Appliances that use asbestos papers for wire insulation include stoves and toasters. The extent to which asbestos paper is currently used for these applications is not clear, but use has dropped significantly due to asbestos concern from manufacturers and the availability of substitutes. For example, toaster boards made with asbestos in the past are currently being made with mica-board or some other substitute material.

Asbestos paper is used in grade A industrial laminate for low-voltage applications, such as household current.[86] Other uses include low-voltage transformers, armature slot wedges, furnace parts and domestic heating equipment.[48] Industrial laminates generally refer to a class of electrical insulating materials produced by impregnating fibrous webs of materials with thermosetting resins and then fusing multiple layers together under high temperature and pressure. Asbestos paper is only one of many materials used to make these laminates; other materials include cellulose paper, cotton, nylon, and glass. Grade A paper currently has only limited applications for thermoset resin products.[87,88] The sheets may be stamped or fabricated into specialty spacers and washers used in small appliances for electrical and thermal insulation where temperatures are too high for cellulose based laminates.

Asbestos Product Manufacturing Summary--

Manufacturing process--Asbestos electrical insulation paper is formed on conventional papermaking machines. The paper products include rolls, tapes, tubes, or sheets, all of various thicknesses and various sizes. Electrical papers are sold to fabricators in the electrical and electronics industries who saturate the paper with resin to produce an industrial laminate.

Name and number of manufacturers--Asbestos paper for electrical insulation is currently manufactured by the Quin-T Corporation (Tilton, NH), formerly owned and operated by Johns-Manville.[44] Nicolet Industries (Norristown, PA, and Hamilton, OH) no longer produces asbestos electrical paper.[43] The Norristown, PA, plant has closed.[7]

Production volumes--Electrical insulation accounts for approximately 0.4 percent of the asbestos consumed in the paper products category annually, placing it sixth in asbestos consumption, behind flooring felt, roofing felt, gaskets, pipeline wrap, and millboard. Estimated consumption in 1980 for this category is 360 metric tons.[1]

Substitute Products

Methodology--

Search Strategy--Both a literature review and telephone interviews with substitute manufacturers were used to discover more about asbestos electrical insulation and available or potential replacement products.

Summary of contacts--The following companies were contacted in researching this topic:

- Mr. J. Hayman, DuPont, Wilmington, DE, July 1979
- Sales Secretary, Carborundum Corporation, Niagara Falls, NY, September 1979
- Mr. N. Highes, Quin-T Corporation, Tilton, NH, July 1979
- Mr. R. Wilmore, National Electrical Manufacturing Association (NEMA), Washington, DC, August 1979
- Mr. W. Lair, NVF Company, Yorklyn, DE, August 1979
- Mr. L. Heid, Manning Paper Company, Green Island, NY, March 1980, and Mr. S. Wong, July 1979
- Mr. S. Delheim, Crane and Co., Inc., Dalton, MA, March 1980
- Mr. B. Hardy, DuPont, Wilmington, DE, September 1979
- Mr. A. W. McGowen, Masonite Corporation, Laurel, MI, February 1980

Special Qualities--

Substitute products presently available include DuPont's Nomex paper, Carborundum Corporation's ceramic Fiberfrax paper, Manning Paper's Manniglass, and Masonite's Benelex 402. in addition, a product called Fibercoat is produced by Textured Products, Inc., and, as its main use currently appears to be in this category, it will be discussed here.

Nomex papers have qualities of thermal stability, flame resistance, and electrical properties that allow it to compete directly with asbestos paper. Underwriters Laboratories (UL) recognizes Nomex paper as suitable for continuous use at temperatures up to 204°C; it can also be used for short durations at much higher temperatures.[84] Other polymeric materials used as cable coatings may be suitable for temperatures as high as 260°C and can withstand soldering temperatures for short time intervals.[50]

Fiberfrax 110 ceramic paper exhibits good dielectric strength, is somewhat stiff, and can be cut and handled easily. Ceramic fiber cloth has excellent temperature resistance, operating well up to 524°C.

Glass fabrics like Manniglass, are not affected by temperatures up to 204°C. At 343°C, however, their strength is halved. Glass fabrics wrapped tightly onto wire and treated with resins are more vulnerable to abrasion than most other wire coverings and are not suited for applications involving severe flexing.

Benelux 402 is a mechanical-electrical grade able to withstand abrasive action, acidic conditions and steam cleaning.[89] It weighs half as much as aluminum and one-sixth as much as steel. It also holds precise dimensions despite temperature and humidity fluctuations.

Special qualities of Fibercoat, a knitted glass product, include its ability to fuse with ceramic coatings (applied for industrial uses), becoming a dense, true ceramic at 1093°C (2000°F) or greater,* with no combustion, toxic fumes or gases. It can also be coated with abrasion resistant materials such as urethane, while still retaining fire retardant and insulating properties. Fibercoat can be produced in an essentially dimensionally stable configuration, or with a built-in stretchability of as much as 5 percent. This stretchability is vital for important uses such as spiral-wrapping of pipe and electrical cables. Fibercoat can be made considerably more flexible than typical asbestos weaves. Insulating factors of Fibercoat vary with the type of knit and the thickness of the inorganic coatings; they are, however, reported to be comparable or superior to asbestos of similar thickness and cost. Fibercoat, like asbestos, will resist flame temperatures of 1093°C (2000°F) or more and its inorganic binder is not affected by organic solvents, most acids, or water. In addition, Fibercoat can be tailored to withstand a temperature of 2200°C (4000°F) or higher, at a higher cost. One example of this is to knit Kevlar, then coat with a high-alumina ceramic mix. Fibercoat maintains its heat insulating ability after prolonged exposure to flame in the 1200°C (2200°F) range, where, after 3-5 minutes of exposure, it changes to a ceramic as described, and maintains this structural integrity indefinitely. Even if the fire is brought under control with water, foam, or Halon gas, the strong, but now brittle, Fibercoat wrapping protects and insulates the cable. There is no afterburn with Fibercoat and no propagation of flame by the material.[39]

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*Glass loses some strength at 315-430°C (600-800°F).

Other specific properties of Fibercoat include the fact that it does not absorb water, either before or after exposure to high temperatures, although it does pass water vapor in small amounts in most applications. For toxicity, no material used in Fibercoat is considered highly toxic. The components remain tightly bound together in use. Cleanup after a fire is facilitated by the coating's tendency to pull cleanly away in dry chunks. Tensile strength is reported to be fundamentally the same as the glass fiber from which it is knit, which is superior to asbestos. Fibercoat can be laminated to some substances, including ceramic cores. Hydrofluorous and phosphoric acid and concentrated alkalis are the only substances Fibercoat will not resist. It does resist oxidation and reduction and all common organic solvents. Its dielectric strength is similar to asbestos in 110/220V applications, and is thought to be similar at much higher voltages but has not yet been tested. Abrasion resistance is similar to asbestos weaves and paper, but it may not be used in highly abrasion-resistant applications such as automotive brake linings.[39]

Another potential substitute is wet ground mica, which meets ASTM Standard Specifications D-607-42. Wet ground mica is extensively used as a dry powder and in various products due to its dielectric and heat resistant properties.[90]

Polyimide and polyethersulphone are also examples of high temperature polymeric materials which may be used in place of asbestos. In addition, ceramic fibercloth, tape or sleeving, used with glass filament inserts (to maintain high temperature strength) may be used in cable and wire insulation.[91]

Product composition--

Nomex paper is an aramid paper composed mostly (85 percent) of a highly aromatic polyamide synthetic material formed on a Fourdinier machine.[92] The smallest fiber size used in Nomex paper is 1/4-inch long. Fiberfrax® is a homogeneous product composed primarily of silica and alumina held together with an organic binder.[91] Benelux 402 is a dense lignin-resin cellulose laminate. Manniglass is a glass fabric. Fibercoat is a fabric of knitted (versus woven) glass, representing what is reported to be one of the world's few production uses for knitted glass in a process developed by Textured Products, Inc. The glass fiber is coated with a proprietary blend of ceramic and inorganic binders.[39]*

Uses and Applications--

For dry transformer insulation, Nomex can directly substitute for asbestos paper; it already enjoys a high market share. Nomex papers have also replaced asbestos as wire and turn insulation for most industrial motor and generator applications.

Substitutes are also available for industrial laminates using asbestos paper. Nomex paper can be used to prepare industrial laminates[93] and glass papers are currently being used to replace asbestos in various laminated products.[88]

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*The U.S. Patent for this material was applied for in September 1979.

Carborundum Corporation stated that their ceramic paper, Fiberfrax, can be used as dielectric and thermal insulation for transformer coils.[56] The extent of any commercial application of Fiberfrax for this purpose is not clear.

Benelux 402 has been used for insulation barriers in air insulated switching and control devices. Its properties make it usable in a wide range of utility-oriented electrical apparatus.[89]

Fibercoat has been most extensively tested for use in low-voltage cable as insulating and fireproofing wrap. One major cable manufacturer has found that Fibercoat provides excellent protection for 25 pair 24 AWG PVC-insulated control cable. It can be wrapped around wire as small as 14 AWG equivalent, and can also be used to insulate phone wire. It is also approved for use by a major chemical company to protect 300/600V underground cable (see Pipeline Wrap section), and is speculated for use in other applications noted briefly in other sections of this report.[39]

Wet ground mica is used in the rubber industry as an insulation powder and compounds for electric wire and cables.[90]

Substitute Product Manufacturing Summary--

Manufacturing process--Glass fabrics of all kinds (cloth, tape, cords, tubes) may be woven from yarn and used in resin-bonded laminates as a substitute for asbestos. For molded or hand-load composites, glass chopped strand mat may be used; in high temperature windings, glass fiber is wrapped tightly onto wire and treated with suitable resins.[91]

Benelux is made from clean wood chips reduced to fibers by a steam explosion process. Unwanted elements are driven off, leaving only cellulose fibers and lignin, a natural bonding agent. After processing to refine the fibers and form panels of controlled densities, thicknesses and sizes, the panels are placed in steam heated ultra high pressure presses where the fibers and lignin are welded to form the hard, smooth laminate.[89]

Fibercoat can be produced in a variety of configurations ranging from ribbons less than half an inch wide and as thin as 10 mils, to 72 inch wide sheets as thick as a tenth of an inch. The same technology used to knit the glass fiber can also be used to knit more temperature-resistant substrate materials, such as polyimides, with appropriate high-temperature resistant coatings. In addition, Fibercoat can be built into rigid structures much as a fiberglass and resin composite can be. When coated, the coatings such as urethane, polyvinyl chloride and acrylics form mechanical rather than chemical bonds with the woven glass.[39]

Wet ground mica is made most often from Muscovite type mica [$K_2Al_4Al_2Si_6O_{20}(OH)_4$], selected, blended, and treated to obtain maximum color, brightness and purity. While several types of wet ground mica are produced, nominal 325 mesh is most widely used. This is approximately 46 percent silica, 36 percent alumina, 10 percent potassium oxide, and 2 percent ferric oxide.

Name and number of manufacturers--Substitute product manufacturers include: DuPont (Nomex papers), Carborundum Corporation (Fiberfrax), Manning Paper Company (Manniglass), Masonite (Benelux 402) and Textured Products, Inc. (Fibercoat).

Production volume--The exact production volumes of substitute products are unknown; specific information is proprietary. However, it is known that Nomex paper is produced at the rate of several million pounds per year and is readily available.[93,94]

BEVERAGE AND PHARMACEUTICAL FILTERS

Asbestos Product

Special Qualities--

Asbestos is used in filters because it has an exceptionally large surface area per unit of weight and a very unusual natural positive electrical charge.[95] This positive charge is very desirable for removing particles from beverages as the particles are usually negatively charged. Although other substances may be used as filter materials, asbestos appears to provide one property required by some beverage manufacturers which its competitors lack--that of the removal of haze from liquid beverages. The filtering efficiency of nonasbestos sheets is considered about equal to that of asbestos, aside from haze removal capabilities. Substitutes for asbestos filters are readily available and will likely undergo further improvements as they are developed. As far as is known, substitutes seem to equal asbestos in durability and service life.

Product Composition--

The major difference between asbestos beverage filters and other asbestos paper products is the formula. Asbestos beverage filters may contain, in addition to asbestos, cellulose fibers, various types of latex resins and, occasionally, diatomaceous earth. The asbestos content varies from a high of 50 percent for pharmaceutical filters to as low as 5 percent for rough filtering applications. In general, the higher the asbestos content, the better the filtering qualities. The grade of asbestos used is a very high-purity grade (longer fiber; thus in the lower grade numbers) obtained, when available, from Arizona mines; a usable grade is also available from Canada. This particular high-purity grade of chrysotile must be free of trace minerals such as iron and calcium.

Uses and Applications--

Asbestos filter sheets are primiarily used by the beer, wine, and liquor distilling industries to filter (remove) microorganisms, fine, or very fine solids from liquids. In the beverage industry, there are several filtration steps; asbestos filter papers have most commonly been applied for "sterile" filtration, the complete removal of all yeast cells and microorganisms, both aerobic and anaerobic, that might have survived previous filtration.[96] Asbestos filters are also used for haze clarification, removing cloudiness from the liquid product and giving it a sparkling clarity.

At present, about 30 percent of the wine industry, 10 percent of the beer industry, and 25 percent of the distilling industry use some form of asbestos filtration.[97] Asbestos filter paper is also used for specialty applications in the cosmetics and pharmaceuticals industries and for the filtration of various fruit juices, such as apple juice.

Asbestos Product Manufacturing Summary--

Manufacturing process--Asbestos filter paper is made on a conventional cylinder or Fourdrinier papermaking machine. Because demand for this product is low, the machine is used to produce beverage filters infrequently; for the most part, the machine is employed to produce more popular products.

Name and number of manufacturers--The main companies manufacturing asbestos filter paper as part of their product lines are listed in Table 8.

TABLE 8. MANUFACTURERS OF ASBESTOS BEVERAGE AND PHARMACEUTICAL FILTERS

Alsop Engineering[98]	Milldale, CT
Cellulo Co.[99]	Fresno, CA Sandusky, OH
Ertel Engineering[100]	Kingston, NY
Filter Products Co. (H&K Filters)	Richmond, CA

For the companies listed, asbestos filter production represents only a small fraction of their total business. For example, Filter Products Co. makes asbestos filters only once or twice a year for specialty customers.[101] Cellulo Co. is the largest domestic producer of asbestos filters, supplying much of the amount needed by the beverage and pharmaceutical industries.[97]

Production volumes--Asbestos filters (beverage and pharmaceutical) are a subject of the larger asbestos specialty paper category. About 30 metric tons of asbestos are used in filters; most of the remainder of the metric tons used in specialty papers goes into cooling tower fill and transmission paper.[2] Because such a small amount is produced, most producers of asbestos filters make filters only once or twice a year, then revert to other products that are their main earning staples. Thirty metric tons per year is a significant decline from the consumption levels in the late 1960s and early 1970s when over 900 metric tons of fiber were being consumed; projections call for a virtual disappearance of asbestos filters.

Substitute Products

Methodology--

Search strategy--Source material for asbestos filters consisted of literature sources supplemented by industry contacts.

Summary of contacts--The following companies and individuals were contacted during preparation of this section:

- Mr. Don Wheaton, Cellulo Co., Fresno, CA
- Mr. Rumain, Plant Sales Representative, Cellulo Co., NJ
- Mr. Frank Lavery, Mr. Hallet, Ertel Engineering Co., Kingston, NY
- Mr. John Gusmer, President, Cellulo Co., Waupaca, WI
- Mr. Held, Filter Products Co., Richmond, CA
- Company Representative, Alsop Engineering, Milldale, CT

Special Qualities--

Substitute fibers which may be used in place of asbestos fibers in filters include cellulose and glass. According to industry sources, these nonasbestos substitutes have the durability of asbestos filters, but above grade 70 (an indication of filter porosity), asbestos filters are more efficient.[102,103] The service life of any filter is difficult to estimate because of its dependence upon a variety of parameters, including viscosity, temperature, color, clogging rate, and foreign substances. For example, Ertel Engineering's filters (both asbestos and nonasbestos are made) are reported to last longer filtering white wine than red wine.[102] The Cellulo Company's Cellupore nonasbestos filter pads have a shelf life of 1 year versus asbestos filters which are believed to have a slightly longer life.

Chemical treatments can be used to affix a positive electrical charge to substitute fibers, but asbestos filters have other characteristics which have not as yet been incorporated in these filter substitutes. To date, asbestos filters have been able to be made with lower porosity than nonasbestos filters. Cellupore filters (made from cellulose) are available in a variety of "tightnesses" or porosities up to grade 70, but asbestos filters are available through grade 100.[104] Further, nonasbestos filters absorb more liquid than asbestos filters and thus operate at a lower throughput. Evanite literature describes their product in terms of air resistance, air permeability, chemical resistance of the C or B glass fiber used, acid and alkaline resistance and thermal resistance, apparently with satisfactory results.

Product Composition--

A nonasbestos beverage filter made by Filter Products Company of Richmond, CA, is made from two types of specially prepared cellulose fibers, three types of diatomaceous earth and melamine resin.[101] As mentioned earlier, the fibers substituting for asbestos must be chemically treated to give the filter the desired positive charge.

Evans Products Company, Forest Fiber Products Group in Corvallis, Oregon, produces Evanite glass fiber from either a standard borosilicate glass composition or a specially formulated acid resistant grade with significantly higher silica content. Formulations are comprised of various combinations of sand, feldspar, soda ash, borax, dolomite, limestone, barium carbonate, and zinc oxide. These ingredients are first introduced into a glass furnace for melting and glass conditioning. The glass stream then passes through an electrically controlled platinum bushing which regulates the flow into a rotary fiberizer or "spinner." The primary fibers are immediately attenuated by a blast of hot gas into the desired fiber diameter. They are then collected, under partial vacuum, on a moving screen located within a forming chamber. From here the fibers are removed, compacted to a uniform weight, and packaged at a specific density to minimize fiber breakage. The Evanite fiber grades have been developed for use on conventional papermaking equipment to deal with differences in drainage rates, drying time, and shinkage characteristics.[105]

The Cellulo Company produces two lines of nonasbestos beverage filters in addition to their asbestos and acid-washed cellulose filters. One, trade named Cellupore®, is made primarily from cellulose fibers. The other, the 700 Series, combines cellulose, nonfibrous filter aids, and an absorptive binder system. Each is graded by porosity from 10 to 70 in increments of 10, but asbestos filters can attain higher standards. Asbestos filters are available graded from 70 to 100 in increments of 5. All beverage filters are inert, chemically pure and conform to Federal Food and Drug Regulations for food and beverages.

Ertel Engineering manufactures filters in 360 different sizes out of asbestos and cellulose fiber, cellulose and diatomaceous earth, or a mix of cellulose from wood pulp and paper. Each product composition results in a different porosity and density level.[102]

Major purchasers of nonasbestos beverage filters are the pharmaceutical, cosmetic and food industries. The fiber size distribution in filters used in these industries is not known. However, grades used vary with the intended application and higher grades contain shorter fibers.

Uses and Applications--

Nonasbestos substitute filters can be used almost interchangeably with asbestos filters in most applications. Cellupore filter pads are available in sizes to fit virtually all commerical filter holder assemblies, including plate and frame assemblies and stacked disc holders. Like asbestos filters, the substitutes have high wet strength and can clarify, polish, and sterilize a wide variety of liquids, including acids, alkalis, antibiotics, antiseptics, aperitifs, beer, wine, whiskies, cider, cosmetics, detergents, drinking water, fruit juices, hair tonics, inks, insecticides, perfumes, vaccines, and photographic solutions. Applications for Evanite include fluid and air filters, surgical masks, industrial respirator media, and high efficiency thermal and accoustical insulation.

Substitute Product Manufacturing Summary--

Name and number of manufacturers--Two manufacturers of nonasbestos beverage filter products were contacted:

- Cellulo, Inc., NJ and WI, and
- Ertel Engineering Company, Kingston, NY

Evans Products Co., Corvallis, Oregon, is also known to sell its nonasbestos product, Evanite, to AMF, which may manufacture nonasbestos beverage filters.[105]

Production volumes--The production volumes of nonasbestos beverage filters are not known; however, they appear to dominate the beverage filter industry at present.

COST COMPARISON

Flooring Felt

Costs of flooring felt vary widely since the number and type of substitutes themselves differ greatly. The range of substitute costs is perhaps the greatest of any of the paper products, and rests very much upon consumer taste and choice. Substitutes which are less expensive than asbestos and those more expensive are both available. An exact cost comparison for each substitute product is not included in this report. However, it is reported that the Lextar product under development currently costs 10-15 percent more than asbestos felt; Lextar is working actively with the major commerical asbestos felt producers to reduce this cost to an equivalent asbestos cost.[10]

Roofing Felt

Table 9 provides two cost comparisons. First, there is a comparison of the basic roofing material costs of organic, asbestos and fiberglass felts, and the membrane material. Since rolls come in different sizes and the number of layers installed on the roof will vary, the basic unit of comparison in this table is the square, a 100 square foot area of roofing. In terms of material cost per completed square, only organic felt is less expensive than asbestos. More meaningful comparisons, however, are the costs for installed units. Asbestos and fiberglass are nearly equal in quality and durability, but a fiberglass square is 5.6 percent more expensive than a comparable asbestos square. A membrane roof is 13 percent more costly than an asbestos unit. Thus although the membrane roofing is considerably more expensive than any of the felts, the considerable savings in labor and other materials such as tar or asphalt is evident in the comparisons between material and installed costs. A company that manufactures both conventional organic asphalt roofing and the membrane systems estimated that the cost difference between the two systems, installed, is only 5 to 10 percent.[106]

TABLE 9. ROOFING COSTS[11,12,21,106,107]

	Retail cost per roll ($)	Squares	Single square (one layer) ($)	Material cost per square ($)	Installed cost per square ($)	
					Range	Average
Organic felt	10.00	4	2.50	7.50 (three layers)	100-160	126.00
Asbestos felt	23.50	4	5.75	11.50 (two layers)	115-160	132.50
Fiberglass felt	28.50	5	5.60	16.80 (three layers)	110-160	140.00
Single-ply membrane	35.70	1	35.70	35.70 (one layer)	-	150.00

Beater-Add Gaskets

Currently, substitutes for asbestos gaskets are more expensive than the asbestos product. Both ceramic and teflon gaskets fit this description. The cost of Cotromics Corportation's ceramic paper varies depnding on the desired thickness, from 20 to 50 cents per square foot.[33] One-eighth inch thick Fiberfrax is available for 50 to 85 cents per square foot or 3.5 to 5.9 mils per square inch with the exact price dependent upon the quantity ordered.[108] Comparable teflon gaskets may be purchased for about 8.5 cents per square inch placing them at the high end of the cost scale.[35] Hollingsworth and Vose reports, however, that, although currently more expensive, as substitute products obtain wider acceptance and use, manufacturing volumes will increase, thereby diminishing the price gap between the materials.[36]

Pipeline Wrap

In future years, it is thought that the cost advantage of fiberglass systems will improve relative to asbestos pipeline use, making it more competitive with the asbestos product. More specific information, as well as cost information for plastic coatings and extruded coatings of epoxy resin was not available through industry contacts.

Millboard

Substitutes discussed here generally have insulating qualities equal or superior to asbestos board, but most have significantly higher prices. Vermiculite boards, although meeting required specifications, are generally inferior to asbestos products and cost about 30 percent more. Cobalt rollers have been used as a millboard substitute in steel heat treatment applications, but are considerably more expensive than comparable asbestos products.[50] Table 10 provides a price comparison between asbestos millboard and the most frequently proposed substitute products. Johns-Manville has been working to develop a product suitable for temperatures up to 816° to 870°C to sell for 15 percent less than their Ceraform 102. It should be closer to a direct substitute for asbestos millboard.

TABLE 10. COST OF ASBESTOS MILLBOARD AND SUBSTITUTE PRODUCTS--
$ per square foot (square meter)

Thickness (inches)	Asbestos[48]	Pars No. 9[48]	Johns-Manville[49] Ceraform 102*	Carborundum Fiberfrax[32] Duraboard	Carborundum Fiberfrax[32] Hotboard*	Carborundum Fiberfrax[32] GH Board†
1/8	0.32 (3.55)	0.86 (9.55)	0.96 (10.65)	- -	- -	- -
1/4	0.61 (6.75)	1.44 (16.00)	1.16 (12.90)	- -	- -	3.08 (34.20)
1/2	1.15 (12.75)	2.82 (31.35)	1.63 (18.10)	2.16 (24.00)	1.30 (14.45)	- -

*Price for 1000 ft^2 or more.

†Price for 75 ft^2 lots.

Commercial Papers

Ceramic paper is a great deal more expensive than asbestos paper, averaging 5 to 10 times as costly. Cellulose and fiberglass paper substitutes such as Nomex by DuPont are also more expensive.

Electrical Insulation

While Nomex paper can replace asbestos paper in most electrical insulations, the resultant price is higher. For most applicatons, Nomex generally costs two to four times as much as asbestos electrical paper.[84] Nomex is priced as follows for the four sizes of paper manufactured:[109]

Thickness (mil)	Price $/yd^2 ($/m^2)
3	1.84 (2.30)
5	2.92 (3.65)
8	4.40 (5.50)
10	5.47 (6.85)

Fiberfrax is available in two thicknesses. Its cost varies in accordance with the quantity ordered. Large volume purchasers can achieve a savings of as much as 42 percent.[91]

Thickness (inches)	Price Range $/yd^2 ($/m^2)
1/16 (62.5 mils)	2.70 - 4.59 (3.40 - 5.75)
1/8 (125 mils)	4.50 - 7.65 (5.65 - 9.55)

The cost of Fibercoat by Textured Products is comparable to woven asbestos products, but slightly more than asbestos paper. The literature cites a typical cost for 25 mil flexible sheets as 50-75 cents per square foot.[39]

Polymeric materials used in cable coating are available at relatively high cost, but may be justified by their ability to withstand high temperatures, their durabiliy and their flexibility.[50]

Mica is milled by a relatively costly, slow friction process.[90] Sepcific cost comparisons are not available.

Electrolysis Cell Diaphragm

The membrane cell product by DuPont consumes 2540 KWh/metric ton of chlorine as compared to 2270 KWh/metric ton for asbestos. With escalating energy costs, the cost differential may be significant. Industry research is directed at reducing this difference.

Cooling Tower Fill

Calbestos is somewhat less costly than its nonasbestos substitute, "Veriscore," with product applications about the same. No substitutes for asbestos transmission paper were identified.

Beverage Filters

Cellupore filters cost approximately 10 to 15 percent more than comparable asbestos filters. No blanket statement applies to the Ertel products. At present, the cost of asbestos is increasing rapidly (from $365/metric ton in 1975 to $1090/metric ton in 1979), but so is the cost of wood pulp, making it difficult to determine exactly how costs will compare even in the short run.

Summary

Summarizing the substitutes cost data one notes that for virtually every paper category the commercially available substitutes are more expensive than the asbestos product. The only exceptions to this rule are certain types of flooring and organic felt roofing. For all other asbestos-containing paper products, the substitutes cost from 5 percent to upwards of 40 times more than the asbestos product they are intended to replace. This cost differential may change (decrease) as the substitutes market matures, and production techniques are refined. For the present, however, it appears that the conversion from an asbestos-containing paper product to an available substitute would not be made were there no other considerations except for cost; that is, based on cost alone, the move to total replacement of asbestos products with substitutes would be prohibitive.

CURRENT TRENDS

Flooring Felt

Although asbestos flooring felt is in a high consumption category, future growth is expected to diminish,[3] due to a stabilization of the product mix because the changeover (which has been occuring in the recent past) from jute backing to the newer asbestos backing, is nearly complete. This means that the asbestos product has now replaced the jute in most every application. From 1970 through 1975, growth of the asbestos backing was estimated at 14.8 percent annually, whereas the same source projects that the annual growth through 1980 will be 5 percent and only 2.9 percent from 1980 to 1985. The market currently (1979/80) backs this up with a small positive growth rate. In addition, new substitutes to the asbestos product, particularly foam cushion backings, backless sheet flooring, and new developments using Pulpex* fiber are providing increasing competition for the asbestos flooring felt market, indicating that there may well be yet another transitional growth stage at some time in the future, with the development of suitable alternatives.

Roofing Felt

Industry sources feel that the asbestos roofing felt market is currently stable, but a decline is expected in the near future for two major reasons. First, asbestos roofing is beginning to feel competitive market pressures from fiberglass roofing, and, second, labor unions and the construction industry are becoming more apprehensive about using asbestos products. Fiberglass has many of the same technical advantages and characteristics of asbestos and is less expensive for initial installation. Furthermore, fiberglass requires less saturation than asbestos and as petroleum and asbestos prices climb, the cost differential between fiberglass and asbestos roofing will shift more and more in favor of fiberglass. However, asbestos roofing is considered more durable than fiberglass, possibly making asbestos more cost effective in the long run.

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*This is expected to be a future possibility, pending present testing results. Pulpex is also currently used in other paper products such as filter and decorative papers, thermoformable paperboards, and corrugated paperboard. More information on PUlpex may be found in the Sealants section of this report.

Arthur D. Little[3] expected demand for asbestos roofing to decline at an average rate of 2.8 percent through 1980 and by about 5 percent from 1980 to 1985. Industry sources feel the actual decline will be slightly less.

Beater-Add Gaskets

Although only a marginal increase is projected for asbestos gasket substitutes, 1980 reports indicate that this increase is ongoing. Industry contacts[35] pointed to the fact that substitutes are often not used by industries due to ther expense, but if concern over the use of asbestos products grows and substitute products obtain wider acceptance and use, this attitude could change. Already, marketable substitutes have increased markedly, as noted by industry comments to the Draft version of this report. There have been tremendous changes in this area from late 1980 through 1981 and significant, large new families of materials do exist as replacements to the asbestos product, although their cost is high.[31]

Pipeline Wrap

Saturated asbestos pipe wraps are presently the preferred corrosion protection system for oil and gas pipelines due to their time-tested durability and relatively low cost. However, the market for pipeline corrosion protection is competitive and alternatives to asbestos felt are available.

As might be expected, potential growth in demand for asbestos pipe wrap (or substitutes to it) is a function principally of new pipeline construction and availablility of competitive materials.[3] New pipeline construction has historically experienced rapid growth and this is expected to continue. Competitive alternatives to asbestos wrap, which are becoming more available, will most likely exert some downward pressure on the growth of the asbestos pipe wrap market.

At present, most industry sources view the asbestos pipeline wrap market as stable; however, in the near term, a slight downward shift of the market can be expected, primarily due to the competitive pressures of the relatively new fiberglass pipe wraps and new epoxy resins and extruded coatings that are just becoming commercially available. Cost effectiveness still favors asbestos pipe wraps; however, with the rapidly rising costs of asbestos fiber and petroleum products (asphalt and coal tar), the advantage may shift away from asbestos.

Millboard

Substitute millboard products have been developed to meet the variety of temperature, corrosion, and other environmental conditions imposed on the asbestos product. Thus, asbestos millboard production is not expected to increase significantly in the future. The annual growth rate for asbestos millboard and commercial papers is projected to be only 0.9 to 1.0 percent through 1985,[3] but it is anticipated that U.S. firms producing millboard will cease production of the product as acceptable, economical substitutes are developed.[42] Industry is likely to maintain minimal production capacity for specific applications where alternatives are not available. Nonasbestos products becoming available are generally in heat and flame protection applications.

Commercial Papers

The overall growth rate for asbestos commercial paper is slightly negative and is not expected to change, indicating that substitute products will have an opportunity to establish themselves in this area. Asbestos muffler paper has already been replaced by ceramic and glass papers in the United States, apparently due to concern exhibited by automotive muffler and converter producers about using asbestos-containing materials. As for corrugated paper, the current outlook indicates that it may not be made in the future. Substitute products like ceramic paper can replace asbestos commercial paper in the future if the greater cost of such products is accepted.

Electrical Insulation

Transformer manufacturers are constantly using more substitutes for asbestos electrical insulation papers. Nomex papers are already extensively used by electrical and transformer manufacturers,[84] while Fiberfrax and other replacement industrial laminates are already on the market. Therefore, the market for asbestos electrical paper is declining, although the rate of decline is not known at present. The market for substitute products such as Nomex paper has been steadily growing since it became available in 1965.[94] Fibercoat, although developed through research begun in 1978 on fiberglass as a potential fireproof upholstery and wallcovering fabric, is a relative newcomer to replacement applications in electrical insulation. Nonetheless, its qualities demonstrate that it is indeed another suitable substitute in this area.[39]

Speciality Papers

Saturated asbestos paper is becoming too expensive compared to the readily available plastic substitutes for cooling tower fill;[58] thus the market should favor replacement of the asbestos fill presently in use, with new substitute products. However, in specialty applications, such as cooling for gaseous diffusions, asbestos fill is used rather than other materials because of its superior heat and chemical resistant characteristics. The use of asbestos-cement sheet as a cooling tower fill is rapidly decreasing due to its potential for wear under extreme pH conditions creating a potential health risk. Nonmetal fills are generally lighter than metal fills and, therefore, have advantages in transport costs and handling ease. Asbestos paper is considered the best fill material in terms of chemical and heat resistance, but for most aplications, the extra chemical and heat resistance is not critical. As indicated, plastic fills are becoming the most popular for general applications.

The advantages and disadvantages of DuPont's Nafion membrane product substitute for electrolytic diaphragms have been covered under substitute properties in this section. Even though there are many advantages, the disadvantages in the lack of electrical efficiency as compared to asbestos dictates further research and development before this product is a fully acceptable substitute to asbestos. Clearly, this would affect the demand for membrane cells vis-a-vis asbestos diaphragms, especially with rising energy costs.

For substitutes to asbestos transmission paper, data are not available, but indications are that substitute materials would probably not have the requisite characteristics of asbestos and would be more costly.

Beverage Filters

Nonasbestos substitutes have already replaced asbestos filters in most commercial applications. This trend will most likely continue until asbestos is no longer used commercially for filtration. As indicated, the total quantity of asbestos fiber currently used in making asbestos filters is estimated to be only 30 metric tons annually[1,2] down significantly from the late 1960s and early 1970s when over 907 metric tons of fiber was being consumed. The future outlook points to the virtual disappearance of asbestos filters. This is attributed to the concern of the beverage industry in employing asbestos-containing products and the cost effectiveness of the available substitutes.

Summary

Overall, the trend for asbestos paper products is in a state of flux. Almost all categories show a stable or marginal decrease in the amount of asbestos to be used. Only in a few instances, such as some specialty papers, where the specific qualities of asbestos are absolutely essential, is there a slight increase in asbestos consumption predicted. This "leveling off" of asbestos use is generally attributed to the availability of acceptable, if not closely identical alternatives. Changes in substitute quality and availability will directly affect asbestos use in the paper products sector, especially if the prices of substitute materials become more competitive with asbestos. At the current time, prices of nonasbestos products are higher in almost every paper product category.

CONCLUSION

Flooring Felt

In recent years, asbestos flooring felts have enjoyed an excellent growth rate. During the period of 1971 to 1975, the growth was estimated at 14.8 percent annually, but this is projected to drop in the future, both because asbestos has now replaced jute backings and substitute materials are providing competition.

A diversity of substitutes to asbestos flooring felt currently exist. These substitutes are in the form of alternative floor materials and include foam cushion backed flooring, backless sheet flooring, wood, and carpet. "Place and Press" vinyl tile squares also enjoy high popularity with the consumer. In addition, Pulpex flooring felt is currently being developed by Lextar, which is working actively with major commercial asbestos felt producers to reduce the cost of Pulpex to an equivalent asbestos cost.[10]

Roofing Felt

Since only organic felt roofs have been used for more than 20 years in the United States, it is difficult to draw firm conclusions concerning the long-term durability of the various roofing systems. Industry representatives contacted differed in their opinions of the superiority of asbestos versus fiberglass felts. One problem stems from the apparent variability in fiberglass felts. Also, conversion to fiberglass felt mats requires manufacturing experience and applicator training. Nevertheless, the major manufacturer of fiberglass roofing reports significant gains for their product in the total built-up roofing market. Due to rising asbestos costs, it is expected that fiberglass felts will reduce the demand for asbestos roofing felt. The newest system, the single-ply modified bitumen/plastic membrane, is expected to further reduce the demand for asbestos felt, despite reported performance and application problems, less fire resistance, and greater sensitivity to weathering.[3,19,21,106] Problems with alternative materials are being addressed by manufacturers; many difficulties will be minimized when installers become more familiar with their use. In addition, the cost of asbestos felt may increase relative to the other alternatives as it involves the use of a greater amount of petroleum products.

Beater-Add Gaskets

Very recently, nonasbestos gaskets have been developed which are now in the marketplace. Although alternatives are generally considerably more costly than their asbestos gasket counterparts, and may not fill all of the product niches that asbestos gaskets have created, this is likely to change as the substitutes gain acceptance. For instance, it is reported that asbestos-free materials are currently available that match existing material for cylinder head and hard gasket applications.[37] Companies originally dealing mainly with asbestos products such as Rogers Company and Hollingsworth and Vose, now produce adequate nonasbestos gasketing materials.

Pipeline Wrap

Although competitive products are occasionally used in the oil and gas industry in place of asbestos pipeline wrap, this product is currently preferred because of its cost and proven effectiveness. In addition, this wrap is only needed with demand for new pipeline construction, so this variable must be taken into account. The oil and gas industries currently prefer the hot enamel system of pipeline wrap application which requires either asbestos or fiberglass wrap. If the price of asbestos increases, this preference could well turn to fiberglass. In any case, the magnitude of any drop in demand for asbestos pipeline wrap will not likely exceed several percent annually, since most alternatives need additional product development before they will be able to match the performance of asbestos pipeline wrap at comparable costs.

Millboard

A number of substitutes for asbestos millboard are available which have already led to a decline in demand for asbestos millboard and rollboard. Moreover, substitutes are being developed that may be cheaper than some of those now on the market. Many substitutes, composed of high temperature alumina-silicate refractory materials, can withstand significantly higher temperatures than asbestos and are stronger at higher temperatures as well. Nonetheless, available substitutes are currently two to three times more costly than conventional millboard. With the development of lower cost, lower temperature substitutes, it is likely that, given the current level of regulation and its effect on the costs of asbestos, these prices will approach equality in the near future. In addition, the higher cost, higher temperature substitutes will continue to fulfill needs that asbestos millboard cannot meet.

Commercial Papers

Historically, the growth rate for commercial asbestos paper has been very slow, in fact, in 1975, the growth rate was estimated to be about zero,[3] and it is now slightly negative. The bulk of commercial paper produced is general insulation paper. Industry concern about working with asbestos-containing materials and the availability of some substitutes, although at greater expense, has created the negative growth rate.

All of the primary manufacturers of asbestos commercial paper, except Nicolet, Inc., have now diversified into substitute product lines for this category. In the future, the market for nonasbestos commercial papers is expected to improve, although it appears that the demand for such products is not extensive. Substitute costs are very high at present, but should decline as more research is performed and more substitute products infiltrate the market. In addition, the performance of substitute products should improve as increased knowledge is gained with use of these products.

Electrical Insulation

It appears that this category of asbestos paper products has several viable substitute products available. The substitutes are described as matching asbestos in the special qualities required in this application, but, to date, have generally not matched asbestos in price. Higher prices of the alternative products may become more competitive with consumer acceptance as the length of time the products are on the market increases.

Specialty Papers

This category includes transmission paper, electrolytic diaphragms, filter paper, cooling tower fill, metal lining paper, and laminates. Many of the products developed to replace asbestos specialty papers seem to be readily available. The only exception is transmission paper where there are currently no nonasbestos alternatives available, although research and development is underway in this field. In electrolytic diaphragms, substitutes exist, but are not equal to asbestos in properties and quality. Nonasbestos products have already replaced asbestos in many filter papers and industrial laminates, and comparably priced nonasbestos cooling tower fill and metal lining paper are increasing in market share. There remain some deficiencies to correct; research in such areas as disposal and handling of spent paper generated in electrolytic chlorine production may also be desirable. Some asbestos specialty papers are already being produced in lower volumes. With the many alternative products available, this category appears to have the potential for rapid reductions in asbestos consumption.

Beverage Filters

Asbestos beverage and pharmaceutical filters are not only produced and consumed in very small amounts, but also will likely be totally replaced with available substitutes in the not-too-distant future. However, as this is only a small segment of the asbestos paper products industry, it is unlikely to have any great effect. It has been concluded[95,96] that nonasbestos filter sheets have reached the stage where they can be considered a full substitute for asbestos filters. Further,[96] the comparative economics may favor the nonasbestos filters since the filtering efficiency of the nonasbestos sheets in some applications is considered equal to that of asbestos. However, for haze removal from beverages, asbestos appears superior at present and some beverage manufacturers still require this quality.[97]

The major advantage of asbestos use in the past was its high positive charge which attracts negatively charged ions. In pharmaceuticals, bacteria must be removed from products, and since most bacteria have negatively charged ions, only asbestos filters were able to attract such ions.[102] However, newly developed products can receive such a charge and consequently act similarly.

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SECTION 3

FRICTION MATERIALS

ASBESTOS PRODUCT

Special Qualities

All products containing friction materials rely on the coefficient of friction between mating surfaces to transmit or stop motion. Brakes convert kinetic energy into heat, absorb the heat, and gradually dissipate it into the atmosphere. Brakes consist of two parts, the rotor which is connected to the wheel, and the stator on which the friction material is mounted.* Clutches transfer kinetic energy from a rotating crankshaft to the transmission and wheels. Both brakes and clutches may operate wet or dry. In dry systems, the heat is conducted to the air and surrounding structure while wet systems operate within oil or another fluid which absorbs the heat to maintain temperatures below 200°C (392°F).† The special qualities required by friction materials include:

- Possession of the appropriate coefficient of friction for the desired application
- Ability to withstand the high temperatures generated at friction interfaces
- Dimensional stability

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*This basic description of a brake applies to automotive disc brakes; other friction products including drum brakes and clutches, cone brakes and clutches, band brakes and clutches, centrifugal brakes and clutches, and plate clutches, although composed of different parts, require the same special qualities listed.

†In dry brakes, the heat at the friction surface can be dissipated by convection and/or conduction and/or radiation. In high energy stops on automotive disc brakes or in continual braking coming down mountain slopes, a major amount of heat is lost by radiation from the exposed hot disc.[1] Temperatures at this time may reach 400°C.[1,2]

- Strength
- Durability
- Lack of abrasive characteristics which could lead to scoring of mated surfaces.

In addition, most friction materials also require:[1]

- Low wear rate
- Lack of noise
- Lack of compressibility
- A very high coefficient of friction under cool, humid conditions at low rubbing speeds
- Ability to be manufactured in high volumes with consistent physical properties
- No "rust bonding"; i.e., the material will not become bonded to metal disc or drum while in pressure contact, especially under wet conditions.

Asbestos is used in friction materials because of the properties listed in Table 11. The most important properties are thermal stability, reinforcing abilities, relatively high friction, fiber flexibility, and relatively low cost.

TABLE 11. UNIQUE PROPERTIES OF ASBESTOS APPLICABLE TO FRICTION MATERIALS[3]

Properties	Comments
Fibrous form	Flexibility contributes to forming characteristics. Fibers interlace and interlock, enhancing strength. Flexibility reduces wear at friction interfaces.
Fine fiber diameter	Provides strong reinforcing characteristics because of the large number of fibers per unit weight.
High tensile strength	Provides strength and durability to friction products.
Temperature resistance	Chrysotile unaffected by T <200°C (400°F). Able to withstand high temperatures generated at friction interfaces, up to 400°C (750°F). The temperature of maximum ignition loss is 1000°C (1800°F).
Cost	Provides low cost/performance or cost/physical property ratio.

Product Composition

Friction materials for automotive brakes and clutches are complex composites of three general types of ingredients:

- reinforcing fibers,
- property modifiers, and
- organic binders.

Historically, asbestos fibers have been the major constituent of nearly all organic friction materials, so chosen because of their thermal stability, friction level, reinforcing properties, availability and relatively low cost. Small quantities of other fiber reinforcement may also be used. Because asbestos alone does not provide all of the properties required for friction materials, property modifiers are added to provide various degrees of friction, wear, fade, recovery, noise, and rotor compatibility. A resin binder is used to hold materials together and contributes to the friction characteristics of the mixture. Table 12 lists common ingredients found in several patent formulae.* Following is a more detailed description of the raw materials used in organic friction material.

Binders--

In wet mix processing, a viscous material (usually a creosol) is used. In dry-mix processing, a powdered material (usually a novolac) is used. Phenolic and cresylic reins (both synthetic) are the most commonly used binders and are normally modified with drying oils, rubber, cardanol, or epoxy.

Fibrous Reinforcements--

The asbestos normally used in friction material is chrysotile. The size distribution of asbestos fiber consumed by the friction materials industry in 1980 consisted of chrysotile grades 3 through 7 (predominantly grades 7 and 5).[6] A total of 43,700 metric tons was consumed. Long-fiber asbestos (grades 3, 4, and 5) is used in dry-mix processing and short-fiber asbestos (grades 6 and 7) is used for wet-mix processing. The longer fibers permit the bending of linings from flat to curved segments. Clutch materials contain additional continuous-strand reinforcements including cotton, asbestos, yarn, brass wire, and copper wire.

Property Modifiers--

Property modifiers can be classed as nonabrasive and abrasive. Table 13 lists property modifiers and their functions in organic friction materials.

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*The formulations shown in Table 12 contain little or no resin and therefore could not be made commercially through the dry mold process discussed, but would instead be made by extrusion or in some cases by the sheeter process.[1] These formulations are not for organic linings but rather for more heavy-duty applications requiring less resin.

TABLE 12. TYPICAL INGREDIENTS USED FOR SOME FRICTION MATERIALS (IN WEIGHT %)[4,a]

	Copolymers[b]	Asbestos[c]	Sulfur	Zinc oxide	Cardolite[d]	Resin	Barite	Rottenstone	Other additives
A	22	49	2	4			12	12	
B	11	63	1	2			12	12	
C	17	54	2	3			12	12	1[e]
D	15	58	2	3			12	12	
E	15	58		3			13	12	
F	15	79	1	3		2			
G	15	69	1	3	10	2			
H	15	69	1	5	10				
I	15	79	1	3					
J	15	69	1	3		2	10[f]		
K	13	55	1	2	9	2	17[g]		
L	13	64	1	3	10	6	1[h]		1[e]
M	15	15		6		5	40[i]		19[j]
N	15	69	1	3		2	10[f]		
O	15	69		4	10	2			
P	17	49		4	30				
Q	17	65		4	10		4[k]		
R	17	69		4	10				

[a]As these ingredients consist of only small amounts of resin for the formulas given, the friction materials arising from these formulas are assumed to be for stiffer, heavy-duty applications which require less resin content than organic linings.

[b]Acrylonitrile-butadiene copolymer

[c]Grade 5K chrysotile.

[d]Friction dust made from cashew-nut shell oil (3M tradename).[5]

[e]Abundum (600 x) - aluminum oxide.

[f]Unidentified friction particle.

[g]Zinc dust.

[h]Paraformaldehyde (curing agent).

[i]Steel wool.

[j]Iron oxide.

[k]Orlon fiber.

TABLE 13. PROPERTY MODIFIERS IN FRICTION MATERIALS[5,7-9]

Modifier	Function
Nonabrasive	
Cardolite (cashew friction dust) Ground rubber Carbon black Petroleum coke flour Graphite Gilsonite	Noise, wear and abrasion control
Abrasive	
Brass chips Copper powder Rottenstone (decomposed siliceous limestone) Quartz Wollastonite Zinc Aluminum	Scavengers, breakup surface films
Zinc chips	Recovery of normal performance after fade
Limestone Clays Finely divided silicas	Improve wear resistance
Barite Alumina } -200 mesh Silicon carbide } -200 mesh Kyanite	Increase friction level
Molybdenite Calcium fluoride Lead and compounds	Lubricant
Antimony compounds Calcium compounds Barium hydroxide Potassium dichromate Magnesium carbonate Iron oxide Cryolite Nickel Sulfur	Use not defined

Uses and Applications

The primary uses for friction materials are brakes for light- and heavy-duty vehicles, aircraft, railcars, and various types of heavy equipment. Clutch facings are another important friction material product. Minor uses include braking mechanisms for bicycles, presses, hoists, lift trucks, mining and drilling equipment, chain saws, tape recorders, spinning and knitting equipment, typewriters, snowblowers, and washing machines. In addition, many business machines require clutch mechanisms. These applications are very diverse and demanding. Out of hundreds of formulations either tested or developed to meet such standards in the past several years, only a very few nonasbestos compositions have proven suitable.[1]

The primary uses for asbestos-containing friction materials in automotive and railcar applications are listed in Table 14. Additional applications include the use of asbestos friction products in agriculture, construction, mining, logging, marine, oil well drilling equipment, and industrial work.[1]

Product Manufacturing Summary

Manufacturing Process--

Production methods and raw materials used in the manufacture of friction materials vary, depending on the intended application of the final product.

Organic linings, which must bend, require high resin contents and long fibers. Stiffer, heavy-duty materials with less resin require molding for shape and clutch materials require special fiber-forming methods. Major manufacturing methods are described below.

Linings--Most linings are produced from resin wet-mix by extrusion or in rolling processes.* Asbestos and various property modifiers are mixed with liquid resin at 50°C (120°F), then binder solvent is added to yield a putty-like mass with good wet strength. In the extrusion process, the mix is heated to 90°C (195°F) and extruded as a flat, pliable sheet which is dried for 2 hours at 80°C (175°F). In the rolling process, the partially dried mix is fed between two rolls that align the fibers into flat, pliable "green lining." Linings are then cut to length, formed at 150°C (300°F), and molded for 4 to 8 hours at 180° to 250°C (360° to 480°F). The final product is ground to produce finished brake linings.

Linings for heavy-duty use are produced by a dry-mix process. Asbestos, modifiers, and resin are mixed and formed into 60 x 90 cm (24 x 35 inches) briquets that are pressed for 3 to 10 minutes at 140° to 160°C (340° to 375°F), and cured in molds for 4 to 8 hours at 220° to 280°C (425° to 540°F). The brake linings are finished after grinding.

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*Although most linings are made with these processes, other processes used should be noted. These include the rotting, sheeter, and millboard processes. Linings made by last two processes have characteristics that are hard to find in materials made by the other three processes.[1]

TABLE 14. USES OF ASBESTOS-CONTAINING FRICTION MATERIALS[a]

Product[b]	Characteristics	Applications
Drum brake linings[c]	High and stable friction at temperatures up to 250°C (480°F). Tensile strength of 4000 to 5000 psi.	Automobiles and light trucks.
Non-servo linings	Stable friction, wear resistant, tensile strength of 4000 to 5000 psi.	Rear wheel drum brakes of small front-wheel drive vehicles, K-car, Citation, etc.
Class A disc pads	Nonabrasive friction and wear, quiet, wear resistant up to 300°C (570°F), low coefficient of friction, tensile strength of 4000 to 5000 psi, rotor compatibility.	Large and medium-sized United States-made automobiles.
Class B disc pads	Higher friction, wear resistant up to 350°C (660°F) but less wear resistant at lower temperatures, less quiet, tensile strength of 4000 to 5000 psi.	European-made automobiles and light trucks.
Truck segments	Stable friction, wear resistant, tensile strength of 4000 to 5000 psi.	Front drum brakes of medium-duty trucks (10,000-15,000 lbs).
Class C brake blocks	High friction minimal fade, wear resistance to 400°C (750°F) at the expense of other brake characteristics.	Heavy-duty trucks.
Clutch friction materials	Stable friction, good wear up to 250°C (480°F), quiet, very high tensile strength of 10,000 psi.	Automobiles.

[a]Table compiled from Reference 2 and Reference 7.

[b]Listing goes from light-duty applications to heavy duty.

[c]It should be noted that this category includes both "primary" and "secondary" drum brake linings in servo drum brakes. The primary essentially activates the secondary and both linings are exposed to the same environment; i.e., temperature, and since they are in the same brake they fit the same applications. This servo brake is declining in usage.[1]

Disc pads--A dry-mix is prepared as for heavy-duty linings. The mix is formed into briquets at room temperature and 27.6 to 41.4 MPa (4000 to 6000 psi). The briquets are pressed at 160° to 180°C (320° to 355°F) and 27.6 to 55.2 MPa (4000 to 8000 psi) for 5 to 15 minutes and are then cured at 220° to 300°C (430° to 570°F) for 4 to 8 hours. Grinding produces the final product.

Blocks--Asbestos reinforced brake blocks are prepared by a dry-mix process. Briquets are formed at 10.3 to 17.2 MPa (1500 to 2500 psi) and heated to 90°C (195°F) for 15 to 30 minutes to reduce blistering during hot processing. Blocks are formed at 130° to 150°C (265° to 300°F) and 13.5 to 20.7 MPa (2000 to 3000 psi) for 10 to 30 minutes. The blocks are then cut and ground to shape. Final curing takes place in confined or unconfined form. After grinding, drilling, and chamferring, the block is finished.

Clutch materials--A primary concern in one manufacturing method of clutch materials is the placement of the wire reinforcement within the matrix. A dry-mix is used in molding without wire or molding around wire preforms. Another method is to prepare a wet mix and run a wire through the viscous material. The surface is ground to final shape after pressing and curing.

Woven bands--Woven bands for heavy-duty uses are produced by a process that begins with asbestos cord (which may be reinforced with wire) being passed through a wet-mix to pick up resin and modifiers. The saturated cord is then woven into tapes that pass through heated rolls to partially cure the resin. The material can be post-cured at 160°C (320°F) to remain as a flexible roll lining or post-cured at 280° to 230°C (355° to 445°F) to form rigid segments. Such materials are found in large band brakes used to control large machinery.

Name and Number of Manufacturers--

There are 30 major manufacturers of asbestos-bearing friction materials, listed in Table 15. Both large diversified companies such as Raybestos-Manhattan and small single product companies are included in this list. The first few companies listed in this table accounted for a majority of the total estimated sales of asbestos-containing friction materials in 1975, a pattern consistent with the industry's historical trend. From 1954 to 1967, the eight larger companies together accounted for 86 to 91 percent of the industry's value of shipments.

Production Volumes--

Table 16 gives the consumption of asbestos in friction products for the years 1969 to 1980. Figures for production volumes were not available, but a breakdown of the value of asbestos-bearing friction materials projected to 1981 from 1972 values given by Meylan is provided in Table 17.

TABLE 15. U.S. MANUFACTURERS OF ASBESTOS-BEARING FRICTION MATERIALS[10-36]

Company	Plant location(s)	Products: Brakes: Automobile and light truck	Brakes: Heavy duty truck	Brakes: Railcar	Brakes: Industrial	Clutches: Vehicle	Clutches: Industrial	Comments	Estimated 1978 sales ($ million)
Raybestos-Manhattan, Inc.[11] RM Friction Materials Co.	Stratford, CT; Mannheim, PA; Crawfordsville, IN; Marshville, NC; N. Charleston, SC	Drum, disc	Disc segment, block			✓	✓		165.0
Bendix Corporation[12] Automotive GRP	Troy, NY; Cleveland, TN; South Bend, IN	Drum, disc	Block			✓	✓	Brakes - machine tools, off-highway equipment	94.5
Abex Corporation[13] Friction Products Group	Cleveland, OH; Troy, MI; Winchester, VA	Drum, disc	Block	✓					66.6
General Motors[14] Delco-Moraine Div., Inland Div.	Dayton, OH	Drum, disc							16.2
H. K. Porter Company[15] Thermoid Div.	Huntington, IN	Drum, disc			✓				26.5
Chrysler Corporation[12] Cycleweld Div.	Tenton, MI	Drum, disc							-
Borg-Warner Corporation[16]	Bellwood, IL	Drum, disc				✓			-
Nuturn Company[17] (formerly World Bestos Co.) Maremont Corp., Grizzly Products, Div.	Nashville, TN; Paulding, OH		Block						21.5
National Friction Products Corporation[18]	Logansport, IN				✓	✓	✓	Off-road vehicles, cranes, shovels, travel trailers, mobile homes, plant machinery, appliances.	12.0
Auto Specialties Manufacturing Company[19]	St. Joseph, MI	Drum, disc			✓		✓	Off-road vehicles, agricultural equipment.	0.66
Standco Industries[20]	Houston, TX				✓		✓	Off-road equipment, winches, cranes, drilling rigs.	8.7
Friction Products Company[21]	Medina, OH		Block		✓	✓	✓		4.0
Royal Industrial Brake Products Inc.[22]	Danville, KY	Drum, disc						Assembly of parts from Canadian manufacturers.	16.0
Reddaway Manufacturing Company[23]	Newark, NJ				✓	✓	✓		3.0
Molded Industrial Friction Corporation[24]	Prattville, AL		Block					Tractors and trailers.	3.6
Wheeling Brake Block Manufacturing Co.[25]	Wheeling, WV; Bridgeport, OH		Block						4.0
Force Control Industries[26]	Fairfield, OH			✓	✓			Disc and plate brakes, railcar and diesel engine brakes, tramways, off-road vehicles.	-

(continued)

TABLE 15 (continued)

Company	Plant location(s)	Products: Brakes: Automobile and light truck	Brakes: Heavy duty truck	Brakes: Rail-car	Brakes: In-dus-trial	Clutches: Ve-hi-cle	Clutches: In-dus-trial	Comments	Estimated 1976 sales ($ millions)
Brassbestos Manufacturing Corporation[27]	Patterson, NJ	Drum, disc						Rebuilt	5.3
Auto Friction Corporation[28,a]	Lawrence, MA	Drum	Drum						26.5
Gatke Corporation[29]	Warsaw, IN							Custom manufacturing	12.0
Lasco Brake Products Company[30]	Oakland, CA	Drum, disc	Block						3.8
MGM Brakes, Incorporated[31]	Cloverdale, CA		Block					Off-road vehicles, buses, rail-cars, mining equipment, towing vehicles.	<1
Carlisle Corporation[32]	Ridgeway, PA		Block					Buses, off-road vehicles.	28.2
Thiokol Chemical Corporation[33]	Trenton, NJ	Drum, disc						Rebuilt for replacement, as well as original equipment	9.7
Eaton Corporation[34]	Kenosha, WI		Block, disc						-
Scan-Pac Manufacturing Company[35]	Menomonee Falls, WI							Off-road nonautomotive brake linings	2.8
Guardian Corporation, Inc.[36]	Brighton, MA	Disc						Also, brake noise inhibitors	Unknown
H. Krasne Mfg. Co.[36]	Los Angeles, CA	Disc							Unknown
U.S. Automotive Manufacturing[36]	Tappahannock, VA	Disc							Unknown
Virginia Friction Products[36]	Tappahannock, VA	Disc							Unknown

[a]This is also called P. T. Brake Lining Company, Inc.

TABLE 16. ASBESTOS CONSUMPTION BY THE FRICTION MATERIALS INDUSTRY[37] (THOUSAND METRIC TONS)

1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
64	60	62	66	72	73	60	58	83	82	61	43.7

TABLE 17. VALUE OF ASBESTOS FRICTION MATERIAL SHIPMENTS (IN MILLIONS OF 1981 DOLLARS)[a]

Final product	Total product shipments, including interplant transfers 1981	Total product shipments, including interplant transfers 1972	Percentage of total
Brake linings			
Woven, containing asbestos yarn, tape or cloth	27.8	10.2	4.9
Molded, including all nonwoven types	308.4	113.1	54.0
Disc brake pads	38.8	14.2	6.8
Clutch facings			
Woven, containing asbestos yarn, tape or cloth	54.2	19.9	9.5
Molded, including all nonwoven types	132.2	48.5	23.1
Other	9.8	3.6	1.7
Total asbestos friction material	571.2	209.5	100.0

[a]Projected by Meylan et al. 1972 data adjusted to 1981,[10] p. 61, using September 1981 Engineering and Mining Journal cost index factors. The 1972 breakdown was the best available data, but it should be noted that corresponding percentages of total, for example with disc brakes, may have changed more than this table shows.

SUBSTITUTE PRODUCTS

Methodology

Search Strategy--

Twenty of the largest United States asbestos product manufacturers, as listed in Meylan,[10] were investigated to determine which friction materials are being produced. These manufacturers were questioned regarding both asbestos and substitute materials. Relevant trade associations were also contacted. Several sources in the literature were recommended by the above contacts. The section in the Encyclopedia of Chemical Technology entitled Brake Linings and Clutch Facings[7] was very useful in the writing of this section.

Summary of Contacts--

The following individuals and companies provided useful information concerning friction materials.

Robert A. Clifton
U.S. Bureau of Mines
2401 E St., NW
Washington, DC 20241

Robert Curran, Chief Engineer
Spring Division
Borg-Warner Corporation
700 South 25th Ave.
Bellwood, IL 60104

George Bason
Director of Advertising and
Public Relations
Abex Corporation
530 Fifth Avenue
New York, NH 10036

Jack Reynolds
Johns-Manville Corp.
Ken-Caryl Ranch
Denver, CO 80217

Leon Kopyt
Mass Transit Systems Corp.
Suite 1428
Suburban Station Building
Philadelphia, PA 19103

Walter Nichols
Sales Representative
Midland-Ross Corporation
55 Public Square
Cleveland, OH 44113

Eugene Connor, National Sales Manager
Johns-Manville Corp.
Ken-Caryl Ranch
Denver, CO 80217

Joe Minsky
P.T. Brake Lining Co., Inc.
18 Shepard St.
Lawrence, MA 01842

Mr. Baltz, President
Baltz Co., Inc.
28 Robinson Rd.
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Raybestos-Manhattan, Inc.
100 Oakview Drive
Trumbull, CN 06611

Kevin Peppard
Asst. Dir. of Business Planning
Automotive Group
Bendix Corporation
40 North Bendix Dr.
P.O. Box 4001
South Bend, IN 46634

Mr. Anderson, Sales Mgr.
Royal Industries, Inc.
Brake Products Division
Stewarts Lane
Danville, KY 40422

Edward W. Drislane
Executive Director
Friction Materials
Standard Institute
East 210, Route 4
Paramus, NH 07652

Michael Jacko
Bendix Materials Center
Bendix Center
Southfield, MI 48037

Mr. Gorney, Mr. Alek
Griffin Wheel Co. (Division
of Amsted Industries, Inc.)
200 W. Monroe St.
Chicago, IL 60606

Terry Blaine
Spring Division
Borg-Warner Corporation
700 South 25th Ave.
Bellwood, IL 60104

Paul Biondo
Auto Friction Corp.
652 Andover St.
Lawrence, MA 01842

Robert Randolf
Gatke Corp.
E. Winona Ave.
Warwaw, IN 46580

Lasco Brake Products Corp., LTD
26th & Magnolia Sts.
Oakland, CA 94607

Mr. Apollogene, Sales Representative
MGM Brakes
21800 Greenfield St.
Detroit, MI 48236

Carlisle Corporation
511 Watnut St.
Cincinnati, OH 45202

Thiokal Corporation/Chemical Div.
P.O. Box 1296
Trenton, NJ 08607

Jack Payton, Shop Superintendent
Friction Products Co.
922 Lake Rd.
Medina, OH 44256

Standco Industries, Inc.
P.O. Box 87
Houston, TX 77001

Bill Shine, Sales Administrator
Auto Specialties Mfg. Co.
P.O. Box 8
St. Joseph, MI 49085

Donna Craven, Customer Service
Scandura, Inc.
P.O. Box 949
1801 N. Tryon St.
Charlotte, NC 28231

Brassbestos Mfg. Corp.
45 E. 5th St.
Paterson, NJ 07524

Earl Fygert
Sales Manager
National Friction Products Corp.
1441 Holland St.
Logansport, IN 46947

Mr. Sleeth
H.K. Porter Co., Inc.
Thermold Division
315 Porter Bldg.
Pittsburgh, PA 15219

Mr. Montgomery, General Manager
Stanley Belting Co. (Distributors
for Reddaway Mfg. Co.)
28 Euclid Ave.
Neward, NJ 07105

Wheeling Brake Block Mfg. Co.
3602 Jacob St.
Wheeling, WV 26003

Reginald Kelley, General Sales Manager
Force Control Industries, Inc.
3656 Dixie Highway
Hamilton, OH 45014

Roy Huckabee, Sales Representative
Nuturn Co. (formerly World
Bestos Co.)
1112 S. 25th St.
New Castle, IN 47362

Fiber Substitutes

Most companies have pursued the development of both fiber and product substitutes to ensure asbestos-free products at the earliest possible date. Both naturally occurring and synthetic materials have been evaluated as substitutes to asbestos in friction products. Evaluations are made on the basis of friction stability, wear, effect on opposing surfaces and noise. In addition, some manufacturers are currently placing equal emphasis on the evaluation of safe materials to eliminate potential health hazards. In many cases, direct substitution of the alternatives mentioned here has resulted in poor friction levels, friction instability, roughness, structural failure, increased noise, mating surface deterioration and/or front to rear brake imbalance, such that complete reformulation is necessary as a further course of action.[38] Processing nonasbestos fibers is difficult as most fibers are very brittle, have little or no surface adsorptivity, and are difficult to handle. Often the nonasbestos product is noisy in use. Whereas asbestos fiber bundles open during mixing to entrap the friction modifiers and resin, giving a consistent mix, nonasbestos fibers often spring back and their low tack leads to weak structures. Asbestos has a high, stable friction level, good adsorptivity for strength and wear resistance and does not contribute significantly to noise; substitute fibers generally show greater frictional instability, little or no surface adsorptivity, and/or a significant contribution both to the noise factor and to mating-surface degradation.[38]

Substituting a class A organic disc pad for a semimetallic, for example, results in greater wear (especially in compact cars with solid rotors). Many factors such as these influence the special quality attributes of asbestos versus substitute materials in this area.

Special Qualities and Product Composition--
These are given for the following materials, which have been proposed as substitutes for asbestos in various friction materials. Some have been successful in replacing organic friction materials for some applications. Table 18 summarizes the advantages and potential problems with these materials as compared to asbestos.

Glass fiber--The overall strength of glass fiber is lower than that of asbestos but strong enough for friction material applications. Although currently produced, problems with glass fiber use include melting at the temperatures reached at braking interfaces even in depths below the operating surface, causing fade. Glass also looses its fibrous form in high shear mixing, has low wear resistance, and wears aggressively.

Steel wool[10]--Compared to asbestos, the overall strength of steel is lower and its cost is higher. The material hardness of steel wool can result in damage to the brake rotors, and special formulating techniques are required to control the friction and adhesive wear properties. Class B organic disc pads usually are more aggressive to the rotor and noisier than semimetallic disc pads.[9]

TABLE 18. REINFORCING FIBERS AND OTHER MATERIALS FOR FRICTION MATERIALS[a]

Fiber	Advantages	Potential problems
Asbestos	High strength and modulus Thermal stability Infusible Good wear Also acts as filler	Linked to health problems due to effects of some fiber sizes
Aramid (Kevlar®)	High strength and modulus Thermal stability Nonaggressive wear characteristics	Needs special attention in mixing
Steel Fiber	Adequate strength and modulus Thermal stability	Noisy Corrosion Low cold friction Costly High density
Glass	Adequate strength and modulus Controllable fiber dimensions	Melts at very high temperatures causing fade Loses fiber form in high shear mixing Molding spring back Low wear resistance Aggressive wear characteristics
Cermets-Sintered Materials	High thermal stability	High cost, insufficient wear resistance, high thermal conductivity
Silicon Nitride	Long service life, high thermal conductivity	Expensive, heavy
Noroloid Fibers	Highly insulating, flame-retardant, nonmelting	
Carbon Fibers	High strength, very high modulus Infusible High thermal stability Low density	Loses fiber form in mixing Costly Low temperature and impact strengths
Mineral Wool	Inexpensive	Low strength, brittle
Semimetallic Materials	Thermal stability Excellent wear resistance	Expensive
Vermiculite	High temperature strength	

[a]Halvar Y. Loken, Industrial Fibers Div., E.I. duPont de Nemours & Co., Inc., Wilmington, DE,[39] in combination with GCA literature reviews.

Mineral wool--The overall strength of mineral wool is very low and brittle to the extent of limiting mixing processes.

Potassium titanate fibers--The National Aeronautical and Space Administration (NASA) has investigated new friction materials and their applications outside the space program. As part of this effort an improved friction material was developed that utilized potassium titanate fibers with the DuPont tradename FYBEX for lightweight cars and trucks. However, unfavorable toxicological effects and other market considerations caused DuPont to withdraw FYBEX from the market.

Silicon nitride[40]--This material was used for the brake pads in prototypes of the Concorde. It has a longer service life than asbestos and higher thermal conductivity (desirable in this application) but is more expensive and heavier than the carbon composites eventually adopted.

Noroloid fibers[41]--Noroloid fibers were invented by the Carborundum Company in the late 1960s. Made from novolak (phenol-formaldehyde) resin, the fibers are compatible with many resin and rubber matrices. The manufacturer claims the highly insulating, flame-retardant and nonmelting fibers are finding increased acceptance as a replacement for asbestos in, among other applications, friction materials.

Carbon fiber[7]--The main properties of carbon fibers are good, especially for carbon-composite friction materials and rotors ("carbon brakes"); in other applications, however, they remain somewhat inferior to asbestos.[9] A major consideration is cost, which is a great deal higher than for asbestos. It is more efficient than asbestos under high service temperature conditions, but heat flow is uneven and the tensile and impact strengths are relatively low. It has high thermal stability and low density, making it especially attractive for aircraft brakes. Abex Corporation of New York, NY took out a patent for a nearly pure carbon article for replacement of brakes or clutch discs in 1971. Abex makes tiger composition brake shoes containing fiber, rubber, resinous material and fillers.

Vermiculite--A British patent was recently issued for a vermiculite-based brake lining. The composition of this product is given in Table 19. Vermiculite is ground and sieved to a grade of fineness, or aspired to a higher grade of fineness, and then cold treated with the ingredients found in this table. Although not produced in volume, it serves as an example of continuing research and development activity aimed at replacing asbestos in brake linings.

TABLE 19. BRAKE LINING TREATMENT FORMULATION FOR VERMICULITE-BASED BRAKES[42]

Material	% Composition
4% solution of rubber	40
Calcium carbonate	15
Barium sulphate	15
Synthetic rubbers	20
Iron oxide, zinc oxide, chromium oxide	10

Delaminated vermiculite is used in friction materials commercially available throughout Europe. They maintain strength at high temperatures, are compatible with phenolic resins, require little attention in manufacturing methods, and may be used with asbestos to help reduce asbestos content.[40]

Aramid fibers--Kevlar® aramid fiber is made of an infusible aromatic polyamide polymer. Inert fillers are then selected on the basis of thermal and wear characteristics, with less concern about other properties due to Kevlar's efficient strengthening. One brake mix tested consisted of: 50 percent wollastonite, 20 percent barium sulfate, 15 percent dry phenolic resin, 15 percent cashew friction particles, strengthened with different forms of Kevlar at the 5 percent level. Kevlar can be bought as cut fiber, which can be processed in a mixer to any length. Kevlar can also come as a continuous filament whch gives the highest strength conversion, or as a pulp which is more fibrillated and shorter than cut fiber and can be readily processed into friction paper.[39]

Aramid fibers are being researched for use in high performance dry clutch facings, automatic transmissions and asbestos-free brakes. Kevlar, for example, has high tensile strength and is reported to be five times stronger than steel on a weight basis.[39] Composites have good resistance to external abrasion, high frictional stability, excellent durability and much better high temperature properties than common organic fibers. They are used in disc brake pads with wear levels between asbestos and semimetallics, and are now in experimental use in drum brake linings and wet friction papers. They do not score mating surfaces and can presently be found in manual transmissions for Mercedes, Audi and Porsche.[43] However, the fibers are not easily dispersed in mixing as they tend to clump together. E.I. duPont de Nemours & Co., Inc. of Wilmington, DE produces Kevlar aramid fiber; however, to date this has not been used in commercial brake pads or linings. In the future, it might be a potential candidate for reinforcement of friction materials, if present experimental tests prove successful.

Other[40]--Various other fibers have been used in phenolic binders, such as aluminosilicates (wollastonite). However, all have drawbacks and not one of them is yet as good as asbestos, especially for higher-temperature applications such as disc brake pads.

Product Substitutes

Special Qualities and Product Composition--

The following materials are currently under development and/or production as direct substitutes for asbestos friction products. Some of these presently occupy a significant share of the friction materials market for some applications.

Carbon composites[7]--These materials are made of carbon fiber - reinforced carbon matrix composites. The fibers are produced by graphitization of organic or pitch fibers by techniques resulting in parallel alignment of carbon chains with fiber length providing maximum tensile strength. In one description, the article is wound up from one or more filaments, resin soaked, and then the whole part is ultimately carbonized by sintering. The carbonized reinforcing filaments used here are described as having a greater strength than the carbonized resin binder. These filaments can be used for strength alone and to back an all-carbon friction facing which has no filaments.[44]

Semimetallics--The major constituent of nearly all semimetallics is iron which may be in the form of iron particles, steel fiber, or a mixture of both. For some semimetallics, iron powder is used in conjunction with a small amount of steel fiber. Property modifiers are added to provide desired performance characteristics and a resin binder is added to hold the materials together. Nonabrasive modifiers including cardolite, ground rubber, carbon black, petroleum coke flour, and natural and synthetic graphite are added to control friction, improve wear, and reduce noise. Abrasive modifiers such as alumina, silicon carbide, and kyanite are also used to control friction. A typical semimetallic friction formula may include metallic powder, sponge iron particles, ceramic powder, steel fiber, rubber particles, graphite powder, and phenolic resin. Because of the ferrous nature of the product, rust inhibitors may be added.

Semimetallics were first introduced in the 1960s, primarily to meet heavy-duty disc brake and extreme duty truck block applications, although they operate satisfactorily against the ventilated cast-iron rotors in the smaller brakes of downsized cars and against the solid rotors found in the lighter brakes of new front wheel drive vehicles. They rely on steel fiber and powder metallurgy techniques for reinforcement without asbestos. Semimetallics are stable to temperatures of 400°C (750°F) and exhibit excellent wear resistance.[7]

Cermets[7]--Cermet friction materials are composed of metal bonded ceramic particles. The metal matrix may be copper or iron. Typical formulae are presented in Table 20.

Cermets have extremely high thermal stability. Friction is not sufficient for automobile use and cost is high. They are used extensively in aircraft and high-speed train brakes. Both carbon fiber and cermet materials are stable to 700°C (1290°F). One problem is high thermal conductivity, which can excessively heat hydraulic brake fluid causing erratic performance.[46] This problem may be avoided by proper design.[47] The major problem is low friction.[9]

Other--Raybestos-Manhattan Inc. manufactures RAYFLEX, a nonasbestos friction material for use in oil-cooled transmissions and brake applications in large, off-the-road vehicles.[48]

Uses and Applications--

Semimetallic, ceremetalics, and carbon composite materials are used in the friction materials industry as substitutes for asbestos-based friction materials for heavy-duty applications.[9]

The Friction Materials Standards Institute polled its membership early in 1980 to obtain information on the use of nonasbestos disc brakes.[49] Results of this survey are presented in Tables 21 and 22. However, the data does not specify the exact type of nonasbestos lining used nor the actual prevalence of

TABLE 20. CERMET FRICTION MATERIALS, WT %[45]

Material	1	2	3	4	5	6	7	8	9	10
Matrix										
copper	47.1	49.6	44.6	44.7	44.9	46.2	52.4	43.6	18.6	46.2
zinc										5.5
tin								7.4		3.3
nickel	7.1	7.1	7.1			7.0	6.6	6.6	7.1	
titanium	3.6	3.6	3.6			3.5	3.3	3.3	3.6	
brass chips									28.6	
iron				15.0	15.0					8.8
Total	57.8	60.3	55.3	59.7	59.9	56.7	62.3	60.9	57.9	63.8
Friction Material										
calcined kyanite	26.1	26.1	26.1	24.9	19.9	25.6	24.0	24.2	26.1	22.0
silica	4.8	4.8	4.8	4.6	4.6	4.8	4.4	4.5	4.8	4.4
Total	30.9	30.9	30.9	29.5	24.5	30.4	28.4	28.7	30.9	26.4
Lubricant										
graphite	1.2	1.2	1.2	1.1	6.1	1.1	1.1	1.1	1.2	8.8
lead						2.0	3.7			
Total	1.2	1.2	1.2	1.1	6.1	3.1	4.8	1.1	1.2	8.8
Antioxidant										
molybdenum	10.0	7.5	12.5	9.5	9.5	9.8	4.6	9.3	10.0	1.0
Total	10.0	7.5	12.5	9.5	9.5	9.8	4.6	9.3	10.0	1.0

TABLE 21. PASSENGER CAR AND LIGHT TRUCK USAGE OF NONASBESTOS DISC BRAKE PADS[49] (See Table 22 for Police/Taxi option usage)

Vehicle type	Nonasbestos lining (with asbestos back)		Nonasbestos lining only
American Motors			
1980, Spirit, Concord 4's	Outer only		
1980, Spirit, Concord, Eagle 6's	Outer only		
1979, AMX	Outer only		
Buick			
1980, Buick Electra			I & O
1979-80, Riviera	I & O		
1980, Regal, Century	I & O	or	I & O
1980, Skylark (Power brakes)			I & O
1980, Skylark (Manual brakes)			Inner only
1976-80, Skyhawk	I & O		
1978-79, Regal, Century (Power brakes)			I & O
1978-79, Regal, Century (Manual brakes)			Outer only
1976-79, Skylark			Outer only
1976-77, Century (Manual brakes)	Outer only		
1973-75, Apollo (Manual brakes)			Outer only
Cadillac			
1979-80, Eldorado (Diesel)	I & O		
1979-80, Seville (Diesel)	I & O		
1968-80, Commercial	I & O		
Chevrolet			
1980, Monte Carlo, Malibu	I & O	or	I & O
1980, Citation (Power brakes)			I & O
1980, Citation (Manual brakes)			Inner only
1976-80, Monza	I & O		
1980, Chevette			Outer only
1976-80, Camaro			Outer only
1978-79, Monte Carlo, Malibu (Power brakes)			I & O
1978-79, Monte Carlo, Malibu (Manual brakes)			Outer only
1976-79, Nova			Outer only
1976-77, Malibu (Manual brakes)	Outer only		
1976-77, Vega	I & O		
1973-75, Nova (Manual brakes)			Outer only

(continued)

TABLE 21 (continued).

Vehicle type	Nonasbestos lining (with asbestos back)		Nonasbestos lining only
Chevrolet Truck			
1978-80, El Camino			I & O
1979-80, C-, K-, P-20	I & O	or	I & O
1979-80, C-, P-30	I & O	or	I & O
1979-80, K-30	I & O		
1979-80, P-30 (JF-9) (Front & Rear)	I & O		
1979-80, G-30			I & O
1976-78, C-, K-, P-20	I & O	or	I & O
1976-78, C-, G-, P-30	I & O	or	I & O
Dodge			
1978-80, Omni	I & O		
Dodge Truck			
1976-78, Mini Bus	I & O		
1976, W-300	I & O		
Ford			
1979-80, Fairmont V8	I & O		
1980, Thunderbird	I & O		
1979-80, Mustang V8, Turbo 4	I & O		
1979-80, Fiesta	Outer only		
1980, Mustang V6	I & O		
Ford Truck			
1976-80, F-100 (4 × 4)	I & O		
1977-80, F-150 (4 × 4)			
1976-80, Bronco	I & O		
1976-78, F-250 (Lt)	I & O		
1976-80, E-250, F-250 (HD), E-350, F-350	Inner only		
1980, E-350 School Bus	I & O		
GMC Truck			
1978-80, Caballero			I & O
1979-80, C-, K-, P-2500	I & O	or	I & O
1979-80, C-, P-3500	I & O	or	I & O
1979-80, K-3500	I & O		
1979-80, P-3500 (JF-9) (Front & Rear)	I & O		

(continued)

TABLE 21 (continued).

Vehicle type		Nonasbestos lining (with asbestos back)		Nonasbestos lining only
1979-80,	G-3500			I & O
1976-78,	C-,K-,P-2500	I & O	or	I & O
1976-78,	C-,G-,P-3500	I & O	or	I & O
Mercury				
1979-80,	Zephyr V8	I & O		
1980,	Cougar	I & O		
1979-80,	Capri V8, Turbo 4	I & O		
1980,	Capri V6	I & O		
Oldsmobile				
1980,	Oldsmobile 98			I & O
1979-80,	Toronado	I & O		
1980,	Cutlass	I & O	or	I & O
1980,	Omega (Power brakes)			I & O
1980,	Omega (Manual brakes)			Inner only
1976-80,	Starfire	I & O		
1978-79,	Cutlass (Power brakes)			I & O
1978-79,	Cutlass (Manual brakes)			Outer only
1976-79,	Omega			Outer only
1976-78,	Toronado	Outer only		
1976-77,	Cutlass (Manual brakes)	Outer only		
1969-75,	Oldsmobile Commercial	I & O		
1974-75,	Toronado	I & O		
1973-75,	Omega (Manual brakes)			Outer only
Plymouth				
1978-80,	Horizon	I & O		
Pontiac				
1980,	LeMans, Grand Prix	I & O	or	I & O
1980,	Phoenix (Power brakes)			I & O
1980,	Phoenix (Manual brakes)			Inner only
1976-80,	Sunbird	I & O		
1976-80,	Firebird (drum rears)			Outer only
1979-80,	Firebird (organic disc rears)	I & O		
1978-79,	LeMans, Grand Prix (Power brakes)			I & O
1978-79,	LeMans, Grand Prix (Manual brakes)			Outer only

(continued)

TABLE 21 (continued).

Vehicle type	Nonasbestos lining (with asbestos back)	Nonasbestos lining only
1978-79, Phoenix		Outer only
1976-77, Ventura		Outer only
1976-77, LeMans (Manual brakes)	Outer only	
1976-77, Astre	I & O	
1973-75, Ventura (Manual brakes)		Outer only
<u>Toyota</u>		
1980, Corolla Coupe	I & O	

Key: I = Inner Lining
O = Outer Lining

TABLE 22. POLICE AND TAXI USAGE OF NONASBESTOS DISC BRAKE PADS ON FRONTS[a,49]

Vehicle type		Nonasbestos lining (with asbestos backing)
American Motors		
1978,	Concord Police, Taxi	Outer only
1975-78,	Matador Police	Both I & O
Buick		
1971-80	Buick Police, Taxi	Both I & O
1979-80	Century Police	Both I & O
Chevrolet		
1971-80,	Chevrolet Police, Taxi	Both I & O
1977-79,	Nova Police	Both I & O
1979-80,	Malibu Police	Both I & O
Chrysler		
1976-80,	Chrysler Police, Taxi	Both I & O
1978-80,	Cordoba Police	Both I & O
1977-80,	LeBaron Police, Taxi	Both I & O
Dodge		
1977-80,	Aspen Police, Taxi	Both I & O
1979-80,	St. Regis Police, Taxi	Both I & O
1977-80	Diplomat Police, Taxi	Both I & O
1977-78,	Monaco Police, Taxi	Both I & O
1977,	Royal Monaco Police, Taxi	Both I & O
Ford		
1978-80,	Fairmont Police, Taxi	Both I & O
1976-80	Ford Police, Taxi	Both I & O
1976-80,	Granada Police, Taxi	Both I & O
1978-79,	LTD II Police, Taxi	Both I & O
Mercury		
1978-80,	Zephyr Police, Taxi	Both I & O
1976-80,	Mercury Police, Taxi	Both I & O
1976-80,	Monarch Police, Taxi	Both I & O

(continued)

TABLE 22 (continued).

	Vehicle type	Nonasbestos lining (with asbestos backing)
Oldsmobile		
1971-80,	Oldsmobile Police	Both I & O
1979-80,	Cutlass Police	Both I & O
Plymouth		
1977-80,	Volare Police, Taxi	Both I & O
1977-80,	Gran Fury Police, Taxi	Both I & O
1978,	Fury Police, Taxi	Both I & O
Pontiac		
1971-80,	Pontiac Police, Taxi	Both I & O
1979-80,	Phoenix Police	Both I & O

[a]Police and Taxi usage of nonasbestos disk brake linings was as a Police/Taxi option — actual usage depended on customers ordering that option. Ford-Mercury in 1976-78 also had nonasbestos disk rears for the Police/Taxi option.

Key: I = Inner Lining
O = Outer Lining

the asbestos substitute.* In other cases, such as for police cars and taxis, nonasbestos brake linings were a buyer option, with actual usage depending on the number of orders placed.

Semimetallic or resin bonded metallic friction materials are presently used in heavy-duty automotive applications such as police cars and taxis. Semimetallic disc pads were able to attain overall excellent properties at both low and high temperatures which ordinary Class A or Class B organics could not accomplish. Downsizing of vehicles, resulting in smaller front brakes and higher operating temperatures, mandated the use of semimetallics; Class A organics gave poor performance and Class B organics made with asbestos were noisy and scored the rotors. Semimetallics gained acceptance initially because of their improved performance in spite of a premium price. Further acceptance came about more recently due to performance combined with their asbestos-free nature.

Semimetallic drum blocks, first used in air brakes in heavy-duty trucks used in the logging industry (an extremely severe application), have been attempted to be scaled down to small drum brakes, but the basic nature of semimetallics has not lent itself to the accurate segment configuration required in this application. Here, semimetallics do not possess the necessary green strength, are difficult to bend into the proper shape, and are more brittle in cured form and therefore subject to cracking. Modifications to date have generally resulted in a product that cannot achieve commercially-acceptable performance characteristics. Work in this area therefore continues. The first generation of asbestos-free drum linings is currently under evaluation by vehicle manufacturers.[38] While their performance may be superior to asbestos drum brake linings, semimetallic drum brake linings tend to perform erratically in different temperatures, fade, and produce more noise than asbestos-based linings. They are more aggressive than asbestos-based linings, that is, they have higher friction levels and cause more wear. Currently, semimetallics are 50 to 60 percent more expensive than asbestos linings but with increased production it is estimated that costs would drop to within 25 percent of asbestos brake linings. Approximately 20 percent of passenger cars using disc brakes in 1977 were equipped with semimetallic disc brakes as original equipment,[50] and it is estimated that in 1985 most original equipment disc brakes in passenger cars and light trucks will be equipped with semimetallics.[38]

As Table 21 shows, General Motors, in the past, has used a hybrid brake consisting of one semimetallic and one organic asbestos lining in some mass-produced passenger cars and light trucks.† There are actually several ways in which (asbestos) organic backing materials may be combined with semimetallic friction materials. One combination is the GM hybrid brake discussed, where there is solid semimetallic friction material on one side of the rotor and solid organic friction material on the other side. This combination has

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*In some years, semimetallics were being phased in and were not included on all models.

†This should not be confused with the use of semimetallic friction materials/organic backing layers on both the inner and outer pads of some disc brakes.

provided good performance. GM also uses friction materials with no organic backing layers; instead they are 100 percent semimetallic materials on both sides of the rotor and strength is provided by the addition of more fiber, which allows them to simplify the tooling process. Beyond this, Bendix makes several types of combinations of friction materials. One is the use of a semimetallic friction material with an organic backing layer, both of which are placed on both sides of the rotor. The organic layer helps: (1) insulate, (2) provide strength to this layer for riveting, and (3) slightly reduces cost. Bendix also produces a combination featuring 100 percent organic friction material on one side of the rotor and the semimetallic friction layer with the organic backing layer on the other.[2] Compared to disc brakes with asbestos-based friction materials, the hybrid brakes have a higher coefficient of friction, higher heat resistance, and longer life. This combination is a compromise in cost and performance compared to a full semimetallic or full Class B. While some industry sources feel that hybrid brakes will capture the market because of superior performance, others believe that trends to lower speed limits and lighter weight cars will reduce the need for high performance brakes. Still others state that fuel-efficient vehicles and front-wheel drive have increased the need for heavier-duty and smaller brakes that need the improved performance that only semimetallics have been able to offer.[9] This trend is reflected in Table 21 where, for example, American Motors reports using a nonasbestos brake lining with an asbestos back on outer brake positions only on their 1980 Spirits (rear wheel drive) while Chrysler uses nanasbestos linings with an asbestos back on both inner and outer brake positions on their 1980 Dodge Omnis (front wheet drive).

The high landing speeds and heavy weights of modern aircraft and high-speed trains require friction materials with high thermal stability. Cermet materials possess this property and, for this reason, their share of the aircraft brake market continues to grow. Currently, nearly 100 percent of all new commercial aircraft use cermet brake linings.* At the other end of the spectrum, nearly all new military aircraft use carbon composites, due to the weight they save and high pressure for performance in these uses.[51] As the use of cermets and full sintered metallics in aircraft brakes began in the 1940s, they are not new replacements for asbestos; in addition, cermets are not likely candidates for highway brakes or small clutch facings.[1]

Cermet materials have also been used for railcar brakes, but, in the last several years, nearly all railcar brakes have been made of rubber polymeric binders with various friction modifiers.[52] In general, asbestos and lead are not present in these brakes.[53]

Substitute Product Manufacturing Summary--

Manufacturing process--Semimetallic disc pads are made using a dry-mix process. Ingredients are blended, then formed into briquets at room temperature and 27.6 to 41.4 MPa (4000 to 6000 psi). The briquets are then hot-pressed at 160° to 180°C (320° to 360°F) for 5 to 15 minutes at 27.6 to 55.2 MPa (4000 to

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*Only the Concorde and possibly one Soviet model use carbon composite.[51]

8000 psi). The pads are then cured at 220° to 300°C (430° to 570°F) for 4 to 8 hours. Final grinding produces the finished disc pads. Briquets are formed at 10.3 to 17.2 MPa (1500 to 2500 psi). Briquets may be heated to 90°C (195°F) for 15 to 30 minutes to reduce blistering during hot pressing. Blocks are formed by heating at 130°C to 150°C (265° to 300°F) at 13.8 to 20.7 MPa (2000 to 3000 psi) for 10 to 30 minutes. After cutting to size, blocks are ground to the appropriate size, followed by curing [unconfined for 15 hours at 180°C (355°F) or confined for 6 hours at 280°C (535°F)]. The final block requires grinding, drilling and chamferring.

Cermet materials are manufactured using the powder metallurgy technique. Desired amounts of individual ingredients are weighed, mixed, compacted, sintered, and coined (or recompacted). The sintering is performed in a reducing or neutral atmosphere, and the sintering temperature has to be high enough so that the metal ingredients will adhere to each other.

In carbon composites, carbon or graphite fibers are embedded in a carbon or graphite matrix. The matrix can be formed by two methods: chemical vapor deposition and coking. In the case of chemical vapor deposition, a hydrocarbon gas is introduced into a reaction chamber in which carbon formed from the decomposition of the gas condenses on the surface of carbon fibers. An alternative method is to mold a carbon fiber-resin mixture into shape and coke the resin precursor at high temperatures. In both of the methods the process has to be repeated until a desired density is obtained.

Name and number of manufacturers--Table 23 lists nonasbestos brake manufacturers, their locations, and the substitute materials they use. Semimetallic disc brake pads and blocks were originally designed and produced by Bendix Corporation. Bendix has reported that some new equipment was required for their manufacture.[54] Abex Corporation and Raybestos-Manhattan, Inc. also make semimetallic disc brake pads.

Cermet materials are manufactured by Bendix Corporation and Abex Corporation. Abex also makes fiberglass disc brake materials. Carbon composite brakes are manufactured by Dunlop, Bendix, Goodrich, and Goodyear.[9] American Filler and Abrasives has been marketing an asbestos substitute called Kay-O-Cel, made primarily of cellulose and clay wastes, which is being tested in brake linings.[45] Kevlar® aramid fiber products are made by E.I. DuPont de Nemours and Co., Inc., Wilmington, DE. Raybestos-Manhattan makes Rayflex for brakes in off-the-road vehicles.

Production volumes--Although production figures for individual firms are not available, it is known that in 1980 semimetallic materials were used in 40 percent of all front disc brakes.[55] Cermet materials are used almost exclusively for commercial aircraft brakes and control almost 100 percent of the current market.[51] Kevlar® products are available from a commercial production facility which is being expanded to 20 million kg/yr capacity.[39,*]

*This expansion is for production of aramid fiber products which are not necessarily friction materials. At present, no company uses Kevlar® in pads or linings for brake products.[9]

TABLE 23. NONASBESTOS BRAKE MANUFACTURERS

Manufacturer	Location	Substitute material
Bendix Corp.	Southfield, MI[a]	
	Troy, NY[a]	Semimetallics
	Cleveland, TN	Cermets
Abex Corp.	Cleveland, OH	Semimetallics
	Troy, MI	Cermets
	Winchester, VA	Fiberglass
Raybestos-Manhattan, Inc.	Stratford, CT	Semimetallics
	Trumbull, CT	
Dunlop	England	Carbon composite
American Filler & Abrasives[b]	Bangor, MI	Kay-O-Cel (cellulose and clay)
Delco-Moraine Div., General Motors Corporation	Dayton, OH	Semimetallics
E.I. DuPont de Nemours[b] and Company	Wilmington, DE	Kevlar (aramid)

[a]Designed at this location.

[b]This company does not currently manufacture brakes or brake-linings; rather it is a materials manufacturer who is attempting to evaluate a new product for friction applications in the experimental stage.[1]

COST COMPARISON

The basic cost of the substitute friction products involves many complex factors, including the amount and types of materials used and the basic raw materials cost. The fixed and variable costs of manufacturing can differ greatly, based on the type of process and its complexity as well as production volumes, labor costs, energy costs, and process yield. Administrative costs and handling/distribution costs are also significant variables as are implementation costs. Here, it appears that timing of test programs will be important as expenses could be minimized by converting to asbestos-free materials as part of the scheduled new vehicle design programs, where significant brake system testing is already necessary. Life cycle costs are also a necessary consideration; semimetallics have higher life cycle costs than organics, yet they are needed on the smaller and lighter vehicles, and these possess better fuel economy.[56]

Although exact costs for semimetallic friction materials are not available, their improved performance compensates for their higher costs due to more expensive ingredients, higher specific gravity, and more costly processing requirements. Currently, they are good candidates and have replaced organic friction materials in disc brakes. Preliminary cost estimates indicate that asbestos-free brake lining may cost 20 to 25 percent more than current linings with disc brakes at 20 to 100 percent greater cost. These preliminary estimates are highly dependent on the characteristics of semimetallics making them extremely difficult and costly to process as drum lining segments. Consequently, a new class of friction materials is currently under development to suit this application.[38]

Cermets cost three to five times as much as asbestos friction materials. Costs for carbon composites are not available but they are considerably more expensive than cermets. Kevlar® (aramid) fiber is available in a short pulp form at \$3.75/lb (\$8.25/kg). Only small amounts of this fiber are reported to be required with deep filler materials, making the cost between 20 and 40 percent greater than for asbestos, with lifetime costs approaching those of asbestos.[43] Table 24 lists the costs of various fibers proposed as substitutes for asbestos in friction material.

TABLE 24. COSTS OF MATERIALS PROPOSED AS SUBSTITUTES FOR ASBESTOS IN FRICTION MATERIALS[57,a]

Material	Price - \$/lb (\$/kg)
Asbestos	0.05 - 0.15 (0.11 - 0.33)
Fibrous glass	0.50 - 0.75 (0.11 - 1.65)
Mineral wool	0.15 (0.33)
Potassium titanate fibers	1.00 - 1.25 (2.20 - 2.75)
Graphite and carbon fibers	10.00 - 12.00 (22.00 - 26.50)
Wollastonite	0.15 (0.33)
Aramid fibers	3.75 - 8.00 (8.25 - 17.65)

[a]Prices should be used for comparison only. Dollars are 1978 U.S.

CURRENT TRENDS

The need for more energy-efficient automobiles and trucks has put an increased demand on friction materials. Major trends are towards smaller, lighter, more efficient vehicles with manual transmissions and smaller brakes. Although organic friction materials will continue to serve the drum brake industry, more and more vehicles are being equipped with ventilated disc brakes. Ventilated brakes may be replaced by solid rotor disc brakes to save weight. As brakes become smaller, braking temperatures become higher. Class B organic and semimetallic friction materials will replace Class A organics because they have higher thermal stability. Heavy vehicles are using more and more efficient disc brakes. More cermet friction materials will be used in heavy-duty clutches. The trend in aircraft brakes may be toward lighter carbon composite materials.

Because of present and future health standards, some automobile manufacturers are in favor of removal of asbestos and lead from brakes.[58] U.S. automakers have cut the average asbestos content of disc brake linings from 0.45 kg to about 28 grams, with the remaining asbestos present in the backing layer.[9] Both General Motors and Ford have asked their suppliers to seek ways to totally eliminate asbestos from disc brakes. Because of the curved shape required for drum brakes, no suitable substitute for asbestos is readily available. However, Rockwell International Corporation, manufacturer of about 60 percent of the brakes used in heavy trucks, has a major development effort aimed at obtaining asbestos-free friction materials from suppliers.[58]

Borg-Warner Corporation,[59] Bendix,[38] and Abex Corporation[13] (among others) have developed proprietary substitutes for automobile brake friction materials. Some are in the consumer testing stage, but no additional information is available at this time. A company such as Bendix is not aggressively pursuing licensing policies but does have many license agreements for the international market which usually include territorial exclusions. Significant company* funds have been expended to develop this new technology. Borg-Warner has spent several million dollars to develop asbestos-free friction materials for employee safety and may enter license agreements or manufacture in Brazil.[59] Although Raybestos-Manhattan, Inc. stated publicly in May 1979 that the company would "halt" the manufacture of brake linings and other parts that contain asbestos by using a blend of 10 to 15 components (40 percent fiber, 20 percent resin binder, and 40 percent friction modifiers), discussions with company representatives revealed that this was not strictly true.[11] The company has developed some nonasbestos substitute products for certain applications and has committed itself to a search for nonasbestos substitutes, but the complete removal of asbestos from their friction materials is not expected in the foreseeable future. Small brake lining manufacturers have a real problem with capital equipment and financing of nonasbestos friction products.[56]

Part of the problem in designing new brake systems is simply that it takes time. Both the materials used and their properties are a result of optimization procedures, with extensive testing programs both by the material supplier and by the customer to ensure suitability, quality, and regulatory conformance. For evolutionary changes, an example of which would be an improved organic disc pad utilizing the same basic components (asbestos, resin, and modifers) but with better wear, improved fade resistance and the same friction and noise properties, years are required. In this case, asbestos organic linings are essentially the product of 40 years of evolutionary changes. Supplier development and validation testing requires 18 to 24 months, consumer application testing 12 to 18 months, and 6 months manufacturing lead-time, or, a total of 3 to 4 years for one evolutionary change. In addition, there are revolutionary changes, which actually advance the state-of-the-art, that are more difficult to come by, and are even longer in the developmental phases. It is

*Bendix Corporation.[36]

unrealistic to apply a timetable to inventions, but for establishing the feasibility of a new concept, 12 to 18 months is a reasonable time period to be expected. Reducing that concept to a product with some or most of the basic characteristics can take another 12 to 24 months. Formulation development for commercial application and validation of properties adds 24 to 36 months. An additional 12 to 18 months is required for customer application testing plus 6 months manufacturing lead-time, or a total change-over requiring 5½ to 8½ years. Eliminating asbestos from automotive friction materials is considered a revolutionary change. As ideas on substitute products came into being around 1975 and later, the first evolutionary changes are now underway to help develop a second generation of materials which have improved properties and the multiple types and assortment of formulations necessary for different applications.[38]

As indicated, semimetallic disc brake pads without asbestos in either the friction material or the backing layer are currently in use, but cannot be used in all vehicle applications. An orderly transition is expected to occur, approaching 100 percent utilization by 1985. Development of asbestos-free organic disc-brake pads and semimetallic drum brake linings is continuing at Bendix with production implementation not yet able to be predicted. In addition, Bendix and others are in the final development stage of work on first generation asbestos-free organic drum-brake linings and some asbestos-free blocks are available commercially for heavy-duty applications, with the first significant production release expected in 1982. All of these new developments show continued effort from industry to move towards a dominance of asbestos-free products in the friction materials area.

CONCLUSION

Semimetallic disc brake friction materials, originally designed and produced by Bendix Corporation and now also manufactured by Delco-Morraine, Abex, and Raybestos-Manhattan, are expected to increase market share relative to asbestos disc brake materials. In fact, it is projected[50] that in 1985 nearly all original equipment disc brakes made for passenger cars and light trucks will be equipped with semimetallics.

At the present time a nonasbestos product for drum brake linings for passenger cars is not available commercially. However, intense research in this area is underway, with specifics still proprietary at this time. The first commercially-available nonasbestos drum lining may contain some combination of steel fibers, synthetic fibers, cotton, ceramic, carbon, natural materials, glass, and mineral fibers. For this model year 1980, commercial nonasbestos linings were not available[50] for drum brakes; however, Bendix Corporation is apparently very close to marketing this kind of product.

As for cermet brake linings, once the problem of their interaction with hydraulic brake fluid can be solved, their use may grow in the heavy-duty clutch field. Cermets are not likely candidates for replacement of passenger car or light-truck brakes.[1] With all of the current research into brake lining substitutes, a nonasbestos product for more universal use should become available in the future.

Clearly, the design of the entire braking system has a great influence on the types of friction material that can be used. The lack of readily available nonasbestos drum brake linings contrasted with the progress toward totally asbestos-free disc brake pads underscores this point. However, redesign appears to be given less consideration than the search for a material to replace asbestos for the following reasons:

- Brake systems in use have been time tested and proven effective. Changes in the existing systems would require that the system and the asbestos replacement both be tested intensively.* Problems could result if replacements are not made of materials similar to those of the original equipment, as the entire brake system is designed as a unit. Without careful study, substitution may cause safety or wear problems. Time is often needed to heal these faults. Testing requirements are significantly reduced if only the asbestos substitute is to be evaluated.

- Any new brake system must be suitable to be maintained by automobile dealers and service stations. Any complex new system or radical changes in brake system construction that would be difficult to maintain properly would be unacceptable.

- Equipment designed to produce brake systems currently in use would either have to be replaced or modified to produce a new brake system, possibly necessitating large capital expenditures at a time the automotive industry is feeling financial constraints.

- The many manufacturers of brake linings must respond to the needs of their customers. Until the automobile manufacturers supply different product specifications, as for the friction material component of a new braking system, the brake lining manufacturers will continue to supply a traditional product. Brake system changes must be initiated by original equipment manufacturers.†

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*This problem is reported to be even greater for suppliers and users of friction materials in the nonautomotive field. In many instances, these clutches and brakes were manufactured 10 to 40 years ago and the testing facilities of the manufacturer have been dismantled. In other cases the volume of replacement friction materials is so low that the manufacturer of the clutches and brakes cannot afford to set up test programs to evaluate friction materials even if the test facilities were available. This is true for commercially acceptable asbestos-based friction materials and probably even more true for untried nonasbestos friction materials.[1]

†The information presented here is taken in part from Reference 38.

It is much easier, more readily acceptable and much less risky for brake lining manufacturers to attempt to find a substitute for asbestos rather than effect a complete redesign of braking systems. Consequently, most research is focussed on the search for substitutes.

The outlook for the use of asbestos in friction material is, at best, mixed. The majority of the industry's products are used in passenger automobiles and, as such, are influenced by the vagaries of the buying public: if a lot of new cars are being sold, a lot of new brakes will be required. Conversely, if fewer new cars are sold, more used cars in the marketplace will result in more sales of replacement brake friction materials. Further uncertainty is introduced by the American automobile manufacturers' avowed intentions to eliminate asbestos from original equipment brakes by the 1985* model year. If successful substitutes are found, asbestos consumption in friction materials will drop precipitously. The target date set for 1985 represents the culmination of a carefully thought-out phased production process on the part of friction materials producers. The use of asbestos in friction materials is likely to continue in industrial equipment such as brake blocks and clutch facings for lathes, presses, hoists, etc. (more limited demand) while asbestos-free products are developed for the automotive industry.

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*Raybestos-Manhattan plans to eliminate asbestos from its friction material products by 1982.[60]

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SECTION 4

ASBESTOS CEMENT PIPE

ASBESTOS PRODUCT

Special Qualities

Asbestos Cement (A/C) pipe products are strong, resilient, flexible, durable, and corrosion resistant. A/C pipe may also be said to be nearly inert (it is subject to certain corrosive media) and, when used inside buildings for drain, waste and vent applications, it is fire resistant. Asbestos imparts not only important flexural strength in pipe (allowing for a certain amount of deflection without failure) but also gives the pipe structural integrity so that it may withstand crushing loads and constant and transient hydrostatic pressure.[1] The laminar structure of the pipe, which results from the basic method of manufacturing, also contributes to greater strength.* This allows for easy tapping for lateral lines or other connectors without a loss of strength. Because of the nature of the raw materials (Portland cement, ground silica and asbestos fibers) used to manufacture A/C pipe, it resists corrosion and most chemical action and is not subject to electrolysis.

The primary purpose of asbestos fibers in A/C pipe is to act as a reinforcing agent. The properties that make asbestos suitable as a reinforcing agent are its high fiber strength, resistance to alkali attack and adhesion to cement. The raw fibers are also readily wetted and thus contribute favorable and controllable drainage properties to an asbestos cement mix, enabling A/C pipe to be produced by a relatively simple and flexible process similar to that used in paper-making.[2] Asbestos can also withstand the autoclave (heat and pressure) process used in the manufacture of pipe and resists the alkali attack of Portland cement. The large surface area of asbestos fibers promotes good adhesion between the cement mixture and the fiber surface.

*Data from unpublished OSHA report on asbestos.

Product Composition

The AWWA[3] defines A/C pipe as a mixture of either:

1. Portland cement or Portland blast furnace slag cement and asbestos fiber, with or without silica.

2. Portland pozzolana cement and asbestos fiber.

If the pipe material simply sets under relatively normal ambient conditions* (Type I), representative formulations are 15 to 25 percent asbestos and 75 to 85 percent cement; however, if the pipe is "cured" by autoclave (Type II) (as is practiced in the U.S.) silica is added so that the representative formulation becomes 15 to 25 percent asbestos, 42 to 53 percent cement, and 34 to 40 percent silica. Finely ground solids from crushed damaged pipe may be added in quantities up to 6 percent as filler material.** In 1980, it was estimated that 83 percent of the asbestos used in A/C pipe was chrysotile (119,700 metric tons), 17 percent was crocidolite (24,100 metric tons), and 0.1 percent was amosite (200 metric tons).[4]

A/C water pipe is classified on the basis of its design internal pressure ranging from 2070 to 6200 kPa and its chemical composition as follows:

- Type I - No limit on uncombined calcium hydroxide

- Type II - 1 percent or less uncombined calcium hydroxide

There is a separate classification for A/C sewer pipe based on resistance to external crushing loads. The chemical composition of the pipe bears no revelance to its pressure class rating, but rather to its method of manufacture.[1] The pipe's ability to withstand attack (which might result in the release of asbestos fibers) from "aggressive"† water depends on chemical type. Only Type II is recommended for moderately aggressive water whereas either can be used for nonaggressive water. In aggressive water applications, the serviceability of Type II pipe must be established by the purchaser in conjunction with the manufacturer (AWWA spec. C-400).[1] For external corrosion from ground water, in addition to acidity, soluble sulfate is an important parameter.[3]

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*Conditions for this pipe to set include total immersion in water for a period of approximately 28 days.[1]

**Data from unpublished OSHA report on asbestos.

†Aggressiveness is computed from pH + log (AH) where A is the total alkalinity and H the total hardness, both expressed as ppm $CaCO_3$.

Uses and Applications

The majority of the A/C pipe produced is used for water mains (pressure pipe) and sewer lines (nonpressure pipe). An indeterminate, smaller amount of A/C pipe is also used as conduits for electrical and telephone cables and for laterals from street mains to the consumer. The exact historical accounting of A/C pipe is unavailable as this information is considered confidential or unknown.

Over the 6-year period from 1974 to 1980, asbestos-cement pipe jumped from 10.8 percent of pipe in place in 1975 to 13.9 percent in 1980. More dramatically, while in 1974, 29.8 percent of all pipe installed was A/C, by 1980, A/C pipe jumped to 40.4 percent.[5] Most (72 percent) of the A/C pipe installed as water main is 6 to 12 inches in diameter. Tables 25 and 26 show a comparison of the different types of pipe used as water mains.[6]

The mileage of sewer mains in systems serving more than 2,500 people was estimated to be 737,100 km by a 1975 American City Magazine study.[7] The study did not make a distinction between sanitary, storm, or combined sewers while estimating that A/C pipe accounted for only 5.4 percent or 40,200 km of this total. Over 77 percent of the A/C pipe was in the 8 to 14 inch category. Tables 27 and 28 provide a comparison of the pipes in use.

Product Manufacturing Summary

Manufacturing Process--

The manufacture of A/C pipe is a wet process, similar to cellulose paper production. The ingredients--asbestos fibers, Portland cement, silica sand--are weighed and added to a dry mixer. The mixed ingredients are added to a beater; water is added producing an A/C slurry containing about 97 percent water.

This slurry is filtered through rotating screens, forming a cement-fiber ply which is picked up by continuous felt, dewatered by vacuum boxes and accumulated on a steel cylinder called a mandrel. The plys are wound around the mandrel under several tons of pressure and compressed into a dense, homogeneous pipe wall. At the proper thickness, the rolling up process stops. The pipe, now in 3 meter (10 foot) or 4 meter (13 foot) lengths, is then precured under controlled heat and humidity. After mandrel removal, it is final cured by water immersion (for Type I) or high pressure steam autoclaving (for Type II). Autoclaving reduces the free lime content, enhancing corrosion resistance to high sulfate soils and waters. The pipe is then finished by precision machining the ends.[1]

A/C pipe may be lined prior to final shipment. The pipe is lined to protect the pipe from aggressive or corrosive fluids. Although a vinyl lining was often employed in the past, the use of vinyl for lining material has virtually ceased in favor of gilsonite, asphaltic-based or proprietary coatings.[1]

TABLE 25. TYPES OF WATER MAIN PIPE NOW IN PLACE (1975)-NATIONAL PROJECTIONS OF MILEAGE*[6]

Population range served	Cast and ductile iron	Asbestos cement	Steel	Reinforced concrete	Plastic	Other	Total
Over 1,000,000	43,388	2,982	1,292	1,441	1	596	48,700
500,000 - 999,999	46,176	11,150	4,158	1,197	1	315	62,997
250,000 - 499,999	43,628	7,552	5,992	1,498	250	3,495	62,415
100,000 - 249,999	65,431	7,703	3,230	1,325	1,408	3,727	82,824
50,000 - 99,999	54,905	7,793	3,862	1,545	211	1,895	70,211
25,000 - 49,999	56,870	11,660	5,235	1,348	714	3.490	,317
10,000 - 24,999	84,044	15,008	6,559	1,001	2,334	2,223	111,169
2,500 - 9,999	87,373	20,023	7,524	728	2,063	3,641	121,352
Total Mileage	481,815	83,871	37,852	10,083	6,982	19,382	639,985
Percent of Total	75.3	13.1	5.9	1.6	1.1	3.0	100.0

*For comparison with the 1975 data presented here, Installed A/C pipe accounted for 40 percent of the water pipe business in 1980, with cast iron at 44 percent.[1]

NOTE: Cast iron is the predominate type of pipe now in place, accounting for three-fourths of the total. Part of the reason for this large amount may also be credited to the fact that cast iron pipe has been sold for 200 years. Asbestos cement has a 13 percent share with none of the other types having more than 6 percent; A/C has been on the market for 50 years.[1]

TABLE 26. WATER MAIN SIZE RANGES BY TYPE OF PIPE NOW IN PLACE-PROJECTED TOTALS (1975) (Percentage of Total in Parentheses)[6]

Type	Under 6"	6" - 12"	13" - 24"	Over 24"	Total
Cast and ductile iron	75,701 (15.1)	369,761 (76.7)	31,645 (6.6)	4,709 (1.0)	481,816 (100.0)
Asbestos Cement	8,088 (9.7)	72,402 (86.3)	3,365 (4.0)	16 (*)	83,871 (100.0)
Steel	20,223 (53.4)	11,171 (29.5)	4,049 (10.7)	2,409 (6.4)	37,852 (100.0)
Reinforced concrete	17 (0.2)	416 (4.1)	4,374 (43.4)	5,276 (52.3)	10,083 (100.0)
Plastic	4,330 (62.0)	2,607 (37.3)	40 (0.6)	4 (0.1)	6,981 (100.0)
Other	7,510 (38.7)	8,829 (45.6)	2,477 (12.8)	566 (2.9)	19,382 (100.0)

*Less than one-tenth of 1 percent.

NOTE: The great majority of cast iron and asbestos cement pipe falls within the 6" to 12" range. Larger sizes predominate in reinforced concrete with over half of this mileage over 24" in diameter. Plastic pipe lies almost exclusively in the two smallest ranges with negligible mileage over 12". Somewhat more than half of the steel total is under 6" but this type also has significant mileage of large-sized pipe.

TABLE 27. TYPE OF SEWER MAIN PIPE NOW IN PLACE-NATIONAL PROJECTIONS OF MILEAGE (1975)[7]

Population range served	Cast and ductile iron	Asbestos cement	Vitrified clay	Reinforced concrete	Plastic	Other	Total
Over 500,000	547	1,504	41,631	17,979	205	6,494	68,360
250,000 - 499,999	434	521	33,456	2,343	521	6,118	43,393
100,000 - 249,999	802	601	28,109	14,080	1,002	5,512	50,106
50,000 - 99,999	1,129	2,207	36,393	10,369	616	616	51,330
25,000 - 49,999	1,512	6,317	30,722	9,395	1,998	4,049	53,993
10,000 - 24,999	1,606	4,435	55,211	10,782	918	3,517	76,469
2,500 - 9,999	9,067	9,182	80,913	9,411	4,132	2,066	114,771
Total Mileage	15,097	24,767	306,435	74,359	9,392	28,372	458,422
Percent of Total	3.3	5.4	66.8	16.2	2.1	6.2	100.0

NOTE: Vitrified clay is the predominate type of pipe now in place, accounting for two-thirds of the total. Reinforced concrete has a 16 percent share with none of the other types having more than 6 percent if the total. The majority of pipe within the "other" category is of the unreinforced concrete category.

TABLE 28. SEWER MAIN SIZE RANGES BY TYPE OF PIPE NOW IN PLACE-PROJECTED TOTALS (1975) (Percentage of Total in Parentheses)[7]

Type	Under 8"	8" - 14"	15" - 24"	Over 24"	Total
Cast and ductile iron	4,006 (26.5)	8,805 (58.3)	1,958 (13.0)	328 (2.2)	15,097 (100.0)
Asbestos cement	3,171 (12.8)	19,248 (77.7)	2,071 (8.4)	277 (1.1)	24,767 (100.0)
Vitrified clay	55,626 (18.2)	208,498 (68.0)	33,341 (10.9)	8,970 (2.9)	306,435 (100.0)
Reinforced concrete	4,256 (5.7)	29,283 (39.4)	17,587 (23.7)	23,233 (31.2)	74,359 (100.0)
Plastic	864 (9.2)	7,756 (82.6)	447 (4.7)	325 (3.5)	9,392 (100.0)
Other	6,354 (22.4)	13,864 (48.9)	4,182 (14.7)	3,972 (14.0)	28,372 (100.0)

NOTE: Over half of reinforced concrete sewer pipe in place is over 14" in diameter. At the other extreme, plastic pipe is almost all under 15" with 83 percent between 8" to 14". The size distributions for cast iron, asbestos cement, and vitrified clay are more representative of sewer main pipe as a whole.

Name and Location of Manufacturers--

The primary domestic producers of A/C pipe are listed below:

- Johns-Manville
  Ken-Caryl Ranch
  Denver, CO 80217

- CertainTeed Corporation
  120 E. Lancaster Avenue
  Ardmore, PA 19003

- CAPCO Pipe Co., Inc.
  P. O. Box 3435
  Birmingham, AL 35205

A/C pipe is produced by J/M in:[8]

- Denison, TX
- Long Beach, CA
- Stockton, CA

CertainTeed locations include:

- Santa Clara, CA
- Hillsboro, TX
- Ambler, PA
- Riverside, CA

CAPCO is located in Ragland, AL and Van Buren, AR.[9]

Production Volumes--

Recent A/C pipe production figures are unavailable. A request for such figures from the A/C Pipe Producers Association was not answered.[10] The producers regard this information as proprietary, and are reluctant to provide exact numbers.

Searches through literature and government reports showed a wide disparity between production and fiber use. One estimate, by the Bureau of Mines[4] places the 1980 fiber use at approximately 144,000 metric tons.

SUBSTITUTE PRODUCT

Methodology

Search Strategy--

The primary objective of this survey was to gather current information on substitute product properties and availability. The survey began with a review of the available secondary sources to obtain a background as to what is known about A/C pipe and its substitutes and what must be verified to complete the assessment.

Journals and magazines were searched for industry contacts and a listing of the applicable Trade Associates was obtained. Calls to the Trade Association provided necessary information and new contacts. Every possible effort was made to obtain and verify the most recent information.

No plant trips were made during this task. However, under a previous GCA contract, a plant visit was made to an A/C pipe plant and the trip report was reviewed for applicable information.

Summary of Contacts--

A partial list of the primary contacts is as follows:

- Mr. Steve Shea
  Boston Sewer and Water Commission
  Boston, MA

- Mr. Stan Mruk
  Plastic Pipe Institute
  New York, NY

- Mr. Richard Bogdanovich
  American Waterworks Association
  Denver, CO

- Mr. John Matticks
  Department of Commerce
  Washington, D.C.

- Mr. Phil Caldwell
  Cem-Fil Corporation
  Nashville, TN

- Mr. Robert Walker
  Uni-Bell Plastic Pipe Association
  Dallas, TX

- Mr. Gene Owen
  American Cast Iron Pipe Company

- Mr. John O'Conner
  American City Magazine
  Pittsfield, MA

- Mr. Mike Higgins
  Ductile Iron Pipe Research Association
  1301 W. 22 St.
  Oakbrook, IL 60521

- Mr. Harry Niles
  Ductile Iron Pipe Research Association
  Jericho, VT

- Mr. Russell Preuit
  American Concrete Pipe Association
  Vienna, VA

- Mr. Ed Sikora
  National Clay Pipe Association
  Crystal Lake, IL

Fiber Substitutes

Manufacturers of pipe products have searched for fibers which could be substituted for asbestos as a concrete reinforcing agent. For general applications, a substitute fiber should be strong, resistant to alkali attack, compatible with current manufacturing equipment, and cost competitive. Of the fibers considered here, only special glass fibers have been employed in a commercial product. A comparison of properties of asbestos and four substitute fibers was tabulated and is presented in Table 29.

Asbestos demonstrates excellent reinforcing ability. Steel fibers also have demonstrated outstanding reinforcement abilities. Carbon fibers have strength, elasticity, and chemical resistance but lack the cohesion necessary for proper binding.*

Steel Fibers--

Special qualities--As Table 29 shows, steel fibers have many properties which could make them suitable as a replacement for asbestos including high strength and good cohesion properties.

*Source is an unpublished document by OSHA on asbestos.

TABLE 29. PROPERTIES OF VARIOUS FIBERS FOR USE IN PIPE PRODUCTS*

Type of fiber	E-modulus	Strength	Fiber surface	Cohesion	Critical length	Age resistance
Steel	+	+	+	++	+	(+)
Asbestos	+	+	++	++	+	++
Carbon	+	+	+	—	—	++
Glass	+	+	+	—	—	—
Organic fibers	—	(±)	+	—	—	(±)

NOTE: + = positive reinforcement.

— = negative reinforcement.

Steel fibers have been used in the production of cement pipe.[11]** The use of steel fibers is certainly more convenient than the use of traditional steel reinforcement. They are, however, more expensive per ton of reinforcement than conventional steel reinforcement. The result of using steel fibers is not readily predictable. An exact knowledge of the amount of reinforcement imparted by randomly oriented fibers is not known. Steel fibers also have a drawback in that unless a sufficient cover of cement is present they will be susceptible to corrosion, thus weakening the pipe wall.

Product composition--Steel fibers are not currently used in the commercial production of an A/C pipe substitute.

Uses and applications--Steel fibers are not currently commercially used as a replacement for asbestos in a pipe product.

Manufacturing summary--Steel fibers are not used in a commercial pipe product.

Glass Fibers--

Special qualities--The glass fiber reinforcement reduces the weight of material in a product and therefore the energy requirement associated with that weight. The energy needed for glass fiber production is roughly one half that of steel per half metric ton; thus the total energy consumption per foot

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*Although steel fibers have been used in producing conventional cement pipe, it should be noted that this does not necessarily mean that they are automatically suitable in A/C pipe; there are significant processing differences between the two products.[1]

**Source is an unpublished OSHA document on asbestos.

of pipe is lower than that required for most other pipes.[11]* In addition glass fiber does not rust and is generally compatible with cement provided it can be made resistant to alkali attack. It is a fine, continuous, flexible, uniform filament which makes it relatively easy to handle with automatic equipment.[11]

CertainTeed products, an asbestos cement pipe producer, reports that alkali resistant glass has only about 60 percent of the tensile strength of asbestos. This company's experience is that glass reinforcing strength is not retained over long periods of time, and some glass fiber is believed to disintegrate during autoclaving.[12] In addition, glass is currently more expensive than asbestos and compatibility with the A/C pipe manufacturing process must be dealt with.[1]

Product composition--Conventional "E" glass fiber, commonly used in reinforced plastics, is severely degraded by highly alkaline cement. However, an alkaline-resistant glass fiber has been developed by Building Research Establishment, Gaston, England. The fiber is marketed by Pilkington Brothers Ltd., of St. Helens, England under the name Cem-FIL. Cem-FIL Corp. of Nashville, Tennessee, is the licensed American manufacturer of Cem-FIL fiber products. The fiber is a high-zirconia, alkali-resistant glass fiber which can be used with the highly alkaline cement commonly used for pipe construction. (See "Glass Reinforced Concrete Pipe" in Pipe Substitute subsection).

Uses and applications--See "Glass Reinforced Concrete Pipe" in Pipe Substitute subsection.

Manufacturing Summary--See "Glass Reinforced Concrete Pipe" in Pipe Substitute subsection.

Other Fibers--

Special qualities--Other fibers which have been examined for use in cement and concrete composites include alumina, plastic, and carbon. Fibers such as nylon, rayon, rockwool, mineral, cotton, acrylic, polyester, Kevlar™, and other organic fibers have been studied, but not seriously considered, due either to high cost, low effectiveness, or inadequate resistance to the alkaline cement environment in Portland cement.**

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*However, asbestos may not be in the class with "most other pipes" as it is a natural product and not energy intensive.[1]

**Source is unpublished OSHA document on asbestos.

Product Substitutes--

A/C pipe is used primarily in the water and sewer main (including laterals) areas. Water main substitutes for A/C pipe are ductile iron, fiberglass reinforced plastic pipe, PVC, and reinforced concrete. Sewer main substitutes for A/C pipe are vitrified clay, concrete, plastic, and ductile iron.

In the more minor areas of conduits, drainage and irrigation pipe, these various types of pipe are also competitive. There is no readily available information on these areas. Less emphasis will be placed on these categories since what applies to water and sewer lines could easily be extended to include these areas.

Concrete Pipe--

Special qualities--Concrete pipe, reinforced and nonreinforced, has qualities which are similar to those of A/C pipe, with steel replacing asbestos as a reinforcing agent. Concrete is a durable, natural material with excellent longevity. It is amenable to specialty uses with only minor adjustments. This pipe is not used for pressure applications with the exception of low pressure agricultural uses.[1]

Product composition--Concrete is an aggregate of sand, gravel, and cement. Concrete pipe may be produced without reinforcement, which is common in the smaller sizes. Reinforced pipe consists of concrete reinforced, circumferentially, with steel bars and/or one or more layers of welded wire mesh.

Uses and applications--Concrete pipe, reinforced and nonreinforced is used for water mains, storm and sanitary sewer mains, irrigation and subdrains. In 1974, concrete pipe accounted for only 1.6 percent of the nation's water mains; however, over 95 percent of this pipe was over 13 inches in diameter.[6] (See Tables 25 and 26). Concrete is used more often as sewer mains, as shown by over 16 percent of the nation's sewers being concrete in 1974. The largest portion is over 24 inches in size (see Tables 27 and 28).[7]

Advantages/limitations--A primary advantage of concrete sewer pipe is its availability, since it is often made out of local materials. This type of pipe has excellent longevity, exceeding 50 to 100 years.[13] Also, at sizes greater than 24 inches, it costs less than A/C pipe. For deep, buried uses this equals properly specified A/C pipe for strength.[1]

Reinforced concrete pipe may also be cast in elliptical or arch shapes.[13] These shapes allow for the same cross-sectional area with a smaller effective height, thus it may be buried in shallower trenches compared to circular pipes. This can contribute to lower installation costs. These shapes also give a design advantage since their hydraulic properties differ from those of circular pipes. This is important since sufficient velocity must be maintained to prevent the settling out of suspended solids from sewerage, and to prevent excess velocities which could lead to increased abrasion of pipe surfaces. Control of the flowing fluids occurs as a result of the changing cross-sectional areas.*

Concrete pipe is also versatile in that it may be designed for a particular use.[13] When stronger pipe is necessary, more steel reinforcement may be added and/or the wall thickness increased. Aggressive fluid or soil conditions may be counteracted with thicker walls or by adjusting the chemical composition of the concrete.**

The primary limitation of all concrete/cement pipes, including A/C, is that they are susceptible to attack by acids.[13] Industrial wastes may contain aggressive substances. High sulfate soils, when they become moist may release sulfates which can attack the pipe. Septic conditions in a sewer pipe can lead to hydrogen sulfide formation, which also reacts with water to form acid, and attacks the inner wall of the pipe. Hydrogen sulfide formation is of particular concern in the warmer southern sectors of the country.

Product manufacturing summary--Non-reinforcing sewer pipe is found in diameters ranging from 6 inches to 26 inches. Reinforced concrete sewer pipe is generally available in sizes from 12 inches to 144 inches, and it is not uncommon to use reinforced concrete for mains in excess of 20 feet in diameter.[14] Pipe length is determined by the standards, uses, and weight of the pipe. The handling of the pipe is a particular design consideration for unreinforced pipe, since the pipe must be strong enough to withstand handling. Six to eight inch diameter pipe is common in 4 feet to 6 feet lengths. The standard length for reinforced pipe is about 8 feet, although pipe may be custom produced in lengths exceeding 20 feet.

There are approximately 375 manufacturers of concrete pipe in 47 states.[15] Production volume information is published by the American Concrete Pipe Association.[1]

Vitrified Clay Pipe (V/C)--

Special qualities--V/C pipe's primary qualities which make it attractive as a replacement pipe include the fact that it is constructed from inert materials (clay). However, its cost is greater than A/C, concrete, or PVC pipe.[1]

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*It should be noted that, although such casting of shapes is useful, they represent only a very small portion of the total pipe market.[1]

**Asbestos is also versatile - three classes of A/C distribution pipe are produced and nine classes of A/C transmission pipe.[1]

Product composition--V/C pipe is manufactured from shales and clay which are inert materials.[16] Hydrous aluminum silicates are the clays most suitable for the manufacture of V/C. They have the plasticity essential for the extrusion process, they are stable at high temperatures and have good drying and firing properties.

Uses and applications--Vitrified clay pipe (V/C) is used primarily in non-pressure applications such as sanitary and storm sewers, septic tank drainage fields, and underground collection systems.[17] Over two-thirds[7] of all sewer mains currently in the ground are V/C pipe.* The majority of the pipe is in the 8 to 14 inch range, while only 3 percent is reported to be over 24 inches in diameter (see Tables 27 and 28).

Advantages and limitations--Among V/C pipe's qualities is the fact that it is one of man's oldest known pipe materials.[16,17] Clay has a proven record of performance, it has been used for centuries. Clay has been used in the United States since 1815.[16] Vitrified clay is an inert material and thus unaffected by most normal components in domestic and industrial sewerage.[17] It also has a long life expectancy, good flow characteristics, and abrasion-resistance. In addition, V/C pipe is produced with domestic materials.

The main limitation of V/C is weight, as it is extremely heavy. It also is a rigid pipe and thus needs extra care in handling and bed preparation. Its lack of flexibility could be a limiting factor, particularly in high stress situations. It also is only manufactured in short lengths which results in the use of more joints per mile of pipe.[1]

Product manufacturing summary--V/C pipe is produced from clays and shales (see Product Composition). The mined clay is mixed and ground to obtain the proper mixture and consistency.[16] The clay pipe is extruded, finished and air dried. This green pipe is vitrified by heating in a kiln at approximately 2000°F (1100°C). Finished pipe is then tested according to ASTM procedures.

V/C pipe is commonly found with nominal diameters from 3 to 42 inches.[16] The length varies, but 6 to 7 feet is common, with some of the smaller sizes available in lengths up to 10 feet.[17]

Name and location of manufacturers--A list of V/C manufacturers who are members of the National Clay Pipe Institute was provided by the National Clay Pipe Institute[17] and is included below. These companies may operate several plants.

- Can-Tex Industries
  Division of Harsco Corporation
  P. O. Box 340
  Minerals Wells, TX 76067

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*However, less than 50 percent of sewer pipe currently being installed is vitrified clay.[1]

- Clow Corporation
  Clay Products Division
  300 S. Gary Avenue
  Carol Stream, IL 60187

- Denver Brick and Pipe Company
  P. O. Box 2329
  Denver, CO 80201

- W. S. Dickey Company
  P. O. Box 6
  Pittsburg, KS 66762

- The Logan Clay Products Company
  P. O. Box 698
  Logan, OH 43138

- Mission Clay Products Corporation
  P. O. Box 391
  Whittier, CA 90608

- Pacific Clay Products, Inc.
  9500 S. Norwalk Boulevard
  Sante Fe Springs, CA 90670

- Pomona Pipe Products Company
  P. O. Box 20400
  Greensboro, NC 27420

- Superior Clay Corporation
  Uhrichsville, OH 44683

Production volumes--Pipe production figures in terms of kilometers of pipe and size distribution could not be located. Yearly production figures reported by the Department of Commerce in its publication Construction Review,[18] are included in Table 30.

TABLE 30. VITRIFIED CLAY SEWER PIPE PRODUCTION FIGURES 1973-1978[18] (thousand metric tons)

Year	Production	Shipments
1973	1,578	1,494
1974	1,355	1,319
1975	1,126	1,080
1976	1,006	996
1977	970	1,004
1978	921	855

Plastic Pipe--

Special qualities--This section on plastic* emphasizes polyvinyl chloride (PVC) although the properties of all plastic pipe are fairly similar. Table 31 is a list of the physical properties of the major thermoplastics. PVC is inert to inorganics such as acids, alkalis, and salts. Plastic is not subject to electrochemical or galvanic action. Ultraviolet radiation can effect the polymer bonds, but is not a concern in pipe which is not exposed to direct sunlight. Table 32 is a listing of the chemical resistance of plastic pipe to various chemicals.

Plastics are viscoelastic, that is, they respond to stress as if they were a combination of elastic solids and very viscous fluids. Consequently, they have elasticity, strength and form stability, as well as flow and sensitivity to time under load, rate of loading, and temperature. The viscous component tends to dampen the response between stress and strain. As a result, material cracking or failure versus creep or excessive deformation, usually becomes the controlling performance criteria for plastics under long term stress. This must be accounted for in the safe design of pipe subjected to continuous loading, such as pressure pipe.

Smooth walled thermoplastic pipes behave as hydraulically smooth pipes. The flow characteristics do not deteriorate with time since plastic is noncorrosive.

Product composition--There are literally thousands of plastic materials. These polymers are formed from reactions with many of the carbon chain molecules found in petroleum products or synthesized in the laboratory. Polyvinyl chloride is formed from the reaction of vinyl chloride monomers, to form the PVC polymer.

Uses and applications--Many types of plastic have been created by polymer chemists, which may be formed into pipes. These include polyvinyl chloride (PVC), polyethylene (PE), acrylonitrile-butadiene-styrene (ABS), and polybutylene (PB), which have a range of characteristics and properties as great if not greater than any other category of traditional piping material.

Plastic piping has a broad range of applications including[19,20,21]: hot and cold water supply; drain, waste and vent lines; abrasive slurry lines; gas distribution; water mains and services; well casings; communications and power ducts; and vacuum lines. Rural water distribution and private sewerage systems are almost exclusive applications of plastic piping. Well over half the piping used for gas transmission and telephone conduits is plastic.

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*Note: Except where otherwise referenced, the material in this section was obtained from: "Thermoplastic Piping, A Report by the ASCE Task Committee on Plastic Pipe." Stanley A. Mruk, Technical Director, PPI. (ASCE Annual Convention, San Francisco, October 17-21, 1977.) 52 p.

TABLE 31. TYPICAL PHYSICAL PROPERTIES OF MAJOR THERMOPLASTIC PIPING MATERIALS[19]

Property @ 75°F	ASTM test no.	ABS		PVC		CPVC	PE			PB	PP	SR
		I	II	I	II		I	II	III			
Specific Gravity	D-792	1.04	1.08	1.40	1.36	1.54	0.92	0.94	0.95	0.92	0.92	1.06
Tensile Strength PSI (10^3)	D-638	4.5	7.0	8.0	7.0	8.0	2.0	2.4	3.2	4.2	3.5	3.8
Tensile Modulus PSI (10^5)	D-638	3.0	3.4	4.1	3.6	4.2	0.90	1.20	1.2	0.55	1.1	3.2
Impact Strength, izod ft-lbs/inch notch	D-256	6	4	1	6	1.5	>10	>10	>10	>10	5	1
Coeff. of Linear Expansion in/in - °F (10^{-5})	D-696	5.5	6.0	3.0	5.0	3.0	10	9.0	9.0	7.2	4.3	6.8
Thermal Conductivity Btu-in/hr-ft - °F	C-177	1.35	1.35	1.1	1.3	1.0	2.3	2.9	3.2	1.5	0.8	0.8
Specific Heat Btu/lb - °F	—	0.32	0.34	0.25	0.23	0.20	0.50	0.54	0.55	0.45	0.45	0.33
Approx. Operating Limit*												
°F, non-pressure	—	180	180	150	130	210	100	130	160	210	200	140
°F, pressure		160	160	130	110	180	90	120	140	180	150	-

*Exact operating limit may vary for each particular commercial plastic material. Effects of environment should also be considered.

Key: ABS - Acrylonitrile-butadiene-styrene
PVC - Polyvinyl chloride
CPVC - Chlorinated polyvinyl chloride
PE - Polyethylene
PB - Polybutylene
PP - Propylene Plastic (polypropylene)
SR - Styrene Rubber

TABLE 32. CHEMICAL RESISTANCE GUIDE AT AMBIENT TEMPERATURES[19]

Compounds	ABS	PVC I	PVC II	CPVC	PE	PB	PP	SR	CAB	POP	Chlorinated polyether	Fluorocarbon TFE/FEP	Fluorocarbon PVF
Inorganic													
Acids, dilute	G	G	L	G	G	G	G	G	L	G	G	G	G
Acids, conc. 80%	L	L	L	G	L	L	L	P	P	L	G	G	G
Alkalies, dilute	G	G	G	G	G	G	G	G	L	G	G	G	G
Alkalies, conc. 80%	L	G	L	G	G	G	G	L	P	L	G	G	G
Gases, Acid (HCl & HF) Dry	L	L	L	L	G	G	G	L	P	L	G	G	L
Gases, Acid (HCl & HF) Wet	L	G	L	G	G	G	G	L	P	G	G	G	L
Gases, Ammonia, Dry	L	G	L	G	G	G	G	L	P	L	G	G	G
Gases, Halogens, Dry	L	L	L	L	L	L	P	L	P	L	L	L	L
Gases, Sulphur gases, Dry	P	G	L	G	G	L	P	P	P	L	G	G	G
Mineral Oil	G	G	G	G	L	G	G	L	G	G	G	G	G
Salts, Acidic	G	G	G	G	L	G	G	L	G	G	G	G	G
Salts, Basic	G	G	G	G	G	G	G	G	G	G	G	G	G
Salts, Neutral	G	G	G	G	G	G	G	G	G	G	G	G	G
Salts, Oxidizing	L	L	L	L	G	G	G	L	L	L	G	G	L
Organic													
Acids	G	G	G	L	G	G	G	L	L	G	L	G	L
Acid anhydrides	L	L	L	P	L	L	L	L	P	L	L	G	L
Alcohols, glycols	L	G	L	G	L	G	G	P	P	L	G	G	L
Estors, Ethers, Ketones	P	P	P	P	L	L	L	P	P	L	L	L	L
Hydrocarbons, Alphalic	L	L	L	G	L	L	L	P	P	L	L	G	L
Hydrocarbons, Aromatic	P	P	P	L	P	P	P	P	P	P	L	G	L
Hydrocarbons, Halogenated	L	L	L	L	P	P	P	P	P	P	L	L	L
Natural Gas, (fuel)	G	G	G	G	G	G	G	P	G	G	G	G	G
Synthetic Gas (Fuel)	L	L	L	L	L	L	L	P	L	L	G	G	G
Oils, Animal & Vegetable	G	G	G	G	L	G	G	L	G	G	G	G	G

*Exact chemical resistance depends upon particular commercial grade of plastic, specific chemical compound and conditions of exposure. Consult piping manufacturers for more detailed listings.

G = Good resistance (Recommended for most cases)

L = Limited resistance (Has many uses; tests recommended)

P = Poor to No resistance (Not recommended for most cases)

Key: ABS - Acrylonitrile-butadiene-styrene
PVC - Polyvinyl chloride
CPVC - Chlorinated polyvinyl chloride
PE - Polyethylene
PB - Polybutylene
PP - Propylene Plastic (polypropylene)
SR - Styrene Rubber
CAB - Cellulose acetate-butyrate
POP - Polyethylene oxide

An American City and County Magazine survey (1974) estimated PVC pipe is used for almost 7,000 miles (11,265 km) of water main,[6] of which 62 percent was under 6 in. (15 cm) in diameter. The same study for sewer mains[7] showed 2 percent or over 9,000 miles (14,485 km) of sewer mains were plastic pipe, of which 82 percent was in the 8 to 14 inch size range. In a 1981 study by the same source, it was noted that growth of plastic pipe did not measure up to the 1974 projections. Even though plastic pipe accounted for nearly 6 percent more installed miles in 1980 as compared to 1974, it was reported as only one percent more of in-place pipe mileage - not a significant gain.[5]

Advantages/limitations--PVC and other plastic pipe materials have many properties which make them suitable, or superior, for use in a wide range of applications. Considered beside traditional piping material, thermoplastics are less rigid and less strong, their maximum service temperatures are lower and their thermal coefficients of expansion are higher. However, they do not corrode, are biologically inert, and resist chemical attack. They are sufficiently strong and their temperature limits are quite adequate for most applications.[19]

Traditional pipes have stiffness values which are an order of magnitude greater than those of plastics. Plastic pipes, being flexible, have unique design considerations. Their flexibility is an asset because the maximum deflection to preclude pipe failure is not as stringent a constraint as it is with other pipe materials. PVC has demonstrated its ability to retain its serviceability of deflections greater than 5 percent, the limit often imposed on traditional pipes.[19]

Because of its high strength and light weight, PVC pipe may be produced in lengths much longer than its traditional counterparts. This means installation is easier since fewer joints are needed. Sizes under 4 inches in diameter are available in 20 foot lengths, while 6 inches and up are available in 10 foot lengths. PVC ranges in size from very small (1/2-inch or less) to 15 inches in diameter. Recently (1978), some manufacturers have made sewer pipe available in the 18 to 27 inch range.[21]

A limitation of plastic piping materials is that cyclic loading, which often results from water hammer or pump vibration, can cause plastics to fail. The maximum stress, temperature, and frequency are all determining factors. The amplitude of the stress is often the primary determinant.[20,21] Such stress causes fluctuations in the pipe diameter which leads to fatigue and ultimately, failure.

These limitations are easily overcome by proper design. Normal practice is to choose a pipe whose rated working pressure is not exceeded by the static plus surge pressure. For example, a 200 psi (1380 KN/m^2) pipe is chosen when 160 psi (1100 KN/m^2) is required. AWWA C-900 standards include a built in surge pressure allowance.

Product manufacturing summary--PVC pipe is a thermoplastic as opposed to thermosetting material. As its name (thermoplastic) implies, the material softens when heated and hardens upon cooling. Thermoplastic pipe is manufactured by the extrusion process. There are numerous manufacturers of plastic pipe. Among the largest manufacturers of plastic pipe for water and sewer use (a direct competitor to A/C pipe) is Johns-Manville Corporation.

Production volumes--PVC accounted for 72 percent or 850 million kilograms of the total 1,170 million kilograms of pipe material manufactured in 1978. PVC also accounted for 86 percent of the plastic pressure pipe shipped in 1978.[22]

PVC pipe is not as new a product as is commonly thought. By 1948 a small thermoplastic piping industry in the U.S. produced about 450,000 kg of product. Phenomenal growth followed and the almost one billion kilograms produced in 1976 is estimated to have accounted for almost 25 percent of the footage of all types of piping. Most of this footage is in the small diameter pipes. Some estimates of PVC pipe in use in 1980 are given as 57,000 miles (91,735 km) of sewer pipe and 1.3 million miles (2.1 million km) of water pipe.[21]

Production Figures for the last few years are given in Tables 33 and 34.

Glass Fiber Reinforced Concrete Pipe--

Special qualities--ARC Concrete, a subsidiary of Amy Roadstone Corp. Ltd., produces a glass fiber reinforced concrete pipe of special construction which they market (in the United Kingdom) under the designation ARC Slimline Glass Reinforced Concrete Pipe.[11,23-25]

TABLE 33. TOTAL PLASTIC PIPE AND FITTINGS PRODUCTION VOLUME ESTIMATES 1960-1978 (millions of kilograms)*[22]

Year	Pipe Production	Year	Pipe Production
1960	27.2	1969	237.7
1961	40.0	1970	318.0
1962	50.6	1971	445.4
1963	59.7	1972	611.4
1964	75.7	1973	792.4
1965	91.8	1974	800.0
1966	124.4	1975	668.1
1967	140.3	1976	891.6
1968	193.2	1977	Committee estimate - 1163.1
		1978	Committee estimate - 1253.0

*Committee estimates total pipe and fittings poundage.

TABLE 34. ESTIMATED PRODUCTION VOLUMES FOR VARIOUS TYPES OF PIPE - 1974-1978[22]

Pipe, tube & conduit by material	1974 (est.)	1975 (est.)	1976 (est.)	1976 (est.)	1978 Reported	1978 (est.)
		MILLIONS OF KILOGRAMS				
PVC	540	475	595	770	800	845
ABS	60	65	85	100	80	85
PE (non-corrugated	55	40	60	75	70	75
PE (corrugated)	70	55	85	95	*	155
SR	20	9	2	0.7	*	*
CPVC	2.5	3	4	5	4	4.3
Total	747.5	647	831	1045.7	954	1164.3

Key: PVS = Polyvinyl chloride
ABS = Acrylonitrile-butadiene-styrene
PE = Polyethylene
SR = Styrene Rubber
CPVC = Chlorinated polyvinyl chloride

*Actual production unknown; total number at bottom reflects original author's estimates for these figures.

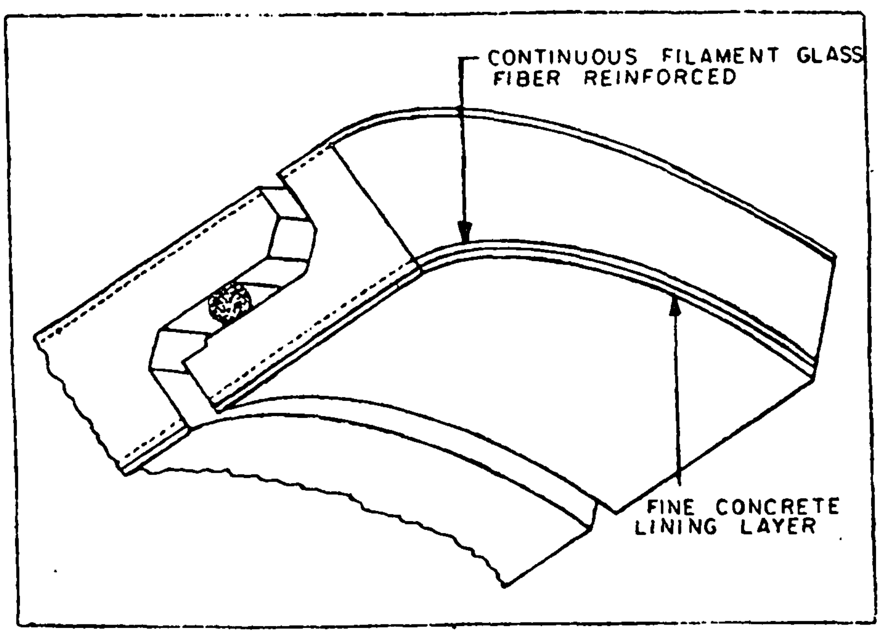

Figure 1. Section through a slim line pipe.[11,24]

In the development of this concrete product one of the first observations was that the fiber appears to act as a crack arrestor rather than reinforcement in the normal sense.[11] When the fiber is placed near the surface of concrete products it arrests cracks by evening out high stress concentrations, thus raising overall stress tolerance.

This is a significant property difference in the behavior of glass reinforced concrete as opposed to glass reinforced cement. In glass reinforced cement the dominant failure mechanism is that of bond slippage rather than fiber failure, preventing the full use of the high fiber tensile strength.[11]

Product composition--The ARC product consists of a centrifugally spun, high strength concrete core, with integrally cast, alkali-resistant glass fiber reinforcement adjacent to the inner and outer surfaces, and an internal unreinforced lining of fine aggregate concrete (Figure 1).

Uses and applications--ARC Slimline Glass Reinforced Concrete Pipe is suitable for use in conveying sewerage or surface water under gravity at atmospheric pressure.[11] The pipes are considered equivalent to conventionally reinforced concrete pipes in terms of strength, hydraulic flow characteristics and durability. Slimline pipes should have a service life equivalent to conventional spun concrete.

Advantages/limitations--Glass reinforced concrete (GRC) combines several of the advantages of concrete and steel reinforced pipe. The properties of concrete (good compression strength and corrosion resistance) allow it to be combined with the fiber to produce a product suitable for use in non-pressure applications.

Because of the nature of GRC, savings can be achieved in areas of material and energy. A strong pipe can be produced which is thinner and lighter than conventional concrete pipe which makes for easier handling.

The slim form of the pipe enables it to be handled and laid in trenches of lower widths than normal. This can show a significant reduction in the amount of excavation and bedding materials necessary, thus lowering installation costs (see Table 35).[24]

Product manufacturing summary--The pipe is centrifugally molded as are most cement pipes. Glass fiber is continuously injected onto the mold where it is helically wound onto the mold surface.[22,23] Cement is added. The body concrete is then added, vibrated, and centrifugally dewatered. The internal GRC is then injected. A final coating of fine concrete is then applied. The pipes are steam cured and allowed to mature at least 4 weeks before delivery. Quality control includes checks on raw materials, visual dimension checks and hydraulic and crushing load tests. The pipes may be made with ordinary Portland cement or sulphate resisting cement, depending upon soil conditions.[24]

TABLE 35. GRC PIPE FORMS[24]

Internal diameter (mm)	Outside diameter (mm)	Effective length (m)	Wall thickness (mm)	Approx. weight pipe (kg)	Traditional recommended overall trench width (m)	Slimline recommended overall trench width (m)
600	700	2.44	50.0	620	1.35	1.00
675	788	2.44	56.5	864	1.45	1.09
750	880	2.44	65.0	1010	1.50	1.18
825	963	2.44	69.0	1178	1.60	1.27
900	1050	2.44	75.0	1395	1.90	1.35
975	1138	2.44	81.5	1642	2.00	1.44
1050	1225	2.44	87.5	1900	2.05	1.53
1125	1313	2.44	94.0	2187	2.19	1.62
1200	1400	2.44	100.0	2480	2.30	1.70

Name and location of manufacturers--There are no domestic manufacturers currently producing a glass fiber reinforced cement pipe. Cem-FIL Corp., of Nashville, Tennessee, is the domestic representative of ARC concrete,[26] but they are not currently producing glass-fiber reinforced cement pipe.[1]

Production volumes--No GRC pipe has been produced domestically but as of 1979 over 13 km is reported in use in Europe.[25]

Cast and Ductile Iron Pipe--

Special qualities--Ductile iron results from the addition of magnesium to the molten iron, which causes a change in the internal grain structure of the iron. The carbon in ductile iron is in the form of nodules rather than the flakes prevalent in gray cast iron. As a result stresses are more easily dispersed. The resulting product is stronger and more ductile than gray cast iron.

Table 36 is a summary of some of the properties of ductile iron.

TABLE 36. PROPERTIES OF DUCTILE IRON PIPE[27,28]

Property	(psi)
Tensile strength	60,000
Yield strength	42,000
Elongation	10%
Elasticity modulus	24,000,000

Product composition--Ductile iron is a ferrous product consisting primarily of iron. Magnesium is added to enhance a change in the carbon in the internal grain structure as explained above. Other materials may be added to adjust the chemistry of the resulting steel.

Uses and applications--Iron pipe is used primarily for the transmission of gas, water, and sewerage. The first recorded use of cast iron pipe was in Germany in 1455. Between 1664 and 1688 the French laid cast iron pipe to supply water to Versailles; this pipe is still in use today. Cast iron pipe was first introduced in the United States in Philadelphia in 1804.[27]

A process for commercial production of ductile iron was developed in 1948. Ductile iron was first used for the commercial production of pipe about 1955.[27,29] Today ductile iron pipe has virtually replaced gray cast iron pipe in the market.[27,29] Much gray cast iron pipe is now in place but essentially all new iron pipe being installed is ductile iron pipe.[30,31]

Iron pipe production is expressed in two categories: pressure and soil.[18] Pressure pipe is the pipe commonly used for water distribution and transmission, gas distribution and transmission, and sewer force mains.[28] Soil pipe is used primarily indoors or as laterials (non-pressure). These uses might include bathroom plumbing mains or the connection to the sewer main. In 1975 it was reported that cast iron pipe accounted for 75 percent of the nation's water mains, primarily in the 6 to 12 inch range (Tables 25 and 26).[6] Cast iron is not popular for sewer mains - only 3 percent of the nation's mains were reported to be iron.[7] However, cast iron was used almost exclusively as sewer laterals until the introduction of plastic pipe.

Advantages/limitations--Ductile iron pipe's high tensile strength allows the use of diameter to thickness ratios in which the deflection of the pipe, under trench loads, is of sufficient magnitude that the principles of flexible pipe design are applicable. Ductile iron pipe can handle excessive stresses due to water hammer, highway traffic, etc., and service repair is infrequent.[1,27,28,32,33] Ductile iron pipe also has high machineability to facilitate and expedite installation and appurtenance installation.[33]

There are some limitations to the use of iron pipe. Its ability to corrode is often mentioned as a limitation; its proven track record disputes any major objections due to added coating materials. Iron corrodes under severe service conditions like aggressive soils (found in less than 5 percent of the nation) or saltwater.[28] Proper internal linings and external protection (including plastic wrap) can offset most corrosive conditions.[28]

Iron pipe is almost always lined with cement mortar to prevent internal corrosion and to improve flow characteristics. Plastics such as polyethylene are used as encasements when necessary to prevent external corrosion due to aggressive soils or electrolysis. Specialized cases may be treated with coatings like asphalt, coal tars, or glass liners.[27,33]

Iron is also susceptible to electrolytic action. The joining of another metal line, like copper, aluminum, or galvanized steel, will induce galvanic reactions although proper design considerations can minimize any adverse effects on the pipe. Cathodic monitoring stations may be required for ductile iron pipe installations, depending on local soils conditions.[14]

Product manufacturing summary--Ductile iron pipe is produced primarily from natural, domestic resources. The iron is mainly scrap and the coke is produced from domestic coal. Ductile iron pipe is cast centrifugally in 18 to 20 foot laying lengths using the deLavaud[27] process. Molds are lined with a mixture of thermosetting plastic and sand. Molten iron flows from a cupola to ladles to electric induction furnaces where the chemistry and temperature is adjusted. The quantity of molten metal introduced to the rotating mold controls the pipe thickness. The force generated by rotation holds the metal to the walls of the mold and forces lighter impurities to the inside surface of the pipe from which they can be cleaned. After the iron solidifies, the pipe is removed, annealed in ovens, cleaned, lined, and tested.

Pipe is cast from 3 to 54 inches in diameter in 18 to 20 foot lengths. The wall thickness is dependent upon the use and ranges from 0.25 inches for 3 inch diameter pipe to over 1 inch for 54 inch diameter pipe.

Asbestos industry sources[12] maintain that cast iron in pressure pipe consumes approximately eight times more total energy in manufacture than A/C pipe, with cast iron in sewer pipe consuming ten times the energy.

List of manufacturers--The primary manufacturers of ductile iron pipe are also members of the Ductile Iron Pipe Research Association. They include:

- American Cast Iron Pipe Company
  Birmingham, AL

- Atlantic States Cast Iron Pipe Company
  Phillipsburg, NJ

- Clow Corporation
  Oakbrook, IL

- McWane Cast Iron Pipe Company
  Birmingham, AL

- Pacific States Cast Iron Pipe Company
  Provo, UT

- U.S. Pipe and Foundry
  Birmingham, AL

Production volumes--Construction Review[18], a Department of Commerce publication, compiles monthly and yearly production figures for cast (ductile) iron pipe. They are given in Table 37.

TABLE 37. PRODUCTION VOLUMES FOR CAST IRON PIPE AND FITTINGS 1973-1978[18] (thousands of metric tons)

Year	Pressure	Soil
1973	1900	865
1974	1775	700
1975	1140	540
1976	1210	600
1977	1455	620
1978	1545	665

COST COMPARISON

Fiber Substitutes*

The most promising route for achieving the objective of a universal replacement for asbestos-cement is the development of glass-reinforced cement technology. With the increasing concern over the rising price of steel for reinforcement and the relatively high energy consumption for its manufacture,[11] glass fibers promise to offer an attractive alternative to both steel and asbestos as cement reinforcement.

During Farahar's studies,[11] which began in 1971, it was noted that although glass fiber was (at that time) more than six times more expensive per ton (compared to steel), it was theoretically capable of providing more than three times the usable tensile strength and its lower specific gravity, at 2.5, suggested that the cost per unit of tensile strength from glass fiber could be less than 2/3 that of steel.[11]

"E" glass fibers could be used with alumina cement to prevent the alkaline attack of regular Portland cement, but the high cost of materials (glass and cement) prohibits all but specialized use. The high-zirconia alkali-resistant glass fiber marketed by Cem-FIL Corp. or a similar product (e.g., a low-zirconia alkali-resistant glass fiber recently patented by

*It should be noted that it is the opinion of the AIA that current technology does not provide a fiber resistant to a cementitous environment, the A/C pipe manufacturing process, or its curing cycle.[1]

Johns-Manville Corporation)[34] seem to be the most likely candidates for glass fiber substitute development, although continued testing now indicates that products may lose strength with time and cannot be used for external or load-bearing applications.[1]

Product Substitutes

Table 38 shows some of the substitute products for A/C pipe may be economically competitive at initial cost comparisons. Other costs which should be determined include: excavation, foundation requirements, maintenance and installation costs including labor, and replacement schedule. Pipe prices are known to fluctuate widely depending upon proximity to manufacturing sites and market conditions.[1]

The rising cost of energy is playing an increasingly important part in the design and operation of municipal services (water and sewerage treatment). Ductile iron pipe can show significant savings not only in repair and replacement costs, but in the energy costs for pumping as well.[39]

Pipe sizing may also affect cost. Pipe sizes are given in terms of a nominal diameter. However, the internal diameter of a pipe is not the same as its nominal diameter. For instance, for a nominal diameter of 8 inches the corresponding internal diameters for various types of pipe are: Ductile iron - 8.39", A/C pipe - 7.85", PVC pipe - 8.044".[39] This shows ductile iron pipe to have a larger internal diameter than that of the other pipes, for the same nominal size. Thus, savings can be accrued since less energy is needed to pump water through an iron pipe, as opposed to pumping an equivalent volume of water through a non-iron pipe.

Other ferrous products including steel pipe can be viable substitutes for asbestos in specialty applications. Steel pipe is generally not used in water or sewer mains, but is employed in such uses as 40-foot diameter penstocks for dams and power plants. Steel pipe is considerably more expensive than A/C pipe but can be used as a very acceptable substitute.[14]

CURRENT TRENDS

Current trends in the pipe industry as a whole are difficult to judge. The demand for pipe is a function of new installations and replacement schedules. Current economic situations have led to a decrease in new housing starts and tightening financial situations in the nation's cities may lead to a decline in the rate of pipe replacement. The reduction in use of one type of pipe may be offset by an increase in another pipe type.

For instance, the production of V/C pipe appears to be decreasing. This may be attributed to several factors. The amount of all types of pipe may be reduced as the installation of new sewers is completed. Henceforth, the majority of new pipe would be needed only for replacement and maintenance. V/C pipes' share of the market may also be assumed by another type of pipe, probably plastic.

TABLE 38. PIPE PRICE ESTIMATES (Feb. 1980)

Material	Approximate price per foot (meter)[a]					
	Water			Sewer		
	8" (20 cm)	15" (38 cm)	24" (61 cm)	8" (20 cm)	15" (38 cm)	24" (61 cm)
Asbestos cement	4.50 (15.00)†	13.00 (43.30)† (16", 41 cm)	_[b]	3.00 (9.80)	10.00-14.00 (32.80-46.00)	20.00-21.00[c,d]† (82.00-98.50)
Ductile iron[e]	6.00 (19.75)	14.50 (47.50) (16", 41 cm)	24.50 (80.40)	6.00 (19.75)	14.50 (47.50) (16", 41 cm)	24.50 (80.50)
Vitrified clay[f]	-	-	-	2.50 (8.20)	9.75 (32.00)	29.00[d] (95.00)
Reinforced concrete	-	-	15.50[g] (51.00)*	-	6.00 (19.75)	11.50[d,h] (37.75)
Nonreinforced concrete[i]	-	10.50 (34.50)*	-	2.25 (7.40)	4.00 (13.00)	8.00[d] (26.25)
PVC[j]	4.25 (14.00)	9.75 (32.00) (12", 31cm)	-	2.75[k] (9.00)	10.50 (34.50) (18", 46 cm)[d]	16.00 (52.50) (18", 46cm)[d]
Fiberglass reinforced PVC[l]	6.25 (20.50)	12.25 (40.00) (12", 31 cm)	-	-	- -	-

[a]All prices rounded to nearest $.25.

[b]J.M. Transite[R] pipe - Coupling and rings with belled ends - 13' (4 meter) lengths.[35] For vinyl coating add: $.18/ft (0.60 meter) for 8" and $.32/ft (1.05 meters) for 16" (41 cm) pipe.

[c]J.M. Transite[R] pipe - Coupling and rings with belled ends - 13' (4 meter) lengths.[35]

[d]May be used as drainage pipe also. (All sizes).

[e]American Cast Iron Pipe - Ductile iron, cement liner, class 50, Pushon Fastite Coupling.[36]

[f]Bell & Spigot with rubber gasket, by the truckload.[37]

[g]Meets ASTM 7678, max price includes freight to furthest point. Suitable for sanitary sewers or pressure mains.[38]

[h]Includes freight for furthest point.[38]

[i]Mortar joint - length 4' (1.2 meters) for 8" (20 cm) and 6' (1.8 meters) for 15" (38 cm) and 24" (61 cm).[30]

[j]J.M. - SDR-26 (160 psi) for use in low pressure areas (no fire hydrants). ASTM D1748, 20' (6 meters) lengths. Much thicker walls are available.[31]

[k]J.M. - SDR-35, ASTM D30334. 12.5 ft (3.8 meter) lengths - sewer pipe.[31]

[l]J.M. - Permanstrain.[31]

*These are not pressure pipes.

†A.I.A comments.

NOTE: This table presents 1980 data which were the best available at time of issue of this report; change in market conditions to the current time period should be noted. In addition, prices may differ according to specific pipe required. Costs presented here should only serve for very general comparison purposes.

Plastic pipe growth in the rural market has reached a steady growth plateau and dominates this market. With the issuance of AWWA C-900, PVC can be expected to enter a high growth phase in the municipal market.[21] The plastic pipe industry expects to account for half of all pipe installed by 1985.[22]

The relatively high price and low availability of some products, such as carbon fiber substitute or Kevlar™ pipe substitute, is largely a function of the early development stage of these materials. As fiber substitutes improve and become more available and cost effective, the evolution of a new generation of asbestos-free pipes could occur. Changes in product demand are likely to influence availability and/or the manufacturer's expected return from the high capital expenditures associated with new product development, hence cost.

Overall, trends can be summed up from review of a June 1981 article in Americal City and County which focuses on a water main pipe survey (1981) and is titled "Cost, not material, shifting pipe choice". Ductile iron is quoted as being the predominant choice of pipe for water main use by 65 percent of the respondants, while A/C pipe claimed 15 percent and plastic pipe, 11 percent. The South Central and Western States prove to be the bastions of A/C pipe use, where there is a far greater proportion of A/C pipe in place than in other regions and also a greater percentage of 1980 pipe installed was A/C, although the preference did not run true in states such as Washington and Oregon. The South also continues to use A/C pipe prolifically (A/C got its start here in the postwar economy). It appears that, where A/C pipe is being installed, it is being laid in greater quantities, in areas of the country expanding their water systems. This accounts for the fact that 70 percent of the replies nationwide indicated that they installed ductile iron pipe last year, yet it made up only 38 percent of total mileage installed whereas A/C pipe made up 40 percent of the mileage installed yet was only installed by 23 percent of the responding utilities. A/C pipe, according to South Central and Western respondants, is chosen over ductile iron due to the fact that, in smaller diameters, it is as much as 50 percent less expensive per foot. They also noted that it was easier to tap than ductile iron, which was much more competitive at larger diameters due to strength characteristics. A/C pipe was suggested as the pipe to specify up to 12 inches, with ductile iron required in the larger sizes. The South Central and Western respondants felt A/C pipe was necessary due to soil electrolytic conditions there which tend to corrode iron pipe.[5]

In general, the trend is towards larger diameter pipe (14 inches or greater) to replace hastily installed undersized mains. With labor costs currently the major factor, pipe costs are a bit less important such that larger diameters may be laid. In addition, the survey revealed that 1981 estimates indicate that, in this year, utilities will install only a little more pipe than in 1980. Replacement, not expansion may be the case in many areas (replacements accounted for approximately 21 percent of all pipe installed in 1980-81).[5]

Data breaking down use of pipe by region points to the Northeast as putting in the smallest number of new pipe, with a large proportion as replacement. They also reported the smallest percentage of plastic pipe in place and installed the smallest percentage of it in 1980. The Southeast, by contrast, reported the largest percentage of in-place and 1980 installed plastic pipe, and showed the strongest preference for plastic. This region has the largest percentage of new pipe. The North Central region reported the highest proportion of cast or ductile iron in place and the smallest proportion of A/C pipe both in-place and installed in 1980. North Central prefers iron pipe over A/C and plastic. The South Central states put in more A/C pipe and much less iron in 1980, and show the weakest preference for iron and the strongest for reinforced concrete. The Great Plains fall between, with only a small amount of pipe being installed, and that consisting of A/C and plastic pipe. The West did not use much iron compared to the others and more A/C and steel are found in the ground there. The West showed the strongest preference for A/C pipe for 1981 construction.[5]

Overall, the survey reflected the influence of budgetary constraints on U.S. water systems, and indicated that the predicted growth of plastic pipe may still be yet to come.[5]

CONCLUSION

The use of substitutes for asbestos cement pipe in new construction or for replacement service is covered extensively in the trends section, especially for water pipe uses. Available substitutes include:

- ductile iron
- concrete pipe
- glass reinforced concrete pipe
- plastic pipe
- vitrified clay pipe

For intermediate size range pipe diameters (6 to 24 inches), asbestos cement pipe is most commonly used, although some regions prefer the use of iron pipe when diameter exceeds 12 inches.[5] Depending on the requirements of each individual case, the alternatives listed offer strong competition, especially outside of this range. For instance, plastic pipe, vitrified clay pipe, and iron pipe are all applicable in the small pipe diameter range. For diameters greater than 24 inches and heads higher than 200 feet, the substitute pipes compare very favorably or are more economical than asbestos cement pipe. In addition, glass reinforced pipe, though not currently produced in the United States, might possibly find use as a direct substitute for A/C pipe, even in the intermediate range pipe size. This might occur in those cases where high strength, resistance to corrosion, and low price are all simultaneously required.

In addition to the diameter size range, cetain other properties show themselves to be important in pipe selection for certain uses. Ductile iron is more suited for situations involving shock loads, vibration, and ground movement in general. For nonpressure applications, vitrified clay pipe is less expensive. Another possible advantage of substitutes may be the small number of asbestos cement pipe manufacturing facilities which lead to greater transportation costs for this product than those for pipes manufactured near to the point of use.

It should be noted that none of the alternative products can substitute for asbestos in all of the uses that it has now become established in. However, as a group, they can meet all of the technical requirements placed on A/C pipe. As both the water and sewer pipe markets appear to be in a state of flux in varying regions due to different preferences, soils, and the general state of the economy, this area is probably one in which significant change could occur in the future.

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9. Telecon. Sharon Jackson, CAPCO, Ragland, AL, (205) 472-2111, with Anne Duffy/Nancy Krusell, GCA Corporation, GCA/Technology Division, 4/15/81 and 4/22/81, respectively.

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13. Preuit, Russell. American Concrete Pipe Association, 703/821-1990. Personal communication with Ed Mussler, GCA Corporation. February 11, 1980. Notebook 3. Call 17.

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26. Telecon. Caldwell, Phil. Cem-FIL Corporation, 615/883-7563, with Ed Mussler, GCA Corporation. January 3, 1980. Notebook 3. Call 7.

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SECTION 5

ASBESTOS-CEMENT SHEET

ASBESTOS PRODUCT

Special Qualities

Asbestos is used as a reinforcing material in cement sheet products because of its high tensile strength, flexibility, resistance to heat, chemical inertness, and large aspect ratio (ratio of length to diameter).[1] Asbestos fiber in cement sheet adds to the strength, stiffness, and toughness of the material, resulting in a product that is rigid, durable, noncombustible, resistant to heat, weather, and attack by corrosive chemicals, as well as being stable. A significant feature of the asbestos-cement (A/C) sheet is that it has sufficient wet strength to be molded into complex shapes at the end of the production process.[1]

This section addresses four product categories of A/C sheet:

- flat sheet
- corrugated sheet
- siding shingles
- roofing shingles

Although these categories reflect differences between the products, they can be readily covered in one section because the composition and manufacturing processes used are the same for each of these products.

Product Composition

Asbestos-cement sheet is made from a mixture of Portland cement and asbestos fiber. Sometimes an additional fraction of finely ground inert filler and pigment may be included.[2] Sheets contain between 15 and 40 percent asbestos fiber. In 1980, the Bureau of Mines reports that 7,900* metric tons of chrysotile asbestos were used in A/C sheet production, with most chrysotile of grades 6 and 7. One hundred metric tons of grade 5 was also used. No other asbestos types were used in A/C sheet production.[3]

*Down from 35,800 metric tons in 1978.[4]

Uses and Applications

Today the use of A/C sheet is narrowing toward applications where its special properties of durability and heat and chemical resistance are not duplicated by other sheet materials.[2]

Flat A/C sheet has been used in the construction industry as soffit material (covering the underside of structural components), roof deck, wall linings in factories and agricultural buildings, industrial partitions, fire-resistant walls, curtain walls, and decorative paneling in both exterior and interior applications. It is also used as cooling tower fill sheets, laboratory table tops and fume hoods, electrical equipment mounting panels, and as a component of vaults, ovens, safes, heaters, and boilers. It is found in schools as well as residential construction.

Asphalt-impregnated flat sheet is used for switchboards, controller plates, and as an insulating spacer in a wide variety of electrical apparatus.

Corrugated A/C sheet is used primarily in industrial and agricultural applications, serving as siding and roofing for factories, warehouses, and agricultural buildings. It is also used as a lining for waterways, canal bulkheads, and as end paneling for cooling towers.[5]

Flat sheet can be textured and cut for special use as siding shingles and as roofing shingles. These shingles are extremely durable, and are available in a range of styles and colors.[6] Another advantage of A/C shingles is their U.L. Class A fire rating.

Product Manufacturing Summary

Manufacturing Process --

A/C sheet is manufactured by using a dry, a wet, or a wet mechanical process.

Dry Process -- In the dry process, plastic bags containing asbestos fiber are slit and dumped into a mixer where cement and filler are added. The resulting dry mixture is uniformly distributed onto a flat conveyor belt, sprayed with water, then compressed by steel rolls to the desired thickness. The moving sheet is cut into individual sheets which are removed from the conveyor and steam cured in an autoclave.[7] Cut off saws using diamond or carborundum wheels are then used to trim the cured sheet to the desired size or into shingles.[8]

Wet Process -- The wet process begins with the mixing of asbestos fiber, cement, and additives as in the dry process. Water is added to the dry mixture and the mix is put in a form where excess water is squeezed out by a press. After the sheets are formed one at a time in the press, they are stacked and air cured for 3 to 4 days, at which time they become rigid. The sheets may then be steam cured to speed up the curing process.[9]

Wet-mechanical process--Used in both A/C sheet and A/C pipe production, the wet-mechanical process is similar in principle to some papermaking processes. Asbestos fiber is combined with cement, silica, and other filler material in a dry mixer and then transferred to a wet mixer. There, underflow solids and water from the saveall (material being recycled from previous operations) are added to form a slurry that is pumped to cylinder vats for deposition onto one or more screen cylinders. Water is removed from the underside of the slurry layer through fine wire mesh screening around the circumferential surface of each cylinder.[10]

A layer of A/C material from 0.02 to 0.10 inch (0.05 to 0.25 cm) thick is produced by the above process. This layer is transferred to an endless felt conveyor so a mat can be built up. More water is removed from the matted material by a vacuum box prior to transfer of the material to a mandrel, or accumulator roll. The mandrel winds the mat into a layer of the desired thickness, and pressure rollers bond the mat to stock already deposited on the mandrel or roll and help remove additional water as well. As the layer of A/C material builds up to the desired thickness, it is cut and peeled away. The resultant sheet can be shaped or molded either by hand or by press roller, and can then be cut into the desired sheet size. Any of the four product types can be made by this process.[10]

Manufacturers use methods such as cylinder showers to clean both the cylinder screen and the felt conveyor, insuring satisfactory operation of the process. Cement and fiber particles are washed out of the holes to prevent "blinding."[10]

Name and Number of Manufacturers--

There are four major companies currently manufacturing asbestos-cement sheet products. They are listed in Table 39.

Production Volumes--

Exact production volumes are not known, although it is known that 7,900 metric tons of asbestos was used in 1980 for the production of all types of A/C sheet products.[3]

TABLE 39. MAJOR MANUFACTURERS OF ASBESTOS-CEMENT SHEET PRODUCTS[6,7,11]

Manufacturer	Location	A/C products
Johns-Manville	Waukegan, IL	Flat sheet
	Nashua, NH	Flat sheet
International Building Products, Inc.*	New Orleans, LA	Flat sheet, corrugated sheet, siding shingles
Nicolet, Inc.	Ambler, PA	Flat sheet
Supradur Mfg. Corporation	Wind Gap, PA	Roofing and siding shingles.

*This used to be called Gold Bond Building Products, a Division of National Gypsum. It was bought out by the new owners this spring. (Asbestos Magazine, March 1981. p. 32).

SUBSTITUTE PRODUCTS

Methodology

Search Strategy--

Information about A/C sheet products and suitable substitutes was obtained from special available literature, telephone conversations, and manufacturer's product specification information.

Summary of Contacts--

Asbestos-Cement Products

- Edmund M. Fenner
  Director of Environmental Services
  Johns-Manville Corp.
  Denver, CO (303) 979-1000

- Richard Mahoney
  Gold Bond Building Products
  Charlotte, NC (704) 365-0950

- Mr. Kaufman, Assistant Manager
  GAF Corporation
  South Bound Brook, NJ (201) 356-3000

- Mrs. Smith, Personnel Secretary
  GAF Corporation
  St. Louis, MO (314) 867-7800

- Judy Gardner
  GAF Corporation
  Mobile, AL (205) 478-6311

- Bob Muderspach
  Celotex Corporation
  Lockland, OH (513) 821-3000

- Kurt Schwarz, Senior Vice-President
  Supradur Mfg. Corp.
  New York, NY (212) 697-1160

- Sales Secretary
  Nicolet, Inc.
  Ambler, PA (215) 646-4000

Substitute Materials (Flat Sheet)

- John Jones
  Cem-FIL Corp.
  Nashville, TN (615) 883-7563

- Bill Lewis
  GRC Products, Inc.
  Schertz, TX (512) 651-6773

- Clare Swanson, Manager of New Applications Division
  Conwed Corporation
  St. Paul, MN (612) 221-1188

- George Alm
  International Housing Corp.
  Sacramento, CA (916) 456-5343

- Bob Baker
  W.B. Arnold and Company
  West Caldwell, NJ (201) 575-0880

- Craig Hamling, Sales Manager
  Zircar Products, Inc.
  Florida, NY (914) 651-4481

- Art McGowen
  Masonite Corp.
  Laurel, MI (601) 425-3611

Substitute Materials (Corrugated Sheet)

- John Jones
  Cem-FIL Corp.
  Nashville, TN (615) 883-7563

- William Tyler
  Aluminum Company of America
  Pittsburgh, PA (412) 553-3922

Substitute Materials (Siding Shingles)

- Art McGowen
  Masonite Corp.
  Laurel, MI (601) 425-3611

- Dave Horner
  Publishers Forest Products/Cladwood Division
  Portland, OR (503) 775-6711

Substitute Materials (Roofing Shingles)

- Jayne Porter, Marketing Assistant
  Monier Company
  Orange, CA (714) 538-8822

Substitute Materials (Fibers)

- Jim Ford
  Owens-Corning Fiberglass Corp.
  Toledo, OH (419) 248-7321

- Dr. Chuck Chaille
  Babcock & Wilcox Refractories Division
  Augusta, GA (404) 798-8000

- Joe Volk
  Gold Bond Building Products/Research Division
  Buffalo, NY (716) 873-9750

There are two approaches to replacing asbestos in asbestos-cement sheet. Either the asbestos fiber can be replaced by a different kind of fiber reinforcement, or an entirely different sheet material can be substituted for the A/C sheet. In any application the qualities or characteristics required of a sheet material must be considered. Quite often all of the qualities of A/C sheet are not demanded of a material for a particular application. Consequently, the suitability and feasibility of a substitute either for the asbestos fiber or for the whole A/C sheet will be determined to an extent by the demands of the application in question.

Fiber Substitutes

The most promising substitute fibers for use in place of asbestos in cement sheet are the specially treated wood fibers used in the cement/wood board mentioned previously, and alkali-resistant glass used in GRC.

A listing of fibers and their performance characteristics appears in Table 40.

Product Substitutes

This section includes both the special qualities and the uses and applications of substitute products for:

- Flat sheet
- Corrugated sheet
- Siding shingles, and
- Roofing shingles

Substitutes for Flat Sheets--

Several cement sheet products containing nonasbestos reinforcing material were identified as potential A/C sheet substitutes. At least three of these, a cement/wood board, a glass fiber-reinforced cement sheet, and a plastic-reinforced concrete sheet, compare favorably with A/C sheet with respect to density, strength, corrosion and weather resistance, noncombustibility, and workability.[5,12] Others should be useful in more specialized applications.

TABLE 40. PERFORMANCE OF POSSIBLE FIBER SUBSTITUTES FOR ASBESTOS IN CEMENT SHEET

Fiber	Performance and Comments
Alkali-resistant glass	Can be used in Portland cement; better impact resistance than asbestos; product loses strength with time; commercial feasible.[13]
Mineralized wood	Lightweight; not as heat resistant as asbestos; superior impact resistance; abundant supply available; commercially competitive.[12]
Steel fibers	Good reinforcement; high impact strength; problems with processing and machining; problems with rust, less expensive than A/C sheet.[14]
Mineral wool	Weak product; does not work well in cement.
Carbon fibers	Increases modular strength of cement sheet; is resistant to alkali attack; no increase in impact strength; very expensive.
Nylon	Provides impact strength; lacks reinforcement.
Ceramic fibers	No success to date; work is continuing.[15]

Glass fiber-reinforced cement (GRC) sheet--GRC is presently finding use in coffin liners, fabrication of fume hoods, cooling towers, permanent formwork for bridge construction, as fascia and soffit panel, electrical closet liner, fireproof partitions, wall panels, permanent form boards, storage sheds and garages, wall liner in factories, decorative trim, and even as road signs and behind woodstoves if it is U.L. rated.[13,16,17] It is now available in commercial quantities in a wide range of thicknesses, from 1/8-inch to 4-inch thickness, and in basic 4 feet by 8 feet sheets. Corrugated sheets are available in either the standard U.S. 4.2 corrugation or specialized corrugations such as the type being developed for bulkhead construction.[18]

GRC, when compared to A/C sheet, exhibits superior overall strength characteristics, especially in resisting damage from impacts (it is more impact resistant than asbestos cement over a 28-day period).[18] A/C sheet tends to crack or break when impacted, while GRC will fail only at the point where it is struck. GRC sheets have been found to possess an initial strength of 4,000 psi, which stabilizes to 2,000 psi, after 4 to 5 years. This has been improved to 3,000 psi in new GRC. Industry is debating whether GRC weakens to the strength of unreinforced cement over time. The asbestos industry claims that GRC, with the alkali resistant glass, looses impact resistance and strength with time.[19] GRC sheet is noncombustible, weatherproof, rot proof and corrosion-resistant, although the cement itself may break down eventually in highly corrosive environments.[17] It can be drilled and nailed as well as A/C sheet, and can also be painted, screwed, glued or bolted. Recent improvements have been made in the overall strength of the sheet by treating the glass fiber with a coating that enhances bonding between the fiber and the cement.[7] GRC is lightweight and the raw materials needed for manufacture are readily available, along with exact, accurate processing techniques.[16] GRC satisfies ASTM-136 and ASTM-E84, and, by changing the density of GRC, thermal conductivity can be improved.[18] However, it is not suitable for all of the corrosion and heat resistant applications that A/C sheet is used for.[19]

On the negative side, because GRC has a much lower percentage of fiber reinforcement than A/C sheet, it shows greater strength loss at 316°C (600°F), the maximum recommended service temperature for both sheets. Therefore, it is considered to be less heat-resistant than A/C sheet. Where GRC is exposed for a short duration with a low rate of temperature rise it probably equals A/C but with prolonged or high temperature applications such as furnaces and ovens, the GRC with portland cement will not perform satisfactorily. However, there may be a possibility of using different cements (such as refractory types) to provide a GRC for this application. Tests on this are presently underway.[18]

GRC does not machine as well as A/C sheet. When cut, the edge tends to chip, making it unattractive for uses such as lab tables, where appearance is important. About the only nonasbestos substitute for lab tables is slate, which is expensive. Tests have shown that GRC suffers about a 30 percent loss of strength (decrease in value of modulus of rupture) over a period of 30 years, but designing with a proper safety factor could prevent this from being a serious problem.[7,20] As GRC has been marketed for 12 years, production and marketing technology are well understood, and a wide variety of processes are now available for high volume production. In addition, work is now progressing towards production of GRC sheets on standard A/C plant equipment, although at present, the product (termed hot check made) does not compare in performance with A/C or with the sprayed GRC. However, it does machine easier and thus has been adopted by a couple of companies for fume hood construction for chemical laboratories and industrial plants.[17]

Cement/wood board--which the manufacturer claims combines the best properties of wood and cement, has been in use in Europe and the Middle East as an all-purpose building board for a number of years.[12] The cement/wood board has been rated as noncombustible and is said by some to be virtually impervious to the influence of any weather condition. However, some argue that cement/wood boards manufactured in Europe during World War II show poor weather resistance. Further, they may be susceptible to excessive expansion due to absorption of water by the wood component during wet weather. This may make its suitability as exterior cladding questionable, although this tendency could be combatted through resin saturation, painting, special fasteners to allow expansion, or incorporation of mica to reduce expansion.[17] Its modulus of rupture and resistance to impact are greater than asbestos-cement board, and unlike A/C sheet, it can be glued and laminated. Cement/wood board has good heat and sound insulating properties, is easily machined, and has surfaces suitable for multipurpose treatment. It also has good elastic properties under a static load.[12] Its weathering characteristics are reported to be similar to those of marine plywood.[17]

Applications of the cement/wood board in construction are numerous, including use as external claddings, sound attenuating walls, balcony parapets and floors, walls separating gardens, partitions, noncombustible wall and ceiling linings, roof soffits, roof underlayment (notably in countries with low supplies of wood), refuse shafts, ceilings, fascia, and lining for farm stables. It has also been used to build prefabricated houses and pavilions.[12] It is often used for interior applications because it is light and flexible. It is similar to masonite except that it has a portland cement binder rather than a resin binder. When used as a fill in cooling towers, it may ruin the efficiency of the tower if it warped. Cement-wood board used in one northwest U.S. cooling tower is reportedly being replaced by A/C sheet.[17]

Polypropylene layered cement sheet--A relatively new A/C sheet substitute, this product is comparable to A/C sheet in its resistance to freezing, thawing, combustibility, and aging. Because it is a type of plastic cement board, it is flexible and will not fracture as easily as A/C sheet. It is used for construction of cooling towers, buildings, and other large structures.[21]

Alumina-Sheet®--An alumina-silica product made by Zircar Products, Inc., this exceeds A/C sheet's resistance to heat. It is available in either a moldable or rigid form and is being used as an insulator in induction core applications, as a molten metal transport trough, and as a material for repairing holes in furnaces. The possibility of using the material for laboratory table tops exists as well. Alumina-Sheet is not as strong as A/C sheet, but has an upper temperature limit several times greater. It is also very tough and abrasion resistant.[22]

Benelex®--Benelex is a laminated hardboard product produced by Masonite Corporation, Laurel, Mississippi. It is readily available and is used as laboratory table tops, for floors of locomotives and cabooses, and as a phase barrier in electrical switchgear and control apparatus.[23] It is not intended for uses requiring resistance to weather or high temperature. Laminated hardboard such as Benelex could replace ebonized asbestos in many electrical applications. A comparison of selected properties is listed in Table 41.

TABLE 41. COMPARISON OF EBONIZED A/C WITH HARDBOARD[24,25]

Property	Asbestos Ebony®	Benelex®
Density, kg/m^3 (lbs/ft^3)	1842 (115)	1394 (87)
Rockwell hardness (M scale)	23-85	90
Maximum operating temp. ^oC (^oF)	120 (250)	90 (194)
Arc resistance (seconds)	125	85
Insulation resistance (megohms)	-	85.5

Forton--Forton combines GRC with a polymer modified cement matrix. The polymer adds toughness to the matrix, improves compatibility, and supresses attack by strongly alkaline hydration products. This technology was developed by DSM, a Netherland based company with interests in chemicals and building materials. Fibers used in the U.S. come from PPG's plant in North Carolina.*

*Information from a letter dated Nov. 17, 1981 to Mr. James Bulman, U.S.EPA, from Mr. Hiram R. Ball, Jr., Director, North American Operations of Forton. Product literature was included.

Monolux®--Monolux is an asbestos-free, noncombustible industrial insulating board, available from W. B. Arnold and Company. Manufactured by Cape Boards and Panels Limited (Uxbridge, England), it is rigid, nonfriable, durable, inert, and resistant to attack by insects and vermin. The board is noncaustic, unaffected by dilute acids and alkalis, brine, chlorine, or volatile solvents. It will not disintegrate, warp, or swell under prolonged immersion in water, and it is more resistant to heat than A/C sheet. It can be used to make small ovens and dryers, high temperature ducts, oven shelves and interleaves, and as secondary insulation for furnaces and kilns.[26]

Table 42 lists cement sheet products and their characteristics for comparison with A/C sheet.

Other--Materials such as masonry, galvanized steel, aluminum sheet, fiberglass-reinforced plastics (especially in cooling towers and even industrial skylights), and wood can compete with A/C sheet in various applications.[17] A product such as fiberglass-reinforced plastic is thought to be stronger than A/C sheet, but flexes more. Polyurethane sandwich panel has also been suggested as a substitute and is apparently used in housing projects in the southern U.S. for both interior and exterior walls, covered with an aluminum skin. However, this product may have extremely toxic byproducts upon combustion as the urethane foam might be exposed if the metal sandwich protector was to fall off.[17] Alcoa also uses asbestos-free marionite as a substitute to asbestos-containing marionite (except in the largest diameter mold sizes); however, this product made by Marietta Resources, Inc., may degrade more quickly than its asbestos counterpart.[30] In this case, suzorite mica replaces the asbestos fiber. Wollastonite is also used in some areas; it is reported to be used in Denmark for example, as a substitute to A/C sheet, but it is not considered to have the properties required of asbestos at this date. Wollastonite tends to act like a ceramic.[17]

Substitutes for Corrugated Sheet--

Corrugated glass-reinforced concrete is already being purchased by industry to replace damaged A/C panels on buildings. Recent advances in the glass-reinforcing fiber have improved the wet strength of GRC which has made the manufacturer more confident of its performance in wet as well as dry applications. Such uses include canal bulkheads, waterway liners, and as end panels on cooling towers.[5]

Depending upon the application, products such as aluminum, galvanized steel, masonry, or reinforced plastics can be used in place of corrugated A/C sheet.

Substitutes for Siding Shingles--

Hardboard siding shingles and paneling are available in styles that are comparable to certain A/C siding shingles. They are very durable, easily worked, and attractive.[31,32]

Other siding products popular in the United States are wood, wood shingles, aluminum, stucco or concrete block, and brick. These products may or may not be suitable as substitutes for A/C shingles, depending upon the preference of the customer and the requirements of the application.

TABLE 42. CEMENT SHEET PRODUCT COMPARISON[5,12,22,26,27-29]

Product	Density kg/m^3 (lb/ft^3)	Maximum service temperature °C (°F)	Modulus of rupture kPa (psi)	Young's modulus x 10^6 kPa (psi)	Tensile strength kPa (psi)	Compressive strength kPa (psi)	Impact strength Nmm/mm^2 (ft-lb/in^2)
J/M Transite® (A/C)	1,762 (110)	316 (600)	27,580 (4,000)	10.34 (1.5)	9,650 (1,400)	82,740 (12,000)	4.8 (2)
J/M Flexboard® (A/C)	1,602 (100)	316 (600)	31,030 (4,500)	13.8 (2.0)	12,410 (1,800)	96,500 (14,000)	--
Cem-FIL 125/S (High density GRC)	2,000 (125)	260 (500)	27,580 (4,000)	13.8 (2.0)	11,030 (1,600)	68,950 (10,000)	24.0 (10)
Cem-FIL TAC board (Low density GRC)	1,300 (81)	--	--	--	--	--	--
Cement/wood board	1,200 (75)	--	--	--	--	--	--
Monolux® 500	768 (48)	482 (900)	--	20.7 (3.0)	--	--	--
Alumina-Sheet®	1280 - 1440 (80 - 90)	1,482 (2,700)	6,895 (1,000)	--	--	41,370 (6,000)	--

Substitutes for Roofing Shingles--

Several asbestos-free roofing products are available which have a U.L. Class A fire rating (the equivalent of A/C shingles). Unreinforced cement shingles are available in Mediterranean and shake styles. The roof looks neat and precise and is able to withstand all climatic conditions. No underlayment is needed in mild climates, and the roof comes with a 50-year warranty.[33] Asphalt shingles made from a fiberglass base are available. A roof using these shingles uses two layers of shingles for a thicker, random look, and is fire-resistant. This type of shingle is made by Johns-Manville and Lunday-Thagard. An imitation wood shake called CeDurShake® is available from Trim Products. It is light weight and has a foam backing that acts as an insulator.[34]

Substitute Product Manufacturing Summary

Product Composition and Manufacturing--

Cement/wood board--is composed of specially treated wood fibers bound by Portland cement. Wood fibers are treated with various chemicals including ammonium chloride, sodium and sodium silicate to remove the resins, acids, and sugars in a process called "mineralization."[12] Wet fibers are mixed with Portland cement and deposited as a mat on individual cauls on a moving belt. A saw or shear separates the continuous mat into mats whose length corresponds to the length of the supporting caul. Each caul with its mat of fiber and cement is transferred to a press where pressure is applied until the cement has set. A series of mats may be stacked and pressure applied to the stack by means of retaining clamps for a period of time. When the pressure is released, the boards are dried.[12]

Glass fiber-reinforced cement sheet--is basically a composite of a hydraulic binder (that is, one which required the use of water in order to get it to set) and materials such as Portland cement reinforced with alkali resistant glass fibers which are randomly distributed throughout the board. GRC may or may not require the use of other fillers or additives. If required, inert fillers such as fine sand or fine silica sand or limestone fines (marble dust) may be used. Glass fibers are specially formulated to resist the alkaline attack of the Portland cement. They are typically 1.3 to 3.8 centimeters long and 13 microns in diameter. These fibers constitute about 5 percent of the weight of the sheet.[27] Additionally, a very small percentage of wood fiber is used in Cem-FIL Corporation's lightweight TAC® board. Like asbestos cement, GRC is not just one material but instead a whole spectrum of different materials, each with performance characteristics varying with the type of cement used. For example, Portland cement dehydrates at temperatures above 260-316°C, whereas high-aluminum or refractory cement has been tested to 538°C and is good at 316°C, which is similar to J/M asbestos transite board. Performance can also be affected by the glass fiber content, the type and quantity of any filler or additive or other mixture that is used, and particularly the resulting density of the composite.[18]

GRC sheet can be made by two methods. In the spray-up process used by Cem-FIL, a gun is used which simultaneously sprays a cement slurry and chops up a continuous roving of glass fiber into a predetermined length. This material is sprayed into a form on a vacuum dewatering bed which draws off the excess water. The sheet produced can be molded, or stacked and cured.[27] Another method of production involves the use of a continuous felt conveyor belt upon which the cement slurry and chopped glass fibers are sprayed. Excess water is removed by vacuum boxes attached to the underside of the conveyor belt.[4] The mat of cement sheet is cut and removed at the end of the conveyor, then stacked and cured. Corrugated sheets are made by placing the wet sheet on a form for shaping before curing begins. Sheets are normally air cured for 28 days.[13] GRC sheets have been found to possess an initial strength of 4000 psi which stabilizes to 2000 psi after 4 to 5 years. This has been improved to 3000 psi in new GRC.[17] Industry is debating whether GRC weakens the strength of unreinforced cement over time.

Monolux--is made of calcium silicate cement and selected filler reinforced with alkali-resistant glass and wood fibers.[26] No information about its manufacture was made known.

Alumina-Sheet--consists of 92 percent aluminum oxide and 8 percent silica fibers.[22] Nothing was learned about manufacturing methods as the patent is still outstanding.

Benelex--is made from wood. Wood chips are first reduced to fibers by a steam explosion process. The unwanted elements in the wood are driven off, leaving cellulose fibers and lignin, a natural bonding agent. The fiber is refined and then formed into panels on a moving screen. These panels are placed in steam heated, high pressure presses where the fibers and lignin are welded together into a dense, hard material.[25]

Cladwood®--is a medium-density particleboard covered by a refined wood overlay.[25] Hardboard siding such as that manufactured by Masonite Corporation consists of wood fibers combined with natural bonding agents under high pressure.[31] No information about the manufacture of these or other siding products was obtained.

Monier Company's Monray Roof Tile--is manufactured on a conveyor-type process from Portland cement, sand and water. A continuous cement mat is formed on a plastic conveyor, sprayed with the desired color, then cut into individual tiles at the end. These tiles are cured at 66°C (150°F) for 24 hours, then sprayed with a sealer to prevent salts from rising.[35]

CeDurShake--is made of fiberglass-reinforced polyester resin.[34]

Forton--contains a sand/cement ratio of 0.2 m/m; water/cement ratio of 0.3 m/m; polymer fraction of 0.15 v/v; and glass fraction of 0.05 v/v.

Other--Fiberglass felt is used as the base mat of the new asphalt shingles made by Johns-Manville and Lunday-Thagard.[34] Other manufacturers of this product include: GAF, Celotex, CertainTeed, Bird & Son, and Owens Corning.[11]

Although patent status is unsure, Australian Consolidated Industries have filed for an invention based on clay reinforced with glass fiber. Findings indicate that the clay matrix does not have the high degree of alkalinity of cement, such that there is no need to use an alkali-resistant fiber and instead E-glass fiber is quite satisfactory. Properties substantially conform to basic requirements of low raw material costs, ready availability of raw material, ability to adapt to rapid mass production techniques, physical and chemical stability and modulus of rupture, density and other physical properties similar to A/C sheet. Ingredients include glass fiber (generally 5-15 percent), bentonite, ball clays, fillers, fluxes, deflocculants, clay and water. Termed glass-reinforced stabilized clay (GRSC), not only can this product meet many A/C product needs, but refutedly, it could possibly be used for such items as window frames and sills, floor planks, pottery ware and outdoor furniture.[36]

Still another idea for an A/C sheet substitute, this time in the form of roofing sheets, comes from the British Intermediate Technology Industrial Services (ITIS) in Rugby, England. Using ingredients like Portland cement, sand and natural fibers including human hair cuttings, common grasses, crop waste from banana, oil palm and coconut plantations or more costly artificial fibers, developing countries are currently testing out such products to determine such factors as tensile strength, interaction of the cement and fibers, and local weathering ability. The production process is kept as simple as possible for low cost and unskilled labor. Production equipment is fabricated on-the-spot out of basic components. Reportedly, with good arrangements, it takes a two-man project team 15 to 20 days to bring about the construction and operation of a complete sheetmaking unit producing up to 100 sheets a week.[36]

Name and Number of Manufacturers--

Glass fiber-reinforced cement flat sheet is made by Cem-FIL Corporation in Nashville, TN.* In addition, 60 other companies, such as Concrete Design Specialties of East St. Paul, MN, make GRC for other specific applications (here, for use behind wood stoves), some of which would not directly substitute for A/C sheet.[17] The International Housing Corporation (Sacramento, CA) is planning to build the first plant in the United States to manufacture cement/wood board. Monolux is made in England by Cape Boards and Panels, Ltd. (Uxbridge) and is marketed in the U.S. by W. B. Arnold and Company. Zircar Products, Inc. (Florida, NY) is the manufacturer of high temperature Alumina-Sheet. Benelex is manufactured by the Masonite Corporation (Laurel, MI). Other flat sheet products such as metal, wood and concrete are available from well-known large manufacturers.

Corrugated glass fiber-reinforced cement sheet is available from the Cem-FIL Corporation (Nashville, TN). Other possible substitutes for corrugated A/C sheet as ordinary siding are made by major steel, aluminum and fiberglass companies.

There are many manufacturers of a variety of siding products. Hardboard siding shingles and paneling are known to be made by the Masonite Corporation (Chicago, IL) and Publishers Forest Products, Inc. (Portland, OR).

Unreinforced cement roofing tiles called Monray® Roof Tiles are made by the Monier Company (Orange, CA). Fiberglass-based asphalt shingles are currently available from Johns-Manville Corp. (Denver, CO) and Lunday-Thagard (Southgate, CA) and will be available from most major asphalt roofing manufacturers by the end of the year.[34] CeDurShake® is made by Trim Products (Torrance, CA). Table 43 presents a summary of substitute manufacturers and products.

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*GRC Products, Inc. of Schertz, TX once made GRC sheet but has since gone out of business.[11,37]

TABLE 43. SUBSTITUTE PRODUCT MANUFACTURERS[5,12,13,22,23,26,32-34]

Manufacturer	Location	Product and name
Cem-FIL Corporation	Nashville, TN	Flat and corrugated glass-reinforced cement sheet (125S, TACboard®)
Forton	Dallas, TX*	Forton-GRC plus polymer
International Housing Corporation	Sacramento, CA	Cement/wood board flat sheets
Cape Boards and Panels, Limited	Uxbridge, U.K.	Calcium silicate cement sheet (Monolux®)
Zircar Products, Inc.	Florida, NY	High-temperature alumina-silica sheet (Alumina-Sheet®)
Masonite Corporation	Laurel, MI Chicago, IL	High-density wood laminate (Benelex®) Hardboard siding shingles and paneling
Publishers Forest Products, Inc.	Portland, OR	Hardboard siding shingles and paneling (Cladwood®)
Monier Company	Orange, CA	Unreinforced cement roof tiles (Monray® Roof Tiles)
Johns-Manville Corporation	Denver, CO	Fiberglass-reinforced asphalt shingles
Lunday-Thagard	Southgate, CA	Fiberglass-reinforced asphalt shingles
Trim Products	Torrance, CA	Fiberglass-reinforced polyester shingles (CeDurShake®)

*Currently, Forton has plants and warehouses in New Jersey and Texas, where all the materials are stored. The polymer compound will be made in the Dallas area, with the possiblity of producing it in five other U.S.locations as the market develops. Fibers are provided from PPG in North Carolina. (Forton letter of Nov. 17, 1981 to James Bulman, U.S. EPA.)

Fiber reinforcing materials for cement sheet are being investigated by several companies, including Babcock & Wilcox (Augusta, GA), Conwed Corp. (St. Paul, MN), and Gold Bond Building Products (Buffalo, NY). No information about actual production has been released; Conwed has, however, just received a patent for their product.

GAF Corp. filed a patent in 1975 for a cotton-cement sheet product consisting of cement, cotton fiber, inorganic filler, silica and water.[38] There is also a Swiss patent, filed in 1978, for a fiber reinforced cement material using short polyvinyl alcohol fibers.[39]

Production Volumes--

The International Housing Corporation has not yet begun to produce cement/wood board, but plans to manufacture 11,150 m^2/day (120,000 ft^2/day) when production begins.[40]

GRC Products, Inc. is currently able to manufacture 557,700 to 929,500 m^2 (6 to 10 million ft^2) of flat sheet per year.[13] Cem-FIL Corp. has not yet begun to produce large quantities of GRC, but currently manufacturers to fill orders.[18]

No other information on production volumes is known. However, plywood, particleboard, hardboard, steel, fiberglass, and concrete are fairly abundant.

COST COMPARISON

Costs are broken down into sheet categories for comparison, including flat sheets, corrugated sheets, siding shingles and roofing shingles.

Flat Sheet Substitutes

According to a product cost comparison between cement/board and A/C sheet done by the cement/wood board manufacturer, the most expensive mill price of cement/wood board is less than half the cost of J/M Flexboard® A/C sheet and less than one-fourth the price of J/M Transite® A/C sheet.[12]

Glass fiber-reinforced cement sheet is expected to be competitive with A/C sheet in the future,[13] although the price of glass fiber is higher than asbestos fiber at present.[17] Like many other materials, the economics depend very much upon the volume of production. With low-volume production of quarter inch spray GRC sheet, costs run about $1.20 per square foot, whereas this price can be lowered to 80¢ with high volume production processes. A/C is still lower at 50¢ to 55¢ per square foot (5.55 to 6.00 per square meter). Prices are expected to get to within 20 percent of asbestos (thickness for thickness) as GRC use grows and the volume of manufacture increases. It may be important to note here that thickness for thickness substitution is not always possible, i.e., one may need 3/8-inch GRC to replace 1/4-inch asbestos. However, in many applications, one is not concerned with thickness so much as that the material will hold up to abuse and minor stress (particularly in industrial uses).[18]

Alumina-Sheet is more than 10 times as expensive as Transite, but the price is expected to be cut in half as production increases this year. Although the cost is high for Alumina-Sheet, in one instance, the Alumina-Sheet was used to replace asbestos rollboard as a pouring trough liner for zinc alloys. The Alumina-Sheet lasted 6 months while the asbestos rollboard was replaced every other day. Because Alumina-Sheet is fairly new on the market, additional comparisons are not currently available.

Table 44 snows a comparison of prices.

Corrugated Sheet Substitutes

Steel is less expensive than A/C sheet and aluminum is competitive.[7] Corrugated GRC is more expensive, at 2 to 2-1/2 times the cost of A/C sheet.[5]

Table 45 shows a price comparison between siding products from quotations made in California in 1979.[12]

Roofing Shingle Substitutes

Monier Monray roof tile, CeDurShake, and the new fire-resistant asphalt shingles cost between \$100 and \$130 for a square (a 100 ft^2 roof surface), installed. Supradur asbestos-cement shingles would cost (per square) about the same as these substitutes.[12]

CURRENT TRENDS

There is a growing interest in substitutes for A/C sheet. A large manufacturer of laboratory fume hoods is buying GRC panels for construction material, and a major manufacturer of appliances is actively seeking substitutes for A/C sheet in pizza ovens.[5] Cooling tower companies are seeking products that can replace A/C sheet in cooling tower construction (in fact, the first full scale use of GRC in a large cooling tower is currently underway in Kentucky),[18] and owners of factories are purchasing corrugated GRC to replace damaged A/C sheets at their facilities.[5] GRC is used quite extensively on the West Coast in high-rise buildings where it is designed and has been tested out to be capable of taking shocks such as seismic loading.[18] The representatives of companies either producing substitute cement sheet or planning to make asbestos-free cement sheet report a growing positive interest from other parties using or needing A/C sheet.[5,13,40]

The construction of a plant producing large quantities of flat glass-reinforced concrete sheet has shown that a nearly equivalent (and in some respects superior) substitute for A/C sheet can be produced at a competitive price.[13] This has occurred in the face of predictions that GRC would not be able to compete with A/C sheet. The move by International Housing Corporation to introduce cement/wood board to the United States will bring to the marketplace a material that has the potential to replace A/C sheet in general construction applications, not only from the viewpoint of material performance characteristics but also because of its relatively low cost. Cement/wood board could also easily be made into textured siding and roofing shingles that

TABLE 44. COMPARISON OF CEMENT SHEET PRODUCT PRICES[12,13,18,22,26,41,42]

Product	Cost ($) per m^2 (ft^2) 1/4 in.	Cost ($) per m^2 (ft^2) 1/2 in.
J/M Flexboard (A/C)	6.50 (0.60)	15.00 (1.40*)
J/M Transite (A/C)	25.00 (2.30)	35.00 (3.28)
Cement/wood board	2.70 (0.25)	5.40 (0.50)
High density GRC	8.60 (0.80)	21.00 (1.95)
Low density GRC	8.60 (0.80)	16.00 (1.50)
Forton	3.90-4.90 (0.36-0.45)	--
Alumina Sheet	160.00 (15.00)	—

*Prices are given at the distribution level; they depend on the quantity of the material ordered. Here, a quantity of over 1000 sq ft is assumed for the J/M products.

TABLE 45. COMPARISON OF SIDING PRODUCT COSTS[12]

Product	Total cost ($) per m^2 (ft^2)[a]
Wood siding, 5/8 in.	8.75 (1.00)
Wood shingle	15.75 (1.50)
Asbestos-cement shingle	13.50 (1.25)
Fiber board	10.75 (1.00)
Brick or stone	61.75 (5.75)
Stucco or concrete block	18.00 (1.75)
Aluminum	13.50 (1.25)

[a]All costs include material price for plywood sheathing of $0.25 ft^2, except the wood siding cost.

would likely be a substantial challenge to A/C roofing and siding shingles, if they were produced.[12] Other roofing materials that are fire-resistant are prominent in California where fire is a persistent threat.[34] Some of these products have the potential to replace A/C roofing shingles. Aluminum and vinyl siding have reportedly forced A/C siding from the residential market except where special fire protection is required or where a slate-like appearance is desired.[31]

In the past 2 years, GAF Corporation and Celotex Corporation have phased out the manufacture of all A/C sheet, and National Gypsum has just sold its Gold Bond Building Products A/C sheet plant in Louisiana (see Table 39).[5] As previously mentioned, several large companies, including two manufacturers of A/C sheet, are developing or experimenting with fibers that would effectively serve as substitutes for asbestos in cement sheet. The current trend seems to be a move towards the use of asbestos-free sheet materials.

CONCLUSION

Asbestos-cement sheet still stands as a versatile, all-purpose material that is relied upon for its excellent durability, heat resistance, workability, and relatively low cost. This unique combination of qualities has until now given it an unrivaled niche in various markets in the United States.

Glass-reinforced concrete appears to be suitable for most corrosion and heat resistant applications where A/C is currently employed, and work to improve the resistance of GRC sheet to heat is continuing.[5]* Cement/wood board, once it is actually under production, should be a cheaper material than A/C sheet for general construction purposes. This product has been used in Europe for a number of years, thus allowing time to test its performance. Unique properties include its ability to be glued and laminated (A/C sheet cannot); it also has a greater modulus of rupture and resistance to impact than A/C sheet. Questions of weather resistance capabilities now being debated may be combatted by solutions such as resin saturation or special paints in the future. Substitutes are available for many specialized applications as well.

No material that can adequately match A/C sheet's qualities as a lab table is available, though other products are currently used. (Slate is one of the materials used here but it is inordinately expensive.) At this time no single material could replace ebonized asbestos sheet in all electrical applications, but Benelex® has been shown to be a usable substitute for some.

In the past there have been no economical, physically comparable substitutes for A/C sheet, but the products described in this section have changed that. While no single product matches A/C sheet's qualities exactly (companies such as Johns Manville claim that all nonasbestos sheets degrade more rapidly than asbestos), there are products that can be identified as suitable substitutes for A/C sheet for most applications. With new replacements, some recognition of the performance requirements of the end use has to be clarified

*In addition, the Forton product discussed is both available and suitable in this product line.

with the user; such requirements have often been neglected in favor of the ease of A/C in that the decision has been made in the past. However, with properly defined requirements, many of these substitute products can adequately fulfill niches delegated to asbestos in the past, even though this may require a certain amount of testing and design work to come up with the right thickness and formulation to make the alternative product work. Most substitutes are currently more expensive than A/C but the differential is shrinking. In the case of GRC, it has shrunk from approximately a 5 to 1 price differential, to a current cost of about one and a half times that of the asbestos product.

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SECTION 6

FLOORING PRODUCTS

ASBESTOS PRODUCT

Two asbestos-containing flooring products are considered here: vinyl-asbestos floor tile and sheet vinyl flooring with asbestos backing. The felt carrier for the vinyl flooring was covered as a paper product previously. Although the vast majority of asbestos used in this category is for vinyl-asbestos products, there is also a very small amount of asphalt-asbestos floor tiles produced. Potential substitutes for floor tile and sheet vinyl products are discussed. It will be noted that different asbestos fiber grades and different manufacturing methods are used in the production of these two products, although they are treated together in one report section.

Special Qualities

Asbestos has been used in flooring production chiefly because of its qualities in two areas: end use (consumer product) properties and manufacturing properties. In the consumer field, asbestos offers floor tile and sheet flooring the following advantages:

- dimensional stability,
- durability,
- resilience,
- flexibility,
- resistance to moisture, chemicals, fire, fungus, etc., and
- good indentation strength.[1]

Dimensional stability is provided by the continuous web of asbestos fibers within the floor tile, which help to prevent shrinkage or expansion from change in temperature. Durability is also important in floor tile, as it may be in place for up to 30 years in heavily trafficked areas. Asbestos not only provides an interlocking matrix that offers this needed durability, but also gives the tile resilience due to the nature of the fiber itself (especially the shorter grades) and provides indentation strength to the tile surface. The fibers impart flexibility to the tile, preventing cracking and breaking during installation or use. Resistance to moisture, chemicals, fire and fungus, as well as chemicals and oils and other potentially damaging substances which can effect floors, is also inherent in asbestos.

In addition to benefiting the floor tile in the manner delineated above (during use), asbestos is also essential in the manufacturing process currently used. Here, asbestos fibers provide mill tack, heat resistance, and dimensional stability. The mill tack allows the tile material to adhere to the roll mills; the heat resistance protects the product from potential cracking in the manufacturing process, and the dimensional stability is critical to prevent the sheet from appreciably shrinking or expanding. Without these qualities, production techniques and machinery would have to be altered or replaced to provide for continuous production.

Product Composition

Vinyl-asbestos tile compositions vary with manufacturers and the type of tile produced, but the asbestos content of the tile usually ranges from 8 to 30 percent by weight, or up to 0.13 pounds of asbestos per square foot of tile.[2] Grades 5 and 7 are normally used. Tiles are typically produced in 9 × 9 or 12 × 12 inch sizes, with thickness ranging from 1/32 to 3/32 inches. PVC resin serves as the binder and makes up from 15 to 25 percent of the tile. Chemical stabilizers usually vary little from 1 percent of the total formulation. Limestone and other fillers represent 43 to 73 percent of the weight (depending on reference used), while pigment content usually averages about 5 percent, but may vary widely depending upon the materials required to produce the desired color.[2,3]

Sheet backing for vinyl flooring is composed of about 85 percent asbestos and 15 percent latex binder.[2]

Uses and Applications

In 1975* asbestos flooring commanded a 91 percent share of the resilient floor covering market.[3] Of this total, 38 percent was floor tile and 53 percent was sheet flooring. Only 9 percent of the resilient floor covering market was held by nonasbestos-containing products, mainly solid vinyl flooring.

Vinyl-asbestos floor tiles and sheet vinyl flooring are installed in industrial, commercial, institutional, and residential buildings.[2,3] They may be installed on concrete, prepared wood floors, or over old tile floors, and are often specified for heavily trafficked areas such as kitchens, entry ways, restrooms, supermarkets, commercial plants and offices. Their chief competitors in the flooring market are hard surface floors, such as terrazo, ceramic tile, brick and stone, as well as wood floors and carpet.

Product Manufacturing Summary

Manufacturing Process--

Vinyl-asbestos floor tile--Vinyl-asbestos floor tile is an outgrowth of asphalt composition sheet and, as a result, has been conventionally formulated with asbestos so that its processing and performance characteristics would match those of the asphalt composition as closely as possible.[4] The manufacture of vinyl-asbestos floor tiles varies from company to company. However, the general flow of raw and finished materials is similar throughout the industry.[3,5]

*Data for more recent years were not available.

Ingredients for tile production, including raw asbestos fiber, pigment, and fillers, are weighed and mixed dry in a Banbury mixer. The mixer works the dry materials into an agglomerated plastic mass. As the material is sheared in the Banbury, the asbestos, fillers, and pigments are dispersed throughout the vinyl mass. Liquid constituents, if required, are then added and thoroughly blended into the batch. While the mechanical working of the material itself generates heat, more heat may be added, if required, to raise the batch temperature to 300°F (150°C) and flux the polymer resin.

The warm plastic mass is then fed to a mill where it is joined with recycled scrap and undergoes final mixing. From this point on, the process is continuous. The mill consists of a series of hot rollers that squeeze the mass of raw tile material down to a desired thickness. During the milling operation, surface decoration in the form of small colored chips of tile (mottle) may be sprinkled onto the top of the raw tile sheet and pressed in to become a part of the sheet. Some tile has a surface decoration embossed and inked into the tile surface during the rolling operation.

After milling, the tile passes through calendars until it reaches the required final thickness and is ready for cooling. Tile cooling is accomplished in many ways and a given tile plant may use one of several methods. Direct water contact in which the tile is immersed in, or sprayed by water, is one method. Indirect water cooling utilizing water-filled rollers is another. Some plants pass the tile through a refrigeration unit to cool the tile surface. After cooling, the tile is waxed, stamped into squares, inspected, and packaged. Trimmings and rejected tile squares are chopped up and reused. Asbestos in the floor tile is thought to be completely encapsulated when it is shipped.

<u>Sheet vinyl flooring (flooring carrier, flooring felt)</u>--is an asbestos paper product which forms the underlayer of sheet vinyl flooring. The backing is produced on a paper machine, following production techniques outlined in Section 2 of this report. During manufacture, the asbestos fibers are coated with latex and are reported to be fully encapsulated when the sheet backing is readied for use in the manufacture of sheet vinyl flooring. The major steps in the manufacture of sheet vinyl flooring are coating, printing, fusion, trimming and packaging. The flooring may be manufactured in the same plant as the sheet backing or in a separate facility.[2]

Production of sheet vinyl flooring begins with a coating operation. Here the sheet backing is coated with a latex and/or plastisol coating. These coats are applied by reverse roll coaters or blade coaters. Once the coatings are applied, the sheet is passed through an oven where these layers are dried and jelled. The coated sheet is then transported to a printing operation where one or more engraved cylinders transfers designs to the coated sheet. In some cases, there will be several printing stations which separately apply one color or aspect of the design patterns. The printed sheet then goes to a fusion step where the sheet is coated with another layer of material called the "wearlayer." The wearlayer is a homogeneous polymer application that provides an impervious surface for the finished product. The coated and printed sheet is next fed through an oven where the backing itself, the layers of latex and plastisol and the wearlayer are fused into a single product. After fusion, these layers remain distinct but are no longer chemically or mechanically separable. The vinyl sheet is then cooled, cut to size, packed and shipped.[3]

Name and Location of Manufacturers--

The major manufacturers of asbestos-containing resilient floor covering and their plant locations are presented in Table 46. The manufacturers sell floor tile directly to retailers, lumber yards, etc.; there are no secondary fabricators in this industry.

TABLE 46. MAJOR U.S. MANUFACTURERS OF ASBESTOS FLOORING[2,3,6]

Manufacturer	Plant location: Vinyl asbestos tile*	Plant location: Sheet backing
American Biltrite, Inc. Amtico Flooring Division	Trenton, New Jersey	Norwood, Massachusetts
Armstrong World Industries, Inc.	South Gate, California Kankakee, Illinois Jackson, Mississippi Lancaster, Pennsylvania	Fulton, New York
Congoleum Corporation Resilient Flooring Division		Cedarhurst, Maryland
GAF Corporation Consumer Products Group	Long Beach, California Vails Gate, New York	Whitehall, Pennsylvania
Kentile Floors	Brooklyn, New York Chicago, Illinois	
Mannington Mills, Inc.	Salem, New Jersey (Sheet vinyl)	
Uvalde Rock Asphalt Azrock Floor Products Division	Houston, Texas	

*The Flooring Division of the Flintkote Company used to produce vinyl asbestos floor tile, but, according to contact with the East Rutherford,[18] N.J. headquarters, no asbestos floor tile is currently produced.[7] Winburn Tile Manufacturing Co. of Little Rock, AR has also ceased producing V/A floor tile.[8]

Production Volumes--

Asbestos fiber consumption for the resilient floor covering industry was estimated to be 126,000 metric tons in 1978 but by 1980 this figure was down to 36,080 metric tons.[9] Of this amount, approximately 40 percent or 14,400 metric tons was used in vinyl-asbestos floor tile and the remainder in sheet (felt) backing for vinyl sheet flooring. Only the chrysotile form of asbestos is used in tile and felt production.

SUBSTITUTE PRODUCT

Methodology

Search Strategy--

A combination of a literature review of relevant trade journals and a survey of industry representatives was used to gather data on potential vinyl asbestos floor tile substitutes.

Summary of Contacts--

The following industry representatives were contacted to gather data on potential vinyl asbestos floor tile and sheet substitutes.

- Mr. Robert Mauer
  Resilient Floor Covering Institute
  1030 15 St., NW, Suite 350
  Washington, D.C.

- Mr. Robert Luders
  Sales Administrator
  Armstrong Cork Company
  Fulton, New York

- Mr. Paul Graham
  Monsanto Company
  800 N. Lindbergh Blvd.
  St. Louis, Missouri

- Mr. Jack Clegg
  Kentile Floors
  Brooklyn, New York 11215

- Mr. Frank Andrejak
  Amtico Flooring Division
  American Biltrite, Inc.
  Trenton, New Jersey 08607

- Company Representative*
  The Flintkote Company
  Flooring Division
  Dallas, Texas 75221

- Company Representative*
  GAF Corporation
  Consumers Product Group
  New York, New York 10020

- Company Representative*
  Mannington Mills, Inc.
  Salem, N.J.

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*The name of the person contacted at this company was not obtained.

Fiber Substitutes

Special Qualities--

A few companies are investigating various fibers to act as substitutes to asbestos in flooring tile. Some attempts have been made to introduce such fibers now being experimented with in other asbestos product areas such as roofing, paints, and sealant products.[10] To date however, little is known about specific special qualities that such fibers might display, as the information is kept proprietary by the flooring industry in efforts still underway to test and further develop such potential floor tile substitutes. It is known that Santoweb® (discussed below) may be used in existing manufacturing processes and can withstand temperatures of 149°C during calendering.[4]

In addition, another fiber product by Lextar using Pulpex looks promising.** This product exhibits a melt strength of 10, on a scale of 0-10, and tensile properties (using ASTM D-638 as a guide) at 180°F of 59-72 psi strength and 3 to 22 percent elongation. At 23°C, it exhibits 980-1170 psi strength, 0.29-0.49 percent elongation and for modulus, 365,000-445,000 psi. Water dimensional growth has also been tested and, after immersion at 30°C for 1 to 14 days, there was no growth measured.[11]

Product Composition--

One product currently under research at Monsanto Corp. is called Santoweb and is composed of cellulose fibers.[12] Lextar of Wilmington, Delaware is experimenting with a synthetic polyolefin pulp product that they call Pulpex®.[10] Georgia Bonded Fibers produces Bondex 148 in both Europe and the United States, which is used as sheet flooring underlay.[13]

Information on product composition is available for the Pulpex® product only. Formulations for this product include PVC resins - Butyl Benzyl phthalate plasticizer, stabilizers; fillers-powdered $CaCO_3$, crushed limestone; and fibrous fillers-pulpex.[11]*

Uses and Applications--

The uses and applications for these substitute fibers are similar to those of asbestos. Included is vinyl sheet and tile flooring as well as the use of Pulpex® in the roofing and sealant markets.[10]

Product Substitutes

Special Qualities--

Product substitutes include the traditional vinyl-asbestos floor tile competitors: solid vinyl tile, rubber tile, wood, carpet and hard surface floors. Linoleum was also a competitor in the early years of sheet vinyl (late 1950's), but by 1974, the asbestos sheet had virtually replaced the linoleum product. Although these products each have special qualities, in general they also possess negative aspects that offset the special qualities

*Also includes one formulation where asbestos can be used here. Both Pulpex E (from polyethylene) and Pulpex P (from polypropylene) are used here.

**It should be noted that this product is as yet only in preliminary stages of development and evaluation.

when compared to the asbestos product. This includes less resistance to abrasion or chemicals and less flexibility as in solid vinyl tile. Rubber tile does not resist grease. Linoleum put in place in the past has shown itself to be less stain resistant and more apt to be affected by alkali materials. A product such as carpet is more porous and thus wears at an increased rate. In general, the wear resistance is just not on the same level as that of the vinyl asbestos product. However, some products, such as that now under development by Union Carbide of New York, NY, are reported to exhibit properties closer to those of asbestos, including good flexibility and indentation resistance.[4]

Product Composition--

The major vinyl-asbestos tile manufacturers are researching new asbestos-free tile formulations. The Armstrong Cork Company, for example, offers an asbestos-free vinyl floor tile called Stylistic. Asbestos has been replaced by increasing the limestone and resin contents of the tile.[14] In addition, Mannington Mills produces sheet vinyl flooring without asbestos.[15] Union Carbide Corporation has combined at least two normally-solid thermoplastic vinyl chloride polymers to form their floor-tile composition.[4] Their patent was submitted in 1974. Other manufacturers are also investigating the use of solid vinyl and vinyl blends in their new formulations. These new blends appear to use increasing amounts of resins, binders and fillers in place of asbestos, although specific formulations are confidential.

Advantages/Limitations--

Each of the traditional vinyl-asbestos floor tile competitors lacks one or more of the advantages of vinyl-asbestos tile. Solid vinyl tile, for example, is generally not as abrasion resistant, chemical resistant or as flexible as vinyl-asbestos.[16] Rubber tile, while resilient, is difficult to maintain and is not grease resistant. Linoleum has a lower resistance to alkali materials and stains.[16] Carpeting is less resilient, more porous and therefore less durable.[2]

In general the new asbestos-free tile formulations lack wear resistance and have not been extensively field tested, although these substitutes exhibit some qualities similar to the vinyl-asbestos floor tile. For example, the Union Carbide product, purported to be a "novel floor-tile composition" reputedly exhibits a combination of acceptable processing characteristics including good indentation resistance, good flexibility, improved light resistances, and very low water sensitivity.[4] Often processing refinements are required to improve the dimensional stability of the new asbestos-free tile products. Other design changes will require both time and capital expenditure.[17]

Product Manufacturing Summary--

Production methods for the new tile substitutes are not known, but are expected to be similar to vinyl-asbestos tile manufacturing techniques. For example, production of the Union Carbide substitute mentioned in the previous paragraph is reputed to be conveniently adaptable to existing "asbestos tile" equipment and production lines.[4] Lextar's Pulpex is dry blended in a Henschel mixer.[11] Table 47 lists the current manufacturers of nonasbestos floor tile.

TABLE 47. MANUFACTURERS OF SUBSTITUTES TO VINYL/ASBESTOS FLOOR TILE

Company	Location[a]
Monsanto Corporation	St. Louis, MO
Georgia Bonded Fibers	Newark, NJ; Buena Vista, VA
Lextar	Wilmington, DE
Union Carbide Corporation	New York, NY
Armstrong Cork Company	Lancaster, PA

[a]Thomas Register, 1980.

Production Volumes--

There is a lack of data on current production volumes of these substitute items as most information is proprietary. Some products are still in testing stages.

COST COMPARISON

Armstrong Cork's asbestos-free floor tile costs 25 to 50 percent more than its asbestos counterpart. For the floor tile formulations discussed for Pulpex, cost is reported to be approximately $14.55 per 100 lbs on a weight basis; the formulations with one type of Pulpex, for a specific grade, is 11.3 percent more expensive than the asbestos formulation given. For the Pulpex vinyl floor tile, Lextar estimates a cost of approximately $1.30 per lb (F.O.B. supplier). This can be compared to 0.37 ¢/lb for Firestone's PVC resin floor tile; 0.51 ¢/lb for Monsanto's "Santicizer"; approximately 0.049 ¢/lb for H. M. Royal's (distributor) "atomite $CaCO_3$"; 0.012 ¢/lb for their crushed limestone vinyl floor tile; and finally 0.09 ¢/lb for an asbestos formulation.[11]

CURRENT TRENDS

The flooring industry is, overall, secretive with its innovative studies at this time and will not share technologies. There are tremendous costs involved in research and development for substitutes. Further, the firm which finds an acceptable substitute could make a large profit and perhaps control the entire market.[18]

CONCLUSION

There are no commercially-available substitutes which duplicate all the manufacturing and end use product advantages of vinyl-asbestos flooring products. While products are available which can be used in place of vinyl-asbestos floor tile and sheet flooring, none of these appears to have the low cost, durability, dimensional stability and resistance qualities of asbestos.

New products are being introduced into the market which may ultimately replace asbestos, but they have yet to be universally tested and do not now enjoy widespread use. However, some already established products such as carpeting, even though they lack the wear resistance, are causing the V/A floor tile, as well as the entire resilient floor covering share of the flooring market to decrease at its expense. It has been estimated that up to 10 years will be required to develop, test and market an asbestos fiber replacement for this area of use.[18] However, companies such as Lextar may succeed in shortening this time period if current product testing proves successful.

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SECTION 7

GASKETS AND PACKINGS

ASBESTOS PRODUCT

Special Qualities

Gaskets and packings are found in virtually every mechanical, chemical, and thermal operation or device where fluids are involved. Although both gaskets and packings are used to seal one fluid from another, the primary difference between the two lies in their application. Gaskets are used where no motion occurs relative to the bearing surfaces, whereas packings are applied in situations where motion will take place. Consequently, gaskets provide static seals while packings provide dynamic seals. In some applications, packings are also available which allow a controlled amount of leakage.

Asbestos has been used successfully in both applications because of its unique combination of qualities. It is not only heat resistant, resilient, and strong, but it is also relatively chemically inert, which is important for many chemical applications. Both gaskets and packings are normally composed not only of asbestos but also some form of elastomeric binder and, in the case of some packings, a lubricant.[1] The asbestos imparts its strength, heat resistance, and chemical inertness to the gasket while the binder holds the fibers together.

Assuming the gasket is properly designed for its operating temperatures and pressures, the service life of asbestos gaskets is influenced essentially by two factors: (a) the reaction of the fluid being contained with the binder and (b) scheduled and nonscheduled maintenance of the device being sealed. Although asbestos is essentially chemically inert, the binder used with the asbestos fibers can be affected by the fluid being contained causing the product to fail due to binder properties rather than to the asbestos itself. Selection of the gasket with the most inert binder for the particular application is extremely important. Maintenance, whether scheduled or nonscheduled, prematurely shortens the service life of the gasket by requiring replacement of the gasket, which has been damaged while the seal is broken.

The service life of asbestos packings is determined primarily by wear due to friction. Therefore, a lubricant is generally included in the binder. In the case of pumps, the pump packing must leak to perform properly. Their purpose is to control leakage, not to prevent it. This slight leakage along the shaft provides proper lubrication to the packing. Pump packings have a lubricant which acts as a primary sealant for start-up and break-in phases, during which time the lubricant reduces friction. However, once the pump is on line, external lubrication must be supplied to the packing to keep it running properly and ensure the longest life possible. If not, the lubricant in the packing will bleed out due to heat generation causing the packing to fail.

A valve is packed differently than a pump. In contrast to a pump packing which must leak, a valve packing must not leak. Pressure and temperature on a valve stem packing is normally much higher than on a pump packing. To eliminate the possibility of the lubricant bleeding out of the valve packing, the packing is impregnated with a minor amount of sealing material. Valve stem packings must provide a dense structure that will not permit movement of the fluid through the body of the packing itself, thus acting more like a gasket.

Product Composition

Specific gasket and packing ingredient formulas vary with manufacturer and grade of product. The proportion of fiber and binder in the gasket varies with the temperature of its intended use. Commercial grade asbestos sheet contains 75 to 80 percent asbestos and is used for temperatures up to 204°C (400°F).[2] Temperatures of 483°C (900°F) or higher require gasket sheet of 99 to 100 percent asbestos.[2] Both white chrysotile and blue crocidolite asbestos are used to about 483°C (900°F).[2] AAAA asbestos can withstand temperatures up to 538°C.[3] Above this temperature, the chrysotile becomes unstable due to the release of combined water, and crocidolite predominates.[2,4]

Asbestos content in packings varies considerably--up to 100 percent for some applications such as sealing furnace doors.[1] For most applications, however, a binder/lubricant is impregnated into and onto the fibers. Some typical elastomeric binders used in the packing and gasket industry include:[5,6]

- silicone based rubber,
- neoprene,
- Buna-N rubber,
- natural rubber,
- nitrile rubber,
- Teflon®

- glue-glycerine,
- styrene-butadiene,
- nitrile Buna-N, and
- Hypalon®.

Some of the more common lubricants used in packing manufacture are:[1]

- petroleum based oils and waxes,
- high grade animal fats and waxes,
- Teflon,
- mineral oil,
- natural rubber,
- Buna-S rubber,
- vegetable oil,
- glycerine, and
- graphite.

For some applications, a lubricant may not be necessary.

The consumption of asbestos for this product category was 12,300 metric tons in 1980, most of which was chrysotile.[7]

Uses and Applications

The uses and applications of asbestos gaskets and packings are extreme. In order to classify these applications, one must look at three primary parameters: (a) the operating temperature, (b) the operating pressure, and (c) the nature of the fluid being serviced. Operating temperatures vary from almost absolute zero (-273°C or -460°F) in cryogenic applications up to 538°C (1000°F).[1] Operating pressures range from a vacuum up to 3.45×10^4 kPa (5000 psi). The nature of the fluid serviced is perhaps the most important parameter to be considered. The list of fluids is almost endless. For instance, one gasket and packing manufacturer lists over 700 materials to aid in selecting the proper packing.[1] This manufacturer has assigned a service classificaton to each of the materials on the list as well as to all of the 94 different packings the company produces. The classifications are:

a. general,

b. caustic,

c. pulp and paper,

d. food,

e. water,

f. solvents,

g. acids, and

h. any of the above uses except strong acids where the pH is between 0 and 2.

Although packing is generally sold by weight, it is used by increments of length.

Product Manufacturing Summary

Manufacturing Process--

Asbestos gaskets--There are several methods of gasket production currently in use. Basic steps in manufacture include fiber introduction, mixing, sheet formation, cutting and stamping, and packaging. As beater-add gaskets are discussed in the paper products section, only compressed sheet gaskets will be addressed here.

Raw ingredients including asbestos fiber, elastomeric binder, and a solvent are preweighed and added to a mixer; this mixture is then blended on a batch basis until a dispersed agglomerated mass is obtained. This operation may be wet or dry according to product requirements. A large roll is typically 40 inches in diameter by 130 inches in length and produces a sheet 120 inches square. This calendered gasket sheet is then cut to size and packaged. The sheet may be stamped into products onsite, or, more commonly, sold to secondary manufacturers for further processing or to distributors for the maintenance market. Secondary fabricators, such as gasket cutters, generally form gaskets from sheets by die cutting while the maintenance user cuts the sheet manually.

Asbestos packings--Asbestos-based packings are manufactured by a variety of processes. The most common process is impregnation of dry yarn with a lubricant.

After lubricant impregnation, the yarns are braided into a continuous length of packing which is in turn calendered to a specific size and cross-sectional shape. The formed product may then be coated with more lubricant or even with another material. It may then either be coiled, boxed, and sold to the maintenance trade, or instead be pressed into required shapes at the place of manufacture. Fiber or yarn may also be used as a reinforcement to elastomers and molded to desired cross-sectional shapes.

Another type of packing production involves the extrusion of a mixture of fiber, binder, and lubricants and subsequent braiding of lubricated asbestos yarns over the extrusion. Most final cutting and forming operatons are done by secondary fabricators.

Names and Number of Manufacturers--

Primary gasket and packing manufacturers are listed in Table 48. Actual annual asbestos use for each plant is unavailable. Although primary products such as compressed sheet and impregnated yarn are made by the 26 primary manufacturers listed, much of the material is packaged and resold by a large number of specialty companies. These secondary manufacturers typically rework the gasket sheets and packing yarn into desired shapes and may sheath them in metal, plastic, or cloth or reinforce them with wire insertions. Due to the wide variety of gasket and packing sizes, shapes, sheathing materials and asbestos compositions available, no distinct, all-inclusive product list can be made. Similarly, the number of companies involved in secondary fabrication is impossible to pinpoint, although one 1975 estimate suggested that more than 200 such operations exist.[2]

Production Volumes--

In 1980, approximately 12,300 metric tons (MT) of asbestos were used in the United States to produce gaskets and packings. Of this amount, 12,200 metric tons was chrysotile and the remaining amount was crocidolite.[7] In 1978, 31,100 metric tons of asbestos were used in this category.[20]

SUBSTITUTE PRODUCT

Methodology

Search Strategy--

A combination of a literature review and survey of industry representatives was used to gather data on asbestos gaskets and packings and their potential substitutes.

Summary of Contacts--

The following industrial representatives were contacted to obtain information on asbestos packings and gaskets and their possible substitutes.

- Mr. C. Stein, Pars Manufacturing Co., Ambler, Pennsylvania, January 1980.
- Mr. G. Faber, E. I. DuPont de Nemours & Co., Inc. Wilmington, Delaware, January 1980.
- Mr. H. Stiegler, Excelsior, Inc., Rockford, Illinois, January 1980.
- Mr. S. Dittmeir, Norton Company, Sealants Division, Granville, New York, January 1980.

TABLE 48. U.S. ASBESTOS GASKET AND PACKING MANUFACTURERS[2,8]

Name[a]	Location
Ametex Corporation[b]	Norristown, PA
Anchor Packing	Manheim, PA
Armstrong Cork Co.[9]	Fulton, NY
Braiding and Packing Works of America	Brooklyn, NY
A. W. Chesterton	Everett, MA
Crane Packing	Morton Grove, IL
Detroit Gasket & Mfg. Co.[10]	Detroit, MI
F. D. Farnum	Necedeh, WI
Felt Products Mfg. Co.	Skokie, IL
Fitzgerald Gasket[11]	Torrington, CT
GAF[12]	Erie, PA
Garlock, Inc.	Charlotte, NC
Greene, Tweed & Co.	North Wales, PA
Hollingsworth & Vose[13]	East Walpole, MA
Janak, Inc.[14]	Weatherford, TX
Johns-Manville	Manville, NJ Waukegan, NJ
Lamont Metal Gasket Co., Inc.[15]	Houston, TX New Orleans, LA
McCord Corporation	Wyandotte, MI
Nicolet Industries	Ambler, PA
Parker Seal Gaskets[16]	North Brunswick, NJ
Raybestos-Manhattan, Inc.	Stratford, CT
Richardson Corp., Hercules Div.	Alden, NY
Sacomo Packing Co.	San Francisco, CA
Sacomo-Sierra[17]	Carson City, NV
SEPCO	Birmingham, PA
Standco Rubber Gaskets[18]	Houston, TX

[a]Most of these companies were originally noted in the references listed, then verified by telephone contact by GCA personnel; locations for a few were verified by the 1980 Thomas Register. In addition, an unpublished OSHA document on Asbestos was used.

[b]Manufacture asbestos-containing material that eventually goes into gaskets and packings.19

- Mr. T. Connolly, Janos Industrial Insulation Corp., Moonachie, New Jersey, January 1980.

- Mr. J. Minchella, Miller Products Company, New York, New York, January 1980.

- Mr. R. Swanson, Garlock, Inc., Mechanical Packing Division, Charlotte, North Carolina, February 1980.

- Mr. C. Broecker, Newtex Industries, Inc., Victor, New York, January 1980.

- Mr. B. Holt, Melrath Gasket Co., Philadelphia, Pennsylvania, February 1980.

- Mr. E. Fenner, Johns-Manville, Denver, Colorado, January 1980.

- Mr. M. Call, Boise Cascade, Specialty Paperboard Division, Beaver Falls, New York, February 1980.

- Nicolet, Inc., Ambler Division, Ambler, Pennsylvania, February 1980.

- Mr. E. Huber, Paramount Packing and Rubber, Baltimore, Maryland, Feburary 1980.

- Mr. J. Buechel, Durabla Manufacturing Co., Paoli, Pennsylvania, February 1980.

- Gaddis Engineering Co., Port Washington, New York, February 1980.

- Mr. T. Conaghan, Bently-Harris Mfg. Co., Lionville, Pennsylvania, February 1980.

- Mr. S. Koehler, Greene, Tweed & Co., North Wales, Pennsylvania, February 1980.

- Mr. R. Chiostergi, E. I. DuPont de Nemours & Co., Inc., Wilmington, Delaware, February 1980.

- Mr. V. Bunch, Sheller Globe Corporation, Norfolk, Virginia, February 1980.

- Mr. L. Hall, Southland Industries Incorporated, Norfolk, Virginia, February 1980.

- Mr. M. Black, Armco, Hitco Materials Division, Gardena, California, February 1980.

Fiber Substitutes

Special Qualities--

The special qualities of substitute fibers for gasket and packing applications are summarized below.

Silica fibers--High melting temperature and continuous working temperature, resistant to many chemicals, high tensile strength, exhibit no creep.

Ceramic fibers--High melting temperature and continuous working temperature (greater than silica), no shrinkage or moisture absorption, good flexibility and chemical resistance. Coramic 249, a product of Dana Corp., resists temperatures up to 1260°C (2300°F), and exhibits extremely high crush resistance.[21] Ceramics have a temperature range up to 1650°C (3000°F); their compressive strength is more than twice that of asbestos. Problems include the fact that the binders necessary to keep the systems intact disintegrate at these temperatures. In addition, ceramics are up to 30 times the diameter of asbestos, which makes homogeneity a problem. For high temperature exhaust gas applications however, ceramics may be blended with other fibers to make an acceptable alternative.[22]

Graphite fibers--Heat and chemical resistant, long service life, lightweight, will not harden, near zero thermal expansion and drip rate. Graphite products by Dana Corp., including Victocor and Solicor withstand extreme temperatures, and in the case of Solicor, have maximum radial strength provided by a solid steel core.[21]

Aramid fibers--Aramid fibers have tremendous tensile strength and modulus, while maintaining flexibility in some grades. They begin degrading at 260°C (500°F) but do not disintegrate or gasify at that temperature. At 1095°C (2000°F) they have higher strength than asbestos. They are being used in compounds in small quantities.[22]

Teflon fibers--Will not stain, chemical resistant, low frictional properties.

Product Composition--

Silica fibers--Many different forms of silica fibers are currently on the market.[23-25] Although slightly different in form, silica fibers are essentially pure SiO_2. Products are produced in various forms including cloth, Irish cloth (treated with chromia), slit tape, woven tape, sleeving, yarn, cord, bulk, fiber, batting, and rope.[25]

Ceramic fibers--Ceramic fibers are typically metal oxides, nitrides, or carbides, available in various forms including continuous filament, cloth, tube, rope, tape, and chopped fibers.[26,27] Products by Victor Products Division of Dana Corp. containing ceramic materials are the Coramic series. Coramic 199 consists of a steel layer on one side, with soft material on the opposite side. Coramic 299 is a soft material core mechanically held between two steel outer layers. Coramic 249 is ceramic material applied to a perforated steel core, and 439 is soft material facing on both sides of a perforated steel core.[21]

Graphite fibers--Graphite fibers are available in various forms including plain or diamond textured tape and sheet, die formed rings (with and without wire mesh insertions), cloth, rope, yarn, cord, and bulk fiber.[28,29] These products are black in color. One manufacturer claims a product with nominal filament diameter of 0.076 mm (0.0003 inches).[28] Victocor 189 by Victor Products is composed of graphite sheet reinforced with a perforated steel core; Victocor 289 combines this with an adhesive and Solicor 689 is graphite sheet chemically bonded to a solid steel core.[21]

Aramid fibers[30]--E. I. DuPont de Nemours & Co., Inc., has been granted the generic name "aramid" by the Federal Trade Commission for its family of aromatic polyamide fibers which include Kevlar® 29, Kevlar® 49, and Nomex®. Kevlar 29 will be discussed in this section because it is widely used in the gasketing and packing industry. Both Kevlar and Nomex are discussed in detail in the Textiles Section of this report. DuPont produces Kevlar 29 in filament yarns and stable fibers.

Teflon® fibers[31]--Teflon TFE-fluorocarbon fibers and resins were developed by E. I. DuPont de Nemours & Co., Inc. Teflon fibers possess a higher degree of molecular orientation than their resin counterparts. Consequently, the ultimate strength and resistance of the fibers to cold flow is much greater than that of the resins. Teflon fiber is available as a continuous multifilament yarn, staple, flock, or tow. the natural color of Teflon is dark brown. Pure white bleached fiber is also available.

Uses and Applications--

No single substitute fiber material possesses all of the high qualities exhibited by asbestos; however, for any particular application, a substitute fiber can often be employed to achieve the desired combination of properties. Fiber replacements whose composition has been detailed include: silica, graphite (carbon), aramid (Kevlar), ceramic, and Teflon fibers (see Table 49). Table 50 compares asbestos with these fibers. Disadvantages of asbestos including especially its abrasive properties for packing use and its insulation abilities, have caused the development of substitute products which excel in these areas. For instance the normally positive insulating abilities of asbestos trap frictional heat within the stuffing box containing the packings, which can in turn boil the lubricant and suspensoids out of the packing. In addition, this build-up heat is transferred along the pump shaft, which may eventually overheat the bearings, causing a failure and shutdown of the entire pump assembly for major repairs. As a result, substitute packings have been developed which provide greater heat dissipation than asbestos. The abrasive qualities of asbestos, causing it to grind when compressed as a packing against a rotating shaft (as in a stuffing box) and thus requiring lubricants and maintenance programs to get around this potential problem, have also been avoided with substitute products. Although the costs of nonasbestos packings might seem higher than those of asbestos packings, when operating and maintenance costs are considered, the newer synthetic packings are competitive. Only Teflon packings presently meet FDA regulations for contact with food, drugs, cosmetics, and medical devices,[35] however, Grafoil[36] by Carborundum is reported to be close to FDA approval for its use relative to food additives, and Aramid products may also be approved.[37]

TABLE 49. CHARACTERISTICS OF FIBERS

Fiber	Maximum tensile strength (10^6 kPa)	Maximum tensile strength (10^6 psi)	Continuous duty temperature limits Lower (°C)	Continuous duty temperature limits Higher (°C)	Chemical deterioration	References
Silica	3450	500	-73	990	some molten metals, hydrofluoric acid, fluorides, oxides, hydroxides	23, 32, 33
Ceramic	1720	250	--	1400	hydrofluoric acid, phosphoric acid, hot concentrated alkalis	26, 28, 29
Graphite	2070	3000	-200	3000	strong oxidizing compounds, chromium (VI) and permanganate solutions	29, 34
Kevlar	2758	400	-46	200	strong acids including: hydrochloric, hydrofluoric, nitric and sulfuric	30
Teflon	359	52	-268	290	certain perfluorinated organic liquids at temperatures above 299°C (570°F)	31
Asbestos	3450	500	-273	540	essentially none	2

TABLE 50. FIBER USAGE CHART[3]

Fiber	Advantages	Disadvantage	Most common usage
Asbestos	Heat resistant Pressure resistant Strong (Tear resistance) Availability Price	Heat insulator Abrasive Health hazard Messy Low service life Fluid compatibility	Depending on brake and and lube: General service pumps, valves, etc.
Aramid	Super strong Tear resistant	Hard to cut Cannot be die formed 3-11 pH range 260°C Temp. Limit	Papermill--stock pumps hydrofiner etc. Sewage treatment plants--centrifuge sludge pumps, etc. All slurries in 3-11 pH range. Possible future replace all TFE/Asbestos
Graphite/ TFE Composite	Reduces run in time Chemical resistant Low thermal expansion Nonscoring Good heat dissipation Light weight (more feet per pound) Not messy Nonstaining Flexible Will not extrude A product you can standardize on Great in valves Long service life	If over tightened, it may glaze Possible price	Chemical pumps especially effective on chemical slurries Sewage/slurries General service
TFE	Low friction Chemical resistance Nonasbestos Nonstaining	Thermal expansion Low shaft speed 260°C limit Possible price	Chemical pumps and valves Food and drug pumps and valves Nonstaining applications

(continued)

TABLE 50. (continued)

Fiber	Advantages	Disadvantage	Most common usage
Carbon yarn	Heat dissipation Takes high shaft speeds Least expensive in the carbon/graphite family Temperature resistant to 649°C in steam Operates with a lower drip rate Repack costs reduced total removal not always necessary	Brittle Possibly	The best boiler feed pump packing going especially the large ones in power plants Chemical pumps Boiler recirculation pumps This is a good general power plant packing
Graphite	Heat resistant Heat dissipation Fastest shaft speed Chemical resistance Long service life Light weight Near zero thermal expansion Near zero drip rate A viable alternative to the mechanical seal Will not harden	Brittle Frays Price	In the dry form, it is used in high temperature valve in power plants High speed-low drip rate pumps Very hot chemicals Chlorine agitators Exotic high temperature and highly corrosive materials

As was the case in packings, the aforementioned materials are also suitable substitutes for asbestos in many gasket applications. If the application is under 260°C, compressed asbestos sheet gasketing can be immediately curtailed by applying a substitute material. Graphite sheet, metal gaskets, and Rogers Corp. gaskets[38] can replace asbestos over 260°C but their use consitututes a major expenditure to plant maintenance. Victor Products gaskets have found use as exhaust system gaskets sealing combustion gases under severe operating conditions. Here they have been shown to have superior heat resistance as compared with their asbestos counterparts, frequently withstanding temperatures of up to 2200°F (1204°C), while still maintaining a seal during extreme temperature changes. This product is available in seven material compositions, ranging in application from exhaust manifolds, exhaust pipe flanges, turbo-charger mountings and catalytic converters. Victor's hard gaskets are used as cylinder head and intake manifold gasketing materials. Their soft gaskets resist engine coolants, fuels and lubricants.[21]

Other candidates for gasket applications include glass fiber, coated metals, and, in some areas, cellulose fiber. Glass fiber normally withstands heat to 595°C (1100°F) at which point softening and fusing occurs. Glass has good strength and displays the highest surface area (thinnest diameter) of any manmade fiber. It is recommended in reinforcing mica, clay, or baryte-based compounds, much in the same way aramids and nylons are expected to be used.[22] Coated metals are reported to display the physical strength of the substrate metals, coated with a well-bonded yet embossable sealing coating of nitrile or silicone. No wicking is necessary due to the solid steel barrier. Good relaxation and extrusion properties have been exhibited.[22] Cellulose fiber is favored in some applications, although it is only used sparingly in such areas as materials requiring high temperature resistance, due to its low charring temperature. However, where heat is less than 150°C (300°F), it can be used as a successful carrier web or matrix for a variety of fillers.[22]

In addition to fibers for packings and gaskets, filler materials are important in creating nonasbestos substitutes for this category. Fillers include clay and mica. Clay is inexpensive, compressible in bulk, and fills the voids between the larger fibers such as glass, nylon, or aramid. When clay is added to most materials, it increases the surface area to the magnitude of asbestos. Clays are easily dispersed in water mixtures. For sealing, clay reduces the spring rate of the facing as well as improving the load bearing capabilities. Clay resists temperatures to about 1650°C (3000°F). In addition, clay has better conformity properties than asbestos.[22] Mica has been used for years by the paper industry as a filler. Chemically or thermally expanded, it becomes vermiculite, which is very economical, has high surface area, and good temperature resistance [above 1095°C (2000°F)] Although it has relatively low strength, it has good slip characteristics, caused by the low coefficient of friction of the particle. Compared to asbestos, mica displays better torque and heat resistant properties.

Performance of Substitutes--

General--Greene, Tweed & Co., a supplier of gaskets and packing, have developed a method of selecting a dynamic service packing based on three important criteria: PV and pH factors and the material's resistance to temperature.[3] The PV factor, which is the factor for mechanical conditions, is determined by multiplying the pressure of the stuffing box by the velocity of the shaft. The resultant PV factor will pinpoint a range of applicable packings. The Fluid Sealing Association has developed a chart showing this range, which is presented in Table 51.

The pH factor is a numerical measurement of the intensity of severity of an acid, which in turn determines the potential amount of chemical attack a packing will encounter. Table 52 shows which packings are applicable to a specific pH factor.

The third and equally important criterium is resistance to temperature. Aramid, Teflon and Graphite/TFE composites are generally limited to 260°C. Carbon yarn is rated to 649°C in steam or 343°C in oxidizing atmospheres. Coramic, by Victor Products, resists temperatures up to 1204°C (2200°F).[21] Pure graphite goes all the way up to 3316°C in nonoxidizing atmospheres, 649°C in steam, and 427°C in oxidizing atmospheres. An important factor to consider as far as temperature goes is frictional heat. If the surrounding atmosphere in which the packing must perform is close to the temperature limit of the packing (within 21-38°C), then careful attention must be paid to proper break-in of the packing, and maintaining adequate drip rates to enhance cooling and heat transfer away from the packing and delicate pump components. Even though packing materials such as graphite could withstand the heat, the crystalline structure of the metallic pump components could be altered, causing degradation and failure; in addition, oil seals and bearings may succumb to the heightened temperatures, also causing shutdown for major overhaul.[3]

Table 53 represents an attempt to compare the various packing materials discussed here in a practical manner. It is titled "Experimental Preference Rating Chart," because the ratings are based on testing experience, and take into account more than just the three factors discussed previously. Service life of the packing, efficiency of energy usage, and equipment life are the three criteria which give an experimental rating. The highest a product can be rated is 100, and the lowest a product can be rated is zero. As is clearly seen in Table 53, each substitute material presented provides superior ratings over asbestos in packings.

Fiber Substitutes--

Silica fibers--Silica fibers will not melt or vaporize until temperatures exceed 1704°C (3100°F).[32] Continuous working temperatures of up to 982°C

TABLE 51. PV FACTORS[3]

Pressure	velocity, fpm	PV factor	Stuffing box Temp., °F	Aramid	Carbonaceous	TFE	Graphite/TFE composite
0-50 psi	52-916	45,800	50-150	X	X	X	X
			151-500	X	X	X	X
			501-600		X		
			601-750		X		
51-100 psi	916-1885	188,500	50-150	X	X	X	X
			151-500	X	X	X	X
			501-600		X		
			601-750		X		
101-174 psi	916-1885	328,000	50-150	X	X	X	X
			151-500	X	X	X	X
			501-600		X		
			601-750		X		
175-250 psi	916-1885	471,300	50-150		X		X
			151-500		X		X
			501-600		X		
			601-750		X		

TABLE 52. pH FACTOR DETERMINES CORRECT FACTOR MATERIALS[3]

pH range	Applicable packing materials
0-1	TFE Fiber Carbonaceous Fiber Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
2-3	TFE Fiber Carbonaceous Fiber Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
4-5	TFE Fiber Carbonaceous Fiber Aramid TFE-Dispersion Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
6-7	TFE Fiber Carbonaceous Fiber Graphite Tape Cellulostic Aramid TFE-Dispersion Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
8-9	TFE Fiber Carbonaceous Fiber Cellulostic Aramid TFE-Dispersion Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
10-11	TFE Fiber Carbonaceous Fiber Aramid TFE-Dispersion Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
12-13	TFE Fiber Carbonaceous Fiber Graphite Tape Graphite/PTFE Composite PTFE Impregnated Carbon
14	TFE Fiber Carbonaceous Fiber Graphite/PTFE Composite PTFE Impregnated Carbon

TABLE 53. EXPERIMENTAL PREFERENCE RATING CHART[3]

Application data	Service 1	Service 2	Service 3
Motion	Rotary	Rotary	Rotary
Fluid	Clear, Neutral	Slurry, pH 6-8	Acid Slurry, pH 2
Temperature	93°C	93°C	204°C
Shaft Speed	800 FPM	800 FPM	200 FPM
Discharge Pressure	50 psi	50 psi	150 psi
Drip Rate	100 Drops/Min.	100 Drops/Min.	20 Drops/Min.
Flush	No	Yes	Yes
	Asbestos	Asbestos	Asbestos
Service Life	40	40	10
Energy Use	10	10	10
Equipment Life	5	5	5
	Aramid	Aramid	Aramid
Service Life	60	100	10
Energy Use	60	60	60
Equipment Life	70	70	70
	Graphite/TFE Composite	Graphite/TFE Composite	Graphite/TFE Composite
Service Life	90	90	100
Energy Use	80	80	80
Equipment Life	80	80	80
	Teflon	Teflon	Teflon
Service Life	90	90	25
Energy Use	90	90	90
Equipment Life	60	60	40
	Carbon	Carbon	Carbon
Service Life	95	95	95
Energy Use	90	90	90
Equipment Life	90	90	90
	Graphite	Graphite	Graphite
Service Life	100	100	100
Energy Use	100	100	100
Equipment Life	100	100	100

(1800°F) do not reduce the strength or flexibility of the fibers.[23] Working temperatures as low as -73°C (-100°F) have been reported.[33] The functional cycling temperature of select fiber forms approaches 650°C (1200°F). The tensile strength of silica fibers is temperature dependent, varying from 3.45 x 10^6 kPa (500,00 psi) at 22°C (72°F) to 1.72 x 10^6 kPa (250,000 psi) at 538°C (1000°F)[33] However, another manufacturer[23] of silica fibers claims that working temperatures of up to 982°C (1800°F) do not reduce the strength or flexibility of the fibers although some embrittlement and shrinkage occur above 982°C (1800°F). In addition to their high tensile strength and wide working temperature range, silica fibers exhibit no hysterisis or creep.[33]

The chemical properties of silica fibers allow them to be used in most environments. Most elements do not react with silica fibers, however, some molten metals such as magnesium, sodium, and silicon are exceptions as well as hydrofluoric acid, fluorides, oxides, and hydroxides, the latter two especially at elevated temperatures.[32] Because of the chemical resistance of silica fibers, common lubricants used in packings will not be absorbed into the fibers (as is the case with asbestos fibers) but will instead be adsorbed on the outside of the fibers. Silica fibers can be coated with common elastomers including S.B.R., N.B.R., Hypalon®, Viton®, and Teflon.[33]

Uncoated silica fiber rope can be used where compact, dense, high temperature seals are required such as in partial grooves in furnace oven doors where the rope is not entirely contained.

Ceramic fibers--Ceramic fibers will not melt until temperatures exceed 1800°C (3272°F) and can withstand continuous working temperatures of up to 1427°C (2600°F) with short term use up to 1650°C (3000°F).[27] The tensile strength of ceramic fibers is in the 1.72 x 10^6 kPa (250,000 psi) range. Even at 1093°C (2000°F) one brand of ceramic fiber tested (3M-Nextel)[27] retained 100 percent of its tensile strength. Shrinkage and moisture absorption are virtually nonexistant.[27] Ceramic fibers retain their flexibility and resiliency even at elevated temperatures.[26]

The chemical properties of ceramic fibers, such as the Garlock product, Thermo-Ceram™, allow them to be used in most environments. They are resistant to most corrosive agents with the exception of hydrofluoric acid, phosphoric acid, and hot concentrated alkalis.[28]

Information is unavailable at this time to determine the compatibility of ceramic fibers and common elastomers used in gasketing manufacture. Ceramic can be coated with graphite for added lubricity and can be enclosed in wire mesh for added strength.[28]

Graphite fibers--Graphite fibers have the highest heat resistance of the materials presently under consideration. Its tensile strength increases until 2200°C (4000°F), it is heat resistant above 2760°C (5000°F) and it will not melt but will instead sublime at 3740°C (6700°F).[29] One particular packing[28] produced by Garlock called Graph-Lock® withstands temperatures from -200°C (-328°F) to 500°C (932°F) in oxidizing media and temperatures up to 3000°C (5432°F) in reducing or inert media. Graphite fibers also have excellent resistance to temperature changes and, in addition to their wide temperature range, graphite fibers have high tensile strength.[39] Even at elevated or cryogenic temperatures, graphite fiber products do not exhibit cold flow characteristics and do not soften, harden, or otherwise degrade.[34] When added strength is needed in extremely high pressure applications, mesh inserted sheet can be used. The mesh also helps prevent damage during handling and installation. In addition, graphite has unique low frictional characteristics of platelets, which help where motion is a problem.[22]

Graphite fibers have a high resistance to most agents including organic and inorganic acids and bases, solvents, waxes, and oils. Exceptions are strong oxidizing compounds such as concentrated nitric or sulfuric acids with dissolved oxidizing salts, chromium (VI), permanganate solutions and perchloric acid. In addition, graphite fibers are not resistant to molten alkaline and alkaline earth metals.[34]

Graphite fibers, as a dry packing, have all the inherent lubricating qualities of pure graphite.[34] However, Teflon and other lubricants are impregnated into the graphite packing to block potential leak paths.[40]

Aramid fibers--Kevlar 29, an Aramid fiber, does not melt or support combustion under normal environmental conditions but will carbonize at about 427°C (800°F). At temperatures as low as -46°C (-50°F), Kevlar 29 exhibits essentially no embrittlement or degradation of fiber properties and it does not sublime. The fiber exhibits virtually no shrinkage up to 160°C (320°F). Kevlar 29 can be used as an asbestos substitute up to 204°C (400°F). The tensile strength of Kevlar 29 fiber is temperature dependent but can attain 2.758×10^6 kPa (400,000 psi)(see Figure 2). Creep characteristics of Kevlar 29 are equivalent to that of fiberglass but Kevlar 29 is much less susceptible to creep rupture.[30]

The chemical resistance of Kevlar 29 is excellent except for a few strong acids including hydrochloric, hydrofluoric, nitric, and sulfuric (see Table 54). Its pH range is said to be between 3 and 11. However, compression of Kevlar may increase friction, heat, and therefore wear, in turn increasing degradation that may be caused by the presence of acid in such uses as A/C pipe.[37]

Kevlar 29 has been coated with many elastomers and other materials. These include:

- neoprene synthetic rubber,
- Hypalon synthetic rubber,
- synthetic rubber,
- nitrile rubber,
- Nordel® hydrocarbon rubber,

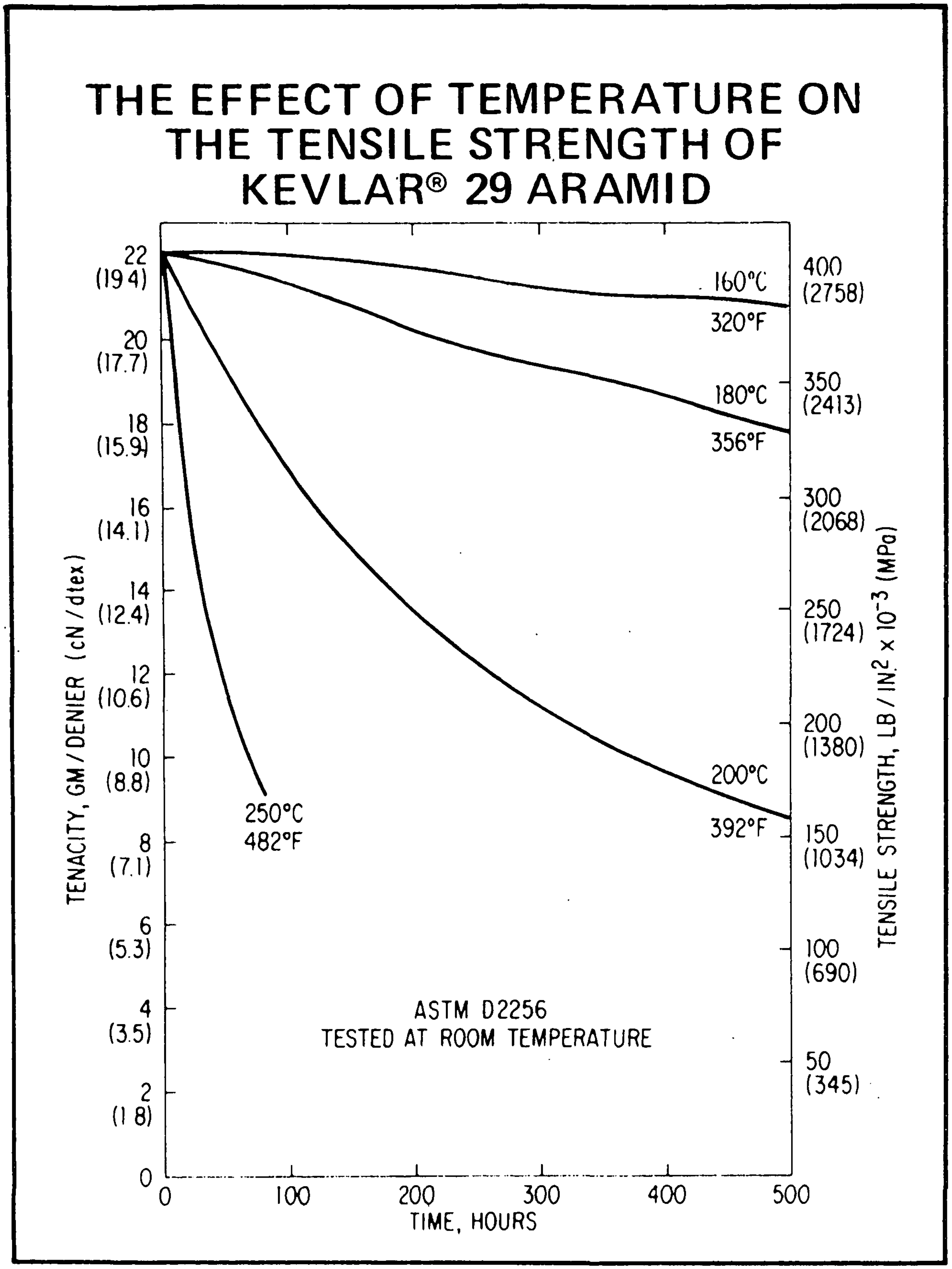

Figure 2. The Effect of Temperature on the Tensile Strength of Kevlar® 29 Aramid[30]

TABLE 54. CHEMICAL RESISTANCE OF YARN OF KEVLAR® 29 ARAMID[30]

Environment (100 hr* exposure at 70°F; 21°C)	Tensile strength loss %
Acids	
Formic (90%)	10
Hydrochloric (37%)	90
Hydrofluoric (10%)	12
Nitric (70%)	82
Sulfuric (70%)	100
Other Chemicals	
Brake Fluid (312 hr)	2
Greases (moS_2 and Lithium base)	0
Jet Fluid (JP-4) (300 hr)	0
Ozone (1000 hr)	0
Tap Water	0
Boiling Water	0
Superheated Water 156°C (313°F) 80 hr	16

* Except where noted.

- Buna-N,
- urethane polymers,
- silicon and fluorosilicon,
- polyvinyl chloride,
- Teflon (TFE, FEP) fluorocarbon resin,
- polyvinyl alcohol,
- Tedlar® polyvinyl chloride, and
- Mylar® polyester.

Teflon fibers--Teflon fibers soften at elevated temperatures and become less ductile at subzero temperatures; however, working temperature limits range from -268°C (-450°F) and 288°C (550°F). The fibers are most ductile and flexible between -73°C (-100°F) and 288°C (550°F). The tensile strength of Teflon fiber is dependent on temperature with maximum strength occurring at 21°C (72°F), or 3.59×10^5 kPa (52,000 psi).[31]

The unique molecular structure of Teflon fiber makes it inert to powerful oxidizing agents and to such reagents as boiling sulfuric acid, fuming nitric acid, and boiling sodium hydroxide. The only known solvents for Teflon fiber are certain perfluorinated organic liquids at temperatures above 299°C (570°F).[31]

Packing braided from bleached and specially impregnated and treated Teflon is currently in use throughout the industry. Gasket tape, made from the same bleached impregnated fiber as packing, is used for such applications as head gaskets on glass lined reactors, pipe flanges, and top and bottom gaskets on centrifuges. Because of the high mechanical strength and resistance to cold flow of Teflon fiber, gasket tape made from Teflon fiber resists extrusion at internal pressures as high as 1.4×10^6 kPa (200 psi).[31]

Product Substitutes

The number of potential gasket and packing materials that do not contain asbestos is extremely large. One distributor/secondary manufacturer (Excelsior, Inc.)[41] lists over 160 different raw materials that do not contain asbestos (see Table 55). At least two manufacturers[4,42] conduct presentations for industry showing nonasbestos packing and gasket materials.

At least two manufacturers[35,44] have already developed materials to compete with asbestos gaskets. In addition, three other manufacturers[42,45,46] are developing alternatives but consider all their information proprietary. For that reason, only those products already in production will be described in this section.

TABLE 55. NONASBESTOS RAW MATERIALS FOR GASKETS AND PACKINGS[41]*

Accopac
Acetate
Aluminum
Aluminum foil
Armaflex
Artus shim
Asphalt-saturated sheathing felt

Backcheck felt
Bakelite
Binders board
Black fibre
Blotting paper
Bond paper
Bucar
Bucote
Buna N-rubber
Buna S-rubber

Cambric
Canvas
Canvas-based bakelite
Canvas-based phenolic
Cardboard
Celluloid
Cellulose materials
Cerafelt
Cerakote
Celcon
Chipboard
Chipboard-treated
Clear cellulose acetate
Cloth
Cloth-inserted rubber
Copper
Cork
Cork-rubber compositions
Cork-synthetic compositions
Crepe barrier paper

Deadening felt
Delrin
Duck
Duracel
Durocork
Duroid

EPDM
EPT
Embossed chipboard
Emery cloth
Ethafoam

Fabric supported rubber
Fairprene materials
Felt
Fibre, vulcanized
Fireboard
Fibreflex
Fiberglass
Fiberglass, neoprene coated
Fiberglass, silicone-coated
Fiberglass, teflon-coated
Fibre-kork
Filter felt
Firm pad felt
Fishpaper (armite)
Flexible fibre
Fluorglass
Fluorosilicone
Foam

Gasket felt
Graphite-coated materials
Graphited rubber
Gum rubber
Gummed kraft paper

Hemp
Hycar (GR-N) rubber

Jute
Jute-lined chipboard
Jute paper

K-grey paper
Kapton
Klingerit
Kraft paper
Koroseal

Leather
Leatherboard
Lexide
Lexan
Linen-base bakelite
Linen-base phenolic

Manila paper
Melamine
Metal finishing felt
Mold-resistant sheathing felt
Molybdenum filled materials
Monocast nylon
Mylar
Mystik tape

Natural rubber
Neoprene-asbestos, compressed
Neoprene-coated materials
Neoprene-cork compositions
Neoprene (GR-M) rubber
Nomex
Nylatron
Nylon

O ring cord
Oil-resistant material
Onion-skin paper

P.V.C.
Packtite
Paper
Paper-base bakelite
Paper-base phenolic
Panelyte
Parchment paper
Phenolics
Plastics
Polyamide
Polyethylene, linear
Polypropylene
Pressboard
Pure gum rubber

Red rope paper
Royal grey paper
Rubber-synthetic compounds

SBR rubber
Saran screen
Sheathing felt
Shim stock
Showcase felt
Silicone
Soft pad felt
Spauldite
Spauldo
Sponge rubber
Stencil board
Supercork
Superpak

Teflon
Teflon-coated fibreglass
Thio-flex
Thiokol-coated materials
Thiokol-impregnated leather
Transformer board
Treated leather
Trimming felt

Upholstery felt
Urethane, homogeneous
Urethane, foam polyester
Urethane, foam polyether
Urethane, foam scott felt
Urethane, liquid cast
Urethane, millable gum

Varnished cambric
Velbestos
Vellumoid
Vinyl
Vinylite
Viton
Viton sponge
Vulcanized fibre

Waterproofed chipboards
Wax-impregnated materials

*This is the best listing of its type to date, however, there are certain limitations that should be noted. It has been pointed out that neither is the list complete, nor would all the materials listed function in asbestos gasket applications. Therefore, this listing should be used only for general purposes. Specific materials listed should be further researched prior to immediate usage as replacement materials. In addition, products listed include generic materials and trade names.[43]

Nu-Board 1800[44,47]--

Nu-Board 1800 is currently being manufactured by Janos Industrial Insulation Corp. It is made of inorganic fiber and inert fiber suitably bonded to provide a material having physical characteristics similar to asbestos millboard.[44]

Nu-Board 1800 can withstand temperatures up to 982°C (1800°F) depending upon application. The tensile strength of Nu-Board 1800 is 4902 kPa (711 psi). The chemical resistance of Nu-Board 1800 is still being tested, however, it has been used as a filler in metal-clad gaskets. An important advantage of Nu-Board 1800 over asbestos millboard is its capability of being wet molded. Wet molding allows awkward shapes to be formed while wet and then dried back to hardness. When dried, molded Nu-Board 1800 can be coated with ceramic cement enabling it to resist temperatures up to 1260°C (2300°F) and more chemical attack. Table 56 lists the nominal physical properties of Nu-Board 1800.[48]

Nu-Board 1800 was developed not only for a gasket material but also as an insulation material. Table 57 lists some of the typical uses of Nu-Board 1800. Janos Industrial Insulation Corp., the manufacturer of Nu-Board 1800, is developing and testing a new asbestos-free product designed to replace compressed asbestos sheet. No information regarding its performance is currently available.[47]

Coramic, Victocor, and Solicor--[21]

These products from Dana Corp., Victor Products Division, are discussed here, although some aspects of their manufacture would classify them as "beater-add" in this report. Made of ceramics (Coramic) or graphite (Victocor, Solicor) they represent an effort by Victor to supply a product which is directly interchangeable with asbestos gaskets. They are competitively priced, have no current regulatory agency restrictions, and can seal components that asbestos cannot--namely, exhaust applications. As totally new products, their temperature resistance has been measured up to 1260°C (2300°F) and Victocor 289 which combines graphite, a steel core, and an adhesive, has the benefits of mechanical and chemical bonding. Victor's hard gaskets (the facings on these gaskets are made on papermaking--Fourdrinier--machines) range from cylinder head and intake manifold applications, to replacements for asbestos millboard. In one, a rubber bound facing material is mechanically attached to a perforated steel core; others use neoprene or nitrile bound facing materials. Victocor 809 is a totally new gasket composition aimed at the 1980's engines. Soft gaskets and packings are also produced--these require crush and extrusion resistance. Characteristics include compatibilty with aluminum flanges; resistance to engine coolants, fuels, lubricants, and oils; and torque retention properties.[21] The wide variety of gaskets offered, including mechanical testing literature, verifies the existence of many suitable substitutes to asbestos gaskets. Currently asbestos-free versions of Victor's Victocor, Solicor, Victopac, Corbestos, and Coramic materials are being sampled and tested by O.E. diesel and gasoline manufacturers in the U.S. and abroad.[22]

TABLE 56. NOMINAL PHYSICAL PROPERTIES OF NU-BOARD 1800[47]

COLOR: BEIGE	
DENSITY	66.8 lb/ft^3
TENSILE STRENGTH	711 lb/in^2
FLEXURAL STRENGTH	1280 lb/in^2
COMPRESSION @ 300 psi	30-40%
IGNITION LOSS	20% max.
MOISTURE CONTENT	3%
THERMAL CONDUCTIVITY	0.0636 BTU/Hr-Ft-F^o
FLAMMABILITY	WILL NOT BURN
HEAT RESISTANCE	UP TO 982°C DEPENDENT UPON APPLICATION
DIMENSIONS:	
THICKNESS RANGE	INCLUSIVE 3/32" to 1/2"
SHEET SIZE	40" X 40"

TABLE 57. TYPICAL USES OF NU-BOARD 1800[47]

• Lining furnances	• Cores for metal clad door
• Moving Pictures Booths	• Stove pad, welding pads
• Elevator Shafts	• Incinerators
• Ceilings, Walls exposed to heat	• Heater lining
• Gaskets	• Strongbox lining
• Stoves	• Kiln lining
• Electric Ovens	• Molded for troughs
• Glass Lehr rolls	• Cable protection
• Float glass conveyor rolls	

Gylon--[49]

Gylon gasketing materials, produced by Garlock, are fomulated by a proprietary process that permits fluorocarbon particles to be restructured with distinctive physical properties not found in Teflon. Three different types of Gylon are produced, each with varied characteristics: Fawn, Blue, and Black.[49] Continuous working temperatures for Gylon range from -212°C (-350°F) up to 260°C (500°F).

Gylon displays a resistance to creep, unlike Telfon resins. Gylon Blue was developed for low gasket loads such as in glass-lined pipe and reaction vessels. Gylon Black is filled with graphite to resist hydrofluoric acid.[49] Table 58 compares gasketing characteristics of Gylon to both Teflon and compressed asbestos, and also lists other physical properties of Gylon.

TABLE 58. GYLON® PHYSICAL PROPERTIES[49]

	35104 Fawn	35120 Blue	35101 Black	PTFE	Compressed Asbestos
Tensile Strength (PSI - Typical) (ASTM F39-59)	2100	2200	3500	2100	3000
Compressibility (% at 5000 PSI) (ASTM F36-66)	4-7	18-20	4-7	5-7	7-17
Recovery (% Minimum) (ASTM F36-66)	40	42	50	34	40
Creep relaxation (%)(ASTM F36-71) Method B at 3000 PSI 1/8"	58	70†	70	80	57
Elongation (%-Typical)(ASTM F39-59)	200	300	300	--	--
Modulus at 100% Elongation (PSI-Typical)(ASTM D1708)	1600	1600	2400	--	--
Durometer (Shore D)(ASTM D2240)	65±5	58±5	65±5	--	--
Specific Gravity (ASTM D792)	2.1	1.62	2.16	--	--
Dielectric Strength (V/MIL)(ASTM D149)	500	305	*	--	--
Volume Resistivity (OHM-CM) (ASTM D257) (BTU-IN/HR/FT2/°F)	2.0×10^{14}	2.6×10^{11}	*	--	--
Thermal Conductivity (ASTM D2214)	2.00	1.19	*	--	--
Coefficient of Friction - Static (ASTM D1894)	0.30	.19	0.22	--	--
Kinetic	0.22	.13	0.19	--	--
Flammability		Will not burn			
Bacterial Growth		Will not support			

†Tested at 1500 PSI
*Information available from supplier

Preox (PAN)--

According to the 1980 EPA/CPSC "Substitutes to Asbestos Conference Gaskets and Packings Roundtable Discussion,[37] Celanese has just begun to market a fiber called Preox (PAN) which is an intermediate material expected to be commercially available in the near future. Preox is a precursor to a carbon product. In carbon fiber production, the main cost factor is apparently a 50 percent yield loss which is made lower with this intermediate fiber product, thus reducing the initial production cost disadvantage. However, installation costs are such that the cost of fiber production is negligible. The fibers have over 10 percent elongation; they are based on rayon precursors which have only a 20 to 30 percent yield, but with Preox, Celanese uses the fiber itself (trade named Celiox ©) and therefore loses less in the production process. PAN produces a 50 percent yield polyacrylonitrile.

Klingersil C-4400--

A premium compressed nonasbestos material for general purpose use. This is composed of nitrile rubber bonded synthetic fibers and conforms to British and American physical standards. Some types use a mild steel wire mesh insert.[50]

Substitute Fiber Manufacturing Summary--

Manufacturing process--In the case of fiber-for-fiber replacements, the same methods used for asbestos packing and gasket manufacture are used for substitute fibers. A material such as DuPont's Kevlar is a pulp, produced in a process similar to wood pulping, resulting in a slurry material with short fibers of random length, amenable to use in wet or dry processes. Typical beater-add applications are a natural for this material.[37]

Substitute Product Manufacturing Summary--

Manufacturing process--In all cases,[30,35] substitute materials are manufactured by a proprietary process. All of the products manufactured by Victor Products are listed in this Gaskets and Packings versus the Paper Beater-Add section for continuity and because manufacturing process/material involved in final product/end uses overlap (see Product Substitutes section).

Name and number of manufacturers--A complete list of manufacturers of substitute products is impossible to determine at this time because, in many cases, this development work is confidential. Manufacturers of substitutes are unwilling to divulge this type of information for fear of losing their competitive edge. Consequently, the following list of substitute manufacturers is not exhaustive:

- Greene, Tweed and Co., North Wales, Pennsylvania
- Garlock, Inc., Palmyra, New York
- Janos Industrial Insulation Corp., Moonachie, New Jersey
- E. I. DuPont de Nemours & Co., Inc. Wilmington, Delaware

- Norton Company, Sealants Division, Granville New York
- Boise Cascade, Specialty Paperboard Division, Beaver Falls, New York
- Victor Products Division, Dana Corp., Lisle, Illinois
- Celanese Corporation, New York, New York
- Celotex Corporation, Tampa, Florida[51]
- Richard Klinger, Ltd.

Production volumes--Information on specific production volumes for substitute products listed in this report is not available at this time.

COST COMPARISON

For a fiber-for-fiber replacement, the cost of packings and gaskets is proportional to the cost of fibers as the manufacturing processes are identical. This assumes that the asbestos substitute gasket has been correctly selected for the specific application and will not prematurely fail because of a reaction between the fluid being contained and the gasket material. Otherwise, gasket life for substitutes is equivalent to that of asbestos gaskets. This service life may extend up to several years, or until the gasket is replaced during periodic maintenance or equipment overhaul. See Table 59 for a cost comparison of various fibers; Table 60 shows a cost comparison of asbestos sheet for gaskets and gasket sheet manufactured from various substitutes.

TABLE 59. COST COMPARISON BETWEEN ASBESTOS FIBERS AND SUBSTITUTES (1976 DOLLARS)[8,35]

Fiber	Approximate cost \$/lb (\$/kg)
Asbestos fiber	1.00 (2.20)
Glass fiber	0.75 (1.65)
Nomex - fiber	5.00-5.50 (11.00-12.00)
- continuous filament	6.50-10.00 (14.30-22.00)
Kevlar	5.50-6.00 (12.00-13.20)
Teflon	7.00-10.00 (15.40-22.00)
Kynol	3.60 (8.00)
Carbon	2.00 (4.40)
Ceramics - 3M	30.00-32.00 (66.00-70.50)

TABLE 60. COSTS OF ASBESTOS AND SUBSTITUTE GASKETING[4,44]

Material	Cost/sq ft 1/16" diam, \$ (m^2)
Asbestos Sheet Garlock 900	1.96 (6.43)
Asbestos Sheet Garlock 7006	1.17 (3.85)
Gylon®Fawn	8.61 (28.25)
Vegetable Fiber Garlock 681	0.51 (1.65)
Cork	0.53 (1.75)
Red Rubber	0.37 (1.20)
Nu-Board 1800	0.87 (2.85)

These tables show that the cost of Teflon fiber is approximately 7 to 10 times that of asbestos. Graphite (carbon) fibers cost approximately twice as much as asbestos and ceramic fiber prices vary greatly, from approximately 9 to 32 times that of asbestos. Gylon ranges from 4 to 7 times the cost of compressed asbestos sheet, and Kevlar 29 is also in this range at 5.5 to 6 times the cost of asbestos.[35] Nu-Board costs consistently less than asbestos sheet at approximately one-half to three-quarters the price of asbestos. Price information on Victor Product's gaskets was not available, however, literature reports that the current price structure is considered attractive.[22]

Of note here is that in many cases, the cost of the gasket or packing is insignificant compared to the cost of its installation.[4] Consequently, it is often more cost effective to install a higher quality and associated higher cost material rather than the lower cost-lower quality material. Lost production while equipment is down because of gasket replacement must also be included in the cost of the replacement.

In general, compressed asbestos sheet gasketing can be replaced with substitute materials at this time with little added expense to the customer unless the application is over 260°C.[3] Graphite and sheet metal gaskets can replace asbestos over 260°C, but their costs will constitute a major expenditure (5 to 7 times the price of compressed asbestos) plus additional plant maintenance. Rogers produces high temperature grades which have been tested up to 425°C (800°F) and yield results equal to and in some cases, better than, compressed asbestos. These grades, however, are sold at approximately 1.75 the price of asbestos.[38]

Specific to packings; it appears that substitute materials are both economically and physically a viable alternative to asbestos in every application. Since substitute materials result in less abrasion on rotating shafts and improved heat dissipaton, lower operating and maintenance costs are experienced. As a result, the new synthetic packings are cost competitive with asbestos packings. Table 61 shows the costs of various packing materials.

TABLE 61. COST OF VARIOUS PACKINGS[4]

Material	Suggested resale $/lb to consumer ($/kg)	$/lin. ft. (meter)
Graphited white asbestos	8.57-17.27 (19.00-38.00)	1.34-3.45 (4.40-11.30)
Graphited blue asbestos	21.22 (46.75)	3.45 (11.30)
Flax, plain or graphited	7.34-9.52 (16.20-21.00)	0.87-1.29 (2.85-4.25)
Flax, TFE-impregnated	11.15 (24.50)	1.34 (4.40)
White asbestos, TFE-impregnated	16.66-17.95 (36.75-39.50)	2.49-2.79 (8.20-9.15)
Blue asbestos, TFE-impregnated	26.72 (59.00)	4.61 (15.15)
TFE filament yarn	45.56 (100.00)	8.29-9.49 (27.20-31.15)
Kevlar, TFE-impregnated	28.42 (62.65)	4.24 (13.90)
Carbon/graphite filament yarn	51.68-161.16 (114.00-355.00)	7.38-18.52 (24.20-60.75)

CURRENT TRENDS

At least six manufacturers[4,21,42,45,46,47] of gaskets and packings are currently marketing or developing alternative products. Two manufacturers/distributors[4,42] conduct seminars for industry to present alternative materials.

Many gaskets are produced to meet military specifications. To a large extent, these specifications are composition standards in addition to performance standards. At this time, consequently, certain quantities of asbestos are required regardless of the performance of the alternatives. Without change in specifications, manufacturers are required to use asbestos in many of their products.

Nonasbestos packings provide superior life characteristics and lower friction and abrasion qualities than does asbestos.[3] It appears that the major obstacle in completely eliminating asbestos from packings is the resistance which sales and engineering people have to changing over to nonasbestos packings. This resistance to substitute usage may be a result of ignorance concerning the overall operating costs of utilizing asbestos packings.

It is perhaps interesting to consider the new options companies now have in purchasing nonasbestos gaskets and packings, by considering data from one of the producers of these materials--Victor Products. A description listing for their asbestos-free materials covers over 30 products, most of which can be used directly in replacing such asbestos products as Corbestos, Asbestopac, and other Victor materials.[52] Victor, in fact, has developed three classes of asbestos-free gasket materials: exhaust system gaskets (for high heat resistance), hard gaskets (strengthened with steel for applications such as cylinder head and intake manifold sealing), and soft gaskets (for general sealing with excellent crush-extrusion resistance).[53] Although many grades are direct replacements for current asbestos-containing materials as mentioned, others are new asbestos-free grades designed to fill other needs. Mechanical test data supplied[54] indicates equal performance (nonasbestos versus asbestos) in actual applications of operation on test engines. A record of over 300,000 miles of actual operation on field test vehicles for asbestos-free cylinder head gaskets shows no major functional problems.[55] In addition, specific customer switch-over trends are reported by Victor,[53,56] an indication that consumer knowledge in the area of substitutes is increasing.

As a result of current industry programs, it has been predicted that certain substitutes will take hold in the following established gasket applications:[22]

Application	Nonasbestos Replacement Material
Exhaust systems and turbochargers	Graphite, ceramic fibers and fillers, and mica, combined with stainless steel substrates
Cylinder head and intake manifolds	Organic fibers and binder, inorganic fillers formed by papermaking processes and combined with metal substrates
High load/high extrusion	Rubber-coated steel, cellulose fibers elastomeric binders, glass fiber with fillers and elastomeric binders, densified organic fibers and fillers with elastomeric binders, and liquid systems such as RTVs and anaerobics.

Embossed steel or aluminum with high temperature coatings is expected to continue use where engine structure permits.[22]

CONCLUSION

One of the greatest advantages of asbestos is its versatility coupled with low cost. As asbestos is so versatile, substitution requires diversified product lines. For this product category, a practically endless list of potential substitutes is available. In fact, in packing materials, the new synthetic materials are preferable to asbestos in capabilities they exhibit.

In gasket applications over 260°C, asbestos appears to have advantages (principally lower costs) over substitute materials. Graphite and metal gaskets and others produced by Rogers (up to 425°C) can replace asbestos over 260°C, but their costs are somewhat prohibitive. In applications under 260°C, there are a variety of substitutes which can replace asbestos with little added expense to the user. In addition, many fibers are available but have yet to be tried because of the present lower cost of asbestos.

In general, asbestos represents a familiar, time-tested fiber for use in gaskets and packings which companies have subsequently designed into many products. The asbestos easily met heat resistance, resiliency, and strength requirements as well as being chemically inert. However, as manufacturers have initiated research on potential substitutes, they have discovered not only a wealth of potential materials that are suitable for this use, but that they also possess qualities that are usually equal to or sometimes even better than the old asbestos product. For packings, the new synthetics not only have the capacity for replacing asbestos, but also can be applied in every application and will require less housekeeping and monitoring procedures, now required for asbestos.[3] For gaskets, again, the replacement materials exist such that compressed asbestos sheet use could be curtailed, with little added expense to the consumer unless the application is over 260°C. Between 260°C and 538°C, cost effective solutions are still being sought, although materials such as graphite and silica are available.[3] In addition to replacement material development, asbestos-free gasket materials which are truly new in the sense of not being a specific substitute for older asbestos-containing materials have been developed in this area. Examples include the high-temperature graphite sheet materials and ceramic fiber compositions.[53] As the replacement or service phase of the gasket business is the dominant area, it is important to note that nonasbestos substitutes have been developed for many of these applications, while in addition, new products have been developed for new niches. The use of asbestos-free gasket materials is not a new phenomenon in itself; rubber, saturated and unsaturated paper, felts, embossed metals, and cellulose fibers have been used effectively for years in sealing applications.[57] One of the most important new developments in mechanical gasketing applications has been support rendered to a rubber-fiber facing by a metallic core. Fibers can be asbestos or nonasbestos. The facing may be compressed or beater-add.[58] Developments such as this, along with new substitute products have increased attention on the gasketing field by many consumers.

In summary, although asbestos currently is present in the majority of U.S. gaskets (often these products have been 80 percent asbestos, with added polymer binder systems and fillers), there are disadvantages to asbestos. These include scarcity in the U.S. (most is imported), especially for longer grades (4 and 5 for example) which are the lengths used in gasket materials and which have been in tight supply for the past 4 years. In addition, asbestos does not always solve all of the problems being asked of it--often better heat resistance, sealability, and crush resistance are required. For years gasket material producers and designers have attempted to improve the binder system in gaskets; now they look to the other 80 percent of the gasket which represents a fiber. As in the other categories covered here, no one manmade fiber or other high temperature material approaches asbestos in its critical physical properties, but blends of other fibers and fillers discussed here have been successful. It is also reported that some companies have eliminated not only asbestos, but gaskets in general, from their current assemblies, replacing them with liquid sealant to reduce tolerances required for assembly.[22]

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4. Swanson, R. C., Sales Rpresentative, Colt Industries, Garlock, Inc. Mechanical Packing Division, Charlotte, NC. Meeting with Mr. T. Curtin, GCA Corporation, February 21, 1980.

5. Johns-Manville Corporation. Sealing Components, All You Need to Know about Gasket Materials. PK-132. Ken-Caryl Ranch, Denver, Colorado. November 1979. 17 pages.

6. Armstrong, Industry Products Division Accobest®, Accopac®, Armstrong Gasket Material Specifications. IP-926-175x. Lancaster, Pennsylvania. 5 pages.

7. Clifton, R. A. Preprint from 1980 Bureau of Mines Minerals Yearbook. Asbestos. p. 4.

8. Arthur D. Little of Canada and Sores, Inc. Characterization of the U.S. Asbestos Paper Markets. Report to the Government du Quebec, Ministere de l'Industrie et du Commerce. May 1976.

9. Telecon. Mr. Ambursal, Armstrong Cork Co., Lancaster, PA, (717) 397-0611, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 16, 1981, Call #20.

10. Telecon. Sales Representative, Detroit Gasket and Mfg. Co., Detroit, MI, (313) 968-2200, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 16, 1981, Call #21.

11. Telecon. Company Representative. Fitzgerald Gasket, Torrington, CT, (203) 482-9366, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call #37.

12. Telecon. Harvey Loud's Office, GAF Corp., New York, NY, (212) 621-5000, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 13, 1981, Call #1.

13. Telecon, Mr. McDoughall, Hollingsworth and Vose, East Walpole, MA, (617) 668-0295, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 16, 1981, Call #22.

14. Telecon. Company Representative. Janak Inc., Weatherford, TX, (817) 549-8771, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call #38.

15. Telecon. Raymond Croucheck, Lamont Metal Gasket Co., Inc., Houston, TX, (713) 222-0287, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call #39.

16. Telecon. Company Representative. Parker Seal Gaskets, North Brunswick, NJ, (201) 247-6800, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call #40.

17. Telecon. Company Representative, Sacomo-Sierra, Carson City, NV (702) 882-7560, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 17, 1981, Call #23.

18. Telecon. Company Representative, Standco Rubber Gaskets, Houston, TX (713) 944-3160, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call #42.

19. Telecon. Tony Rokos, Amatex, with Anne Duffy, GCA Corporation, GCA/Technology Division, May 4, 1981, Call #36.

20. U.S. Bureau of Mines, Mineral Industry Surveys, Asbestos in 1978, by R. A. Clifton, August 22, 1979.

21. Information from Victor Products Division, Dana Corporation; Exhibit 1 of October 21, 1981 letter and enclosures to Mr. Larry Dorsey, U.S. EPA, from John E. Zeitz, Division Chief Engineer, Victor Products Div. of Dana Corp., 1945 Ohio St., Lisle, IL.

22. Article in Diesel & Gas Turbine Progress magazine, What Will Replace Asbestos Gaskets?, by John E. Zeitz, July 1980; included as Exhibit 12 of Reference 21.

23. Newtex Industries, Inc. Zetex. All of the Protection But None of the Health Hazards of Asbestos. Victor, New York. 4 pages.

24. Colt Industries, Garlock, Inc., Mechanical Packing Division, Industrial Packing. Thermosil Textured Fiberglass Cloth, Tape, Tubing. A Nonasbestos Product. LX-7/79-10M. Palmyra, NY, July 1979. 7 pages.

25. Armco, Hitco Materials Division. Refrasil Insulation Textiles Can Take this Test! Can Yours? LHT/MD-10079 10MCP 11-79. Gardena, CA.

26. Colt Industries, Garlock, Inc., Mechanical Packing Division, Compression Packing. Thermo-Ceram®. CMP-121. Sodus, NY, February 1979. 2 pages.

27. Ceramic Fiber Products/3M. Nextel® 312 Ceramic Fiber from 3M. N-MHFOL (79.5) MP, St. Paul, MN. 4 pages.

28. Colt Industries, Garlock, Inc., Mechanical Packing Division. Nonasbestos Packings, Gasketing, Dynamic Seals, Expansion Joints, Oil Seals, Fiberglass Cloth. MP-902. Palmyra, NY. August 1979. 9 pages.

29. Armco. Hitco Materials Division. Hitco Aerospace Materials. LHT/MD-3278 3M TC 9-78. Gardena, CA. September 1978. 5 pages.

30. E. I. DuPont de Nemours & Co., Inc. Textile Fibers Department. Characteristics and Uses of Kevlar 29 Aramid Number 375. Wilmington, DE. September 28, 1976. 7 pages.

31. E. I. DuPont de Nemours & Co., Inc. Properties, Processing and Applications of Teflon TFE Fluorocarbon Fiber. Bulletin TF-2, Wilmington, DE. May 1978. 15 pages.

32. Armco. Hitco Materials Division. Refrasil Refractory Silica in Textile Form Insulation, Technical Data Bulletin Engineering Data. P.O. LHT/MD-3979 R 10M CP 10-79. Gardena, CA. October 1979. 4 pages.

33. Armco. Hitco Materials Division, Refrasil Refractory Silica in Textile Form Insulation Product Data Bulletin All Products. P.O. LHT/MD-1779 15 M CP 11-79. Gardena, CA. November 1979. 4 pages.

34. Colt Industries, Garlock, Inc., Mechanical Packing Division, Compression Packing. Graph-lock® Graphite Packing. CMP-123. Sodus, NY. 3 pages.

35. Chiostergi, R., Marketing Manager, E. I. DuPont de Nemours & Co., Inc., Wilmington, DE, (302) 999-3951, Personal Communication with Mr. Henderson, GCA/Technology Division, February 1, 1980. Notebook #07, Phone Call #20.

36. The Chemical Rubber Co., Handbook of Tables for Applied Engineering Science. Cleveland, Ohio. March 1970. Page 122.

37. Gaskets and Packing Roundtable Discussion, Substitutes for Asbestos Conference, U.S. EPA/CPSC, Arlington, VA, July 14-16 1980.

38. Letter from Robert F. Lee, Manager, Envir. Engineering, Rogers Corp., Rogers, CT, to Mr. Larry Longanecker, U.S. EPA, September 8, 1981.

39. The Chemical Rubber Co. Handbook of Tables for Applied Engineering Science. Cleveland, OH. March 1979. Page 122.

40. Greene, Tweed & Co. Palmetto® Packings, Tephite Style 1387. North Wales, Pennsylvania. 1979. 2 pages.

41. Excelsior, Inc. Advertising List of Raw Materials Publication No. 49758. Rockford, Illinois. 1 page.

42. Koehler, S., Product Manager, Greene, Tweed & Co., North Wales, Pennsylvania, (215) 256-9521, Personal Communication with Mr. Curtin, GCA/Technology Division, February 22, 1980. Notebook #06, Phone Call #40.

43. AIA comments to GCA Draft Final Substitutes Report, received 10/22/81.

44. Connolly, T., Janos Industrial Insulation Corp., Moonachie, NJ, (201) 933-5854. Personal Communication with Mr. Curtin, GCA/Technology Division, February 27, 1980. Notebook #06, Phone Call #42.

45. Pafsarella, M., Laboratory Director, F. D. Farnham Co., Necedah, Wisconsin, (608) 565-2241. Personal Communication with Mr. Curtin, GCA/Technology Division, February 11, 1980, Notebook #06, Phone Call #22.

46. Call, M., Product Development Manager, Boise Cascade Specialty Paperboard Division, Beaver Falls, NY, (315) 346-6111. Personal Communication with Mr. Curtin, GCA/Technology Division.

47. Letter and attachments from Connolly, T. J., Janos Industrial Insulation Corp., to T. Curtin, GCA/Technology Division, February 21, 1980, Information on asbestos substitutes.

48. Janos Industrial Insulation Corp. Nu-Board 1800. The Asbestos Millboard Replacement. Moonachie, New Jersey.

49. Colt Industries, Garlock, Inc., Mechanical Packing Division, Industrial Packing. Gylon. GSK-292. Palmyra, NY, January 1980.

50. Information from Richard Klinger, Ltd., supplied in Reference 21 letter.

51. Telecon. Company Representative, Celotex Corp., Tampa, FL, (813) 871-4811, with Anne Duffy, GCA Corporation, GCA/Technology Division, April 13, 1981, Call #3.

52. Reference 21, Exhibit #2.

53. Zeitz letter of Reference 21.

54. Reference 21, Exhibit #6.

55. Reference 21, Exhibit #7.

56. Caterpillar Tractor Company information supplied as Exhibit #8 of Reference 21.

57. Zeitz, J. E., J. A. Damusis, and J. A. Ulrich, Victor Products Div. Dana Corp. Designing with the New Asbestos-Free Gasket Materials. Presented at the International Congress and Exposition, Detroit, MI, February 23-27, 1981. SAE Paper #810366; included as Exhibit #4 of Reference 21.

58. Czernik, Daniel E., Fel-Pro, Inc./Felt Products Manufacturing Co., Recent Developments and New Approaches in Mechanical and Chemical Gasketing. Presented at the International Congress and Exposition, Detroit, MI, February 23-27, 1981. SAE Paper # 810367.

SECTION 8

PAINTS, COATINGS, AND SEALANTS

ASBESTOS PRODUCT

Special Qualities

Various types of paints, protective coatings, and sealants containing asbestos fibers are considered in this section including:

- Sealants
- Roofing coatings and roofing cements
- Automobile and truck undercoating
- Linings and coatings (nonasphalt)
- Texture paints
- Spackle and dry wall joint compounds

Sealants may be defined as liquid or semi-liquid fillers used to fill gaps in buildings and equipment construction. Coatings are covering products used to rejuvenate and/or protect various types of surfaces. Major manufacturers have indicated that asbestos is no longer used in texture paints, spackle and dry wall joint compounds; however, asbestos may still be present in many older installations.

Asbestos is used as a filler and reinforcement agent in diverse products to impart the following characteristics:

- Strength and durability
- Corrosion resistance - protection from weather, ultra-violet rays as well as water proofing
- Decay, vermin, and thermal resistance
- Sound deadening

- Stability prevents slump and flow on sloped or vertical surfaces
- Economy
- Viscosity and consistency

These characteristics are provided by the unique properties of chrysotile listed in Table 62. The affinity shown by asbestos for asphalt and the ability to control viscosity make it indispensable for asphalt based products. Viscosity control is essential for waterproofing. Without asbestos, asphalt compounds flow, leaving gaps that allow water to penetrate. Asbestos also provides excellent resistance to weathering, which is essential for outdoor sealant uses. The ability to bridge cracks and the fact that asbestos is available in various fiber lengths are important in joint compound and texture paint applications.

TABLE 62. UNIQUE PROPERTIES OF CHRYSOTILE ASBESTOS*

Property	Comment
Alkali resistance	Attack only occurs at extremely high concentrations and temperatures.
Fine fiber diameter	Provides many reinforcing fibers per unit weight.
High tensile strength	2,068,500 kPa to 3,447,500 kPa
High impact resistance	Not brittle at high temperatures; temperature at maximum ignition loss - 982°C
Temperature resistance	Good; brittle at high temperatures; temperature at maximum ignition loss - 982°C
Surface charge	Positive - provides chemical bond to many media, especially asphalt.
Fibrous form	Provides desired viscosity characteristics.
Inorganic origin	Not subject to attack by vermin.
Cost	Provides low cost/performance or cost/physical property ratio.

*Information from non-published document on Asbestos Dust done for OSHA, 1978.

Product Composition

A total of 10,900 metric tons of asbestos were consumed for this category in 1980, down from 19,100 metric tons in 1978.[1,2] Most asbestos used in roofing products is Grade 7 (shortest fiber length) chrysotile.[1] Over 90 percent of the asbestos used for the remaining paints, coatings, and sealants in this category is also Grade 7 chrysotile.[3] Approximately 98 percent of milled asbestos is Canadian.

The bulk of sealants are asphalt-based and contain 5 to 30 percent asbestos and 55 to 80 percent asphalt cut with up to 50 percent naphtha, mineral spirits or petroleum solvents to achieve the consistency appropriate for the desired use. Other ingredients include rust-proofing chemicals, pigments, powdered aluminum and other metals for heat reflectance and appearance, plaster of paris in spackle and dry wall joint compounds, insulating materials such as cork, emulsifiers, and resins, and miscellaneous fillers such as clay, barite, etc. The asbestos fibers are thought to be completely encapsulated in all of the products included in this category.

Roofing materials consist of coatings and cements containing 5 to 6 percent and 9 to 10 percent asbestos, respectively.[4] Both contain greater than 70 percent asphalt and are thinned to the desired consistency with naphtha, mineral spirits, or petroleum solvents.

Texture paints consist of a small amount of asbestos (less than 1 percent)[5] combined with various pigments and fillers.

For automotive and truck underlinings, the quantity of asbestos used in production may vary widely due to the rudimentary manufacturing process.[6]

Uses and Applications

Asbestos is normally used in asphalt and tar bases for such products as roof sealants, waterproof coatings, and automobile undercoatings. It has also been used in plaster of paris bases for spackle and dry wall joint compounds. Table 63 lists all uses of asbestos in the sealants category and the characteristics that make asbestos desirable here.

The primary use of asbestos is in roofing materials. Coatings are brushed or sprayed on and cements are trowelled on. Another important use of asphalt-based compounds is in automobile and truck undercoatings. Other asphalt-based compounds for waterproofing applications are listed in Table 63.

The remaining uses listed in Table 63 consume minor amounts of asbestos and in some cases no longer use asbestos. In 1977, the Consumer Products Safety Commission banned the use of asbestos in spackling and dry wall joint compounds.[7] Until then, nearly all of these products contained asbestos as a reinforcing agent. The use of asbestos in tennis court coverings and blacktop sealants has been cited in the literature, but the high viscosity imparted to these products by asbestos would inhibit sealant flowage into cracks and holes, which is a necessary property in these applications.[5]

TABLE 63. ASBESTOS USES IN THE SEALANTS CATEGORY[a]

Use	Distinguishing characteristics of asbestos[b]
Roof coatings	A, E, G
Roof cements	A, G
Flashing cements	A, G
Chimney stack paints	B, E, G
Automobile and truck undercoatings	A, B, E, F, G
Appliance insulating coatings	E, F
Corrosion-resistant coatings (resistant to salt solutions including seawater spray, organic acids, mineral acids, petroleum products)	B, G
Waterproof coatings for underground pipelines, concrete foundations, side walls, tanks, and other structures such as mobile homes and cooling towers in nuclear power plants	A, C, E, G
Anticondensation coatings for low temperature refrigeration services	B, G
Tile cements	A
Woodblock and concrete floor mastics	F, G
Spackle	A, C, D
Dry wall joint compounds	A, C, D
Caulking compounds	A, C, D
Texture paints	A, C, D
Sprayed-on ceiling finishes	A, C, D
Welding rod coatings	B, E

[a]Compiled by GCA Corporation during research on sealants; including phone calls listed in notebook 1-619-007-02, 1980.

[b]Letters correspond with the characteristics listed below. Stability, durability, and economy of asbestos are relevant to all uses listed above.

Key:
- A. Strength
- B. Corrosion resistance
- C. Decay resistance
- D. Vermin resistance
- E. Thermal resistance
- F. Sound deadening
- G. Waterproofing

Although asbestos may still be used in a number of minor products, many manufacturers are no longer including asbestos in their formulae. None of the welding rod or cement distributors contacted were familiar with currently manufactured products containing asbestos.[8-11] Small amounts of asbestos (approximately 1 percent) can be added to texture paints to provide texture and crack-bridging abilities. None of the texture paint manufacturers contacted precently use asbestos in their formulae.[12-15]

Product Manufacturing Summary

Production processes for sealants, coatings and paints are essentially the same. All three categories are therefore grouped as "sealant products" in this manufacturing process description.

Manufacturing Process--

Small manufacturing plants consist of one production line for all sealant products. Large plants producing a wide variety of products may have several production lines, each of which is designed for a specific product. Production facilities for all sealants are essentially the same. Operations are normally part time, especially for minor products with low market requirements. One major manufacturer (Armstrong Cork) of roof coating emulsions and joint insulation compounds stated that asbestos emulsions for roof coating are made 5 days per week in a one-or-two shift operation.[16] Other facilities are used less frequently to manufacture joint insulation. Because of seasonal fluctuation in demand, the process generally operates one shift from November through March and two shifts the rest of the year.

Sealants are produced by batch processes. Basically, the fiber is introduced, fluffed, put in a batch mixing tank, mixed with asphalt or tar and solvents or other additives as required for an even dispersion, pumped to packaging (containerizing) operations, and finally shipped out to market.

First, pallets of bagged asbestos are moved from a shipping or storage area to a staging area where the appropriate quantity is weighed out, and then dumped either directly into a hopper or into a fluffing machine. This machine is used to separate the compressed fibers facilitating dispersion and encapsulation during asphalt mixing. Typically, fluffed asbestos fiber is transferred to hoppers or directly to a batch mixing tank,[17] where they are mixed with other dry ingredients and the asphalt and solvents, as required. Mixing proceeds until the material is evenly dispersed. When a batch is finished, the material is pumped to the packaging (containerizing) operation and placed in appropriate sized containers. The predominant container for coatings is 5-gallon metal pails with sealed lids. Special orders may use drum containers. Bulk shipments in tank cars may take place, but are infrequent.

The batch sizes vary from several hundred gallons for small manufacturers with one production line to several thousand gallons for large manufacturers with several production lines oriented to specific products.[17] Batch sizes vary with size of company, type of product, method of containerization, type of existing equipment, and size of order. Sealant products are shipped out ready for distribution and use; therefore, there are no secondary fabricators.

Name and Number of Manufacturers--

Listed in Table 64 are the national manufacturers of asbestos sealant products.

Production Volumes--

Sealants consumed approximately 10,900 metric tons of asbestos or 3 percent of all asbestos used in the United States during 1980, according to the Bureau of Mines.[2] Asbestos Magazine estimated that 29,000 metric tons (32,000 tons) of asbestos or 5 percent of the United States total was consumed by the sealants category in 1978.[3] The value of asbestos consumed in 1978, calculated from Bureau of Mines consumption data and current asbestos prices, is $3.2 million. An expenditure of $3.2 million represents 1.6 percent of total annual sales for sealants, which amounts to approximately $200 million.[17]

SUBSTITUTE PRODUCTS

Methodology

Search Strategy--

The major national trade associations related to paints, coatings, and sealants were contacted regarding asbestos products and substitute products. Mr. Edward Fenner of Johns-Manville was given as a reference and subsequently contacted. He provided an excellent framework for the information provided in this section. The 20 largest United States asbestos product manufacturers as listed by Meylan[18] and various sources in the literature were investigated.

Summary of Contacts--

The following individuals and organizations provided useful information regarding paints, coatings, and sealants.

- Mr. Robert Pigg
  Asbestos Information Association of North America
  1745 Jefferson-Davis Highway
  Arlington, VA 22202

- Mr. Edmund Fenner, Director of Environmental Services
  Johns-Manville Corporation
  Ken-Caryl Ranch
  Denver, CO 80217

- Company Representative
  International Slurry Seal Association
  Suite 700
  1101 Connecticut Avenue NW
  Washington, DC 20005

- Mr. Ken Brzozowski
  TREMCO Incorporated
  10701 Shaker Boulevard
  Cleveland, OH 44104

TABLE 64. NATIONAL MANUFACTURERS OF ASBESTOS SEALANT PRODUCTS[18,19]

Manufacturer	Plant location	Product
Celotex Corporation (A Division of Jim Walters Corporation)*	Lockland, OH	Roofing products
	Houston, TX	Roofing products
	Memphis, TN	Roofing products
GAF Corporation	Millis, MA	Roofing products
	S. Bound Brook, NJ	Roofing products
Gibson Homans Co.	Cleveland, OH**	Roofing products
Johns-Manville	Waukegan, IL	Roofing products
	Manville, NJ	Roofing products
	Savannah, GA	Roofing products
	Marrero, LA	Roofing products
	Los Angeles, CA	Roofing products
	Fort Worth, TX	Roofing products
	Pittsburg, PA	Roofing products
Koppers	Youngstown, OH	Roofing products
	Wickliffe, OH	Roofing products
Monsey Products Co.+	East Rutherford, NJ	Roofing products
	Garland, TX	Roofing products
	Kimberton, PA	Roofing products
	Rock Hill, SC	Roofing products
	Troy, NY	Roofing products

*Sealants were produced in New Jersey in the past but this has been discontinued.[20]

**Corporate headquarters; other branches throughout the U.S.

+Telecon with manufacturer.

- Mr. William Pass, Lab Technician
  Synkoloid Company
  400-T Colgate Drive
  Atlanta, GA 30336

- Mr. Eugene Connor, National Sales Manager
  Johns-Manville Corporation
  Ken-Caryl Ranch
  Denver, CO 80217

- Mr. Fred Mallay, Sales and Marketing
  Consolidated Protective Coatings Corporation
  1801 E. 9th Street, Suite 202
  Cleveland, OH 44114

- Mr. Jack Fleming, Treasurer
  Bondex International
  2682 Pearl Road
  Medina, OH 44256

- Company Representative
  Igo's Welding Supply Company
  71 Arlington Street
  Watertown, MA 02172

- Mr. Colin Hemms, Marketing Manager for Roof Maintenance Products
  Koppers Corporation
  1050 Koppers Building
  Pittsburgh, PA 15219

- Mr. David L. Hall, Marketing and Technical Coordination
  Fiber Materials Incorporated
  Biddeford Industrial Park
  Biddeford, ME 04005

- Ray Connor, Director of Technical Division
  National Paint and Coatings Association
  1500 Rhode Island Avenue NW
  Washington, DC 20005

- Charles Spector, Vice President
  Everseal Manufacturing Company, Incorporated
  477 Broad Avenue
  Ridgefield, NJ 07657

- Harry Schwartz, Assistant Technical Director
  Dutch Boy Paints - Baltimore Paint and Coatings Group
  2325 Hollis Ferry Road
  Baltimore, MD 21230

- Jack H. Engel, Manager of Rubber and Plastics Lab
  Chrysler Corporation, Chemical Division
  5455 W. Jefferson Street
  Trenton, MI 48183

- Ken Heffner, President
  Electro Chemical Engineering and Manufacturing Company
  Acid Proof Lane
  Emmaus, PA 18049

- Sika Chemical Corporation
  P.O. Box 297 T
  Lyndhurst, NJ 07071

- Tom Dudick, President
  Dudick Corrosion-Proof Manufacturers, Incorporated
  578 E. Highland Road
  Macedonia, OH 44056

- N.R. Fernandez, Product Manager, Specialty Products
  Jim Walter Corporation (Celotex Corporation)
  1500 N. Dale Mabry Street
  Tampa, FL 33622

- Welders Supply Company, Incorporated
  1 Plant Street
  Billerica, MA 01821

Fiber/Product Substitutes

For this category, fiber and product substitutes are covered together since for many of the asbestos sealant and coating products the only substitutes available are the fiber replacement category. The consensus of the asbestos industry is that, for most sealant and coating products, no viable substitutes for asbestos exist at this time. Because of this, manufacturing plants, especially those producing roofing products, are subject to shutdowns as a result of slowdowns or strikes at the asbestos mines.[4] In an effort to avoid this problem in the future, most major manufacturers are actively searching for viable substitutes. An acceptable substitute must be:

- Noncombustible
- Resistant to decay, many acids, and vermin
- Durable
- Strong enough to reinforce other binders
- Unaffected by temperatures up to 500°C (930°F)
- Economic

There are no substitutes available that possess all of the above, but for applications where several of the characteristics are not necessary, a substitute may be applicable. Alternatives for each sealant category including special qualities, product composition, uses and applications, manufacturing and current market considerations are presented next, by individual category.

Sealants--

Special qualities--The resistance to decay, many acids, and vermin displayed by asbestos must also be a quality of substitute sealants, as well as the ability to withstand temperature changes and remain durable and effective. One alternative fiber, Pulpex, by Lextar, is currently being evaluated for this application. It gives high viscosity, improves slump resistance, and minimizes shrinkage. Specific Pulpex qualities include a specific gravity of 0.90, melting point of 165°C, average fibril length of 0.8 mm-1.5 mm, fibril diameter of 20-40 μ, a surface area of 5-10 m^2/g, a moisture content of less than 5% and an essentially inert chemical reactivity state.[21]*

Product composition--Caulks and sealants may be defined as liquid or semiliquid fillers used to fill gaps in building and equipment construction. They consist of elastomers and synthetic or natural oils which are fashioned in suitable consistency to be either pourable or of greater thickness. Kayocel®, created by American Fillers and Abrasives, Inc., of Bangor, Michigan, is a product that may replace asbestos in asphalt-based sealants. Their product brochures indicate that this substance is made from volatiles (such as cellulose, starch and wood fiber impurities) and ash. As the components of this material are essentially natural, common, every day products (derived, in part, from waste recycling methods of landfill throwaways), they are not listed in the NIOSH registry of Toxic Effects of Chemical Compounds (1977).[22] Another substitute product that is currently being evaluated for caulk and sealant applications is Lextar's Pulpex polyolefin pulp fibers. A suggested formulation for this particular product is represented by Pulpex-P (polypropylene), Grade AD-H for chlorinated rubber mastic. In percent by weight figures, this may contain the following:

19.3	chlorinated rubber
5.7	chlorinated paraffin
9.5	another chlorinated paraffin
3.2	Pulpex
4.8	TiO_2
46.0	Toluene
11.5	aliphatic distillate

*Reacts with strong oxidizing agents at elevated temperatures.

Uses and applications--Currently, only a very small amount of asbestos fiber is thought to be used in caulks and sealants. It appears that only in some aircraft sealants asbestos has not been replaceable to date. No regulations exist to date banning the use of asbestos in caulks and sealants; industry has found customer resistance in certain cases where substitute material use has been questioned, but, in general, it is felt that this category has alternative products available, either currently or under formulation. For example, Pulpex grade AD-H dry fluff polypropylene pulp may replace asbestos in trowelable mastics that are formulated with chlorinated rubber or paraffin used for crack filling of concrete and corrosion prevention.[21]

Manufacturing summary--Specific details about substitute product manufacture were not obtained for this category; however, it is assumed that most are made by batch process as described in asbestos sealant manufacture. It is known that Pulpex is made by adding sufficient solvent to cover the blade of a Cowles disperser, then mixing in ingredients at 2,000 rpm until smooth. After this, other components such as Pulpex are added and again, this time at a slow speed, the batch is mixed until smooth.[21]

Roof Coatings and Cements--

Special qualities--For both roof coatings (cold applied liquids) and roof cements (trowel applied compounds with a consistency of soft margarine), no single raw material has been found that can either replace the functions performed by asbestos in solvent thinned asphalt roof coatings or equal the properties of asbestos fiber in achieving needed cement body. In the case of cement substitution, the product must still be suitable for troweling and at the same time must contain enough bitumen after evaporation of the solvents to deposit a thick film on the roof surface which also resists weathering.[23]

Asbestos is usually used, due to the fact that:

- It enables the liquified asphalt to remain as a protective layer on the surface in question, otherwise it would penetrate entirely into the surface it should be rejuvenating; on surfaces where penetration would be minimal (such as metal) or with a great slope, the asbestos fibers stop running or sagging.

- It reinforces the asphalt; after the solvents have evaporated, the asbestos fibers prevent the asphalt from cracking as expansion and contraction from temperature fluxuations affect the surface.

- It retards the oxidation and deterioration of the asphalt from the sun rays.

- It retards melting and running of the roof coating in the event of fire.[23]

Any substitute product must also possess such properties. Several companies have investigated the use of other available fibers such as fiberglass, polyethylene, polypropylene, polyesters, acrylics, cotton, and other threads and fibers, but none have proven to be an acceptable substitute for asbestos.[4,5,24,25] A major problem is that none of the above become wetted by the asphalt; they "ball-up" when applied with a trowel.[4] Fiberglass provides adequate reinforcement but does not contribute to the viscosity of the product and lacks chemical affinity for asphalt. A number of proprietary materials are currently being investigated but more specific information is not available in most cases. Information on Pulpex by Lextar was available, and will be covered here.

At low concentration and in combination with talc, Pulpex is reported to improve product mixture uniformity with excellent wet and dry slump resistance. It can also be airless sprayed. Specific qualities include, in percent by weight, brookfield viscosity (cps) at 22°C (73°F) and 10 rpm of 22,000 and 270,000 cps for roof coating and roof cement respectively. Product uniformity data includes, after 22°C (73°F)/7 days a slight bleeding and stirring in for both products, and after 65°C (150°F)/7 days more bleeding and stirring in. A "pass" rating was given on wet slump resistance at 38°C (100°F), dry slump resistance at 65°C (150°F) and pliability at 0°C (32°F).[21] It should be noted that only a low concentration of Pulpex is needed to achieve the same viscosity level as with asbestos.[21]

Product Composition--There are a number of types of roof coatings, the largest segment of sales being devoted to asphalt liquified with solvents and bodied with asbestos fiber. The asphalt is liquified with solvents so that heating is not necessary before application.

Roof cements, used in large quantities for construction and repair of all types of roofs, commonly consist of solvent thinned asphalt or coal tar bodied into a heavy consistency with asbestos and other mineral fillers.[23]

Substitute products have attempted to replace the asbestos mentioned above with replacement fibers. Tremco uses a cellulosic material costing approximately $1.35/lb. The average fiber length in their product is greater than the asbestos used in roofing sealants and only one-sixth as much fiber is required in the product.[24]

Consolidated Protective Coatings Corporation uses a fiberglass/asbestos mixture in its roofing sealants. The fiberglass, which has longer fiber length, forms an interlocking "jackstraw" mesh with the shorter asbestos fibers improving the strength of the product. However, this combination is not actually a substitute because the quantity of asbestos is comparable to that used in conventional sealants.[25]

One Lextar Pulpex product consists of (% by weight):[21]

	Roof Coating	Roof Cement
Ashpalt cutback (65% solids)	87.5	70.0
Talc (5 μ average size)	5.5	13.5
Talc (16 μ average size)	5.5	13.5
Pulpex P* grade AD-HR	1.5	3.0
	100.0	100.0

*Pulpex "P" is the polypropylene pulp

Others are made with aluminum paste resulting in aluminum asphalt roof coatings.[21]

Uses and applications--Roof coatings are used to rejuvenate and protect most types of roofs, except the typical home owner's shingle roof. They are often found on home garages, porch decks, apartment houses, sheds, farm buildings, industrial buildings and commercial buildings of all sorts, including stores, shopping centers and office buildings. They can also be used as water proofing mastics on porous walls of buildings above and below ground and on surfaces such as concrete block, poured concrete and brick. They are applied either by brush or by spray. Roof cements are used to seal the openings too large for liquid application. Again, they are used on almost every type of building, no matter what type of roofing system is employed, including, in the case of cements, the typical shingle roofed home. They are used to seal such places as vent pipes, chimneys, roof heating and air conditioning units, gutters, gravel stops; anywhere a vertical and horizontal surface meet or where a projection is encountered. One Pulpex grade has been designed specifically for use in asphalt, solvent cutback coatings, and mastics.[21]

Manufacturing processes--Industry has had a strong incentive to find ways of manufacturing roof coatings and cements without asbestos fibers. Asbestos supply may be disrupted and cannot be assured, and other alternatives are currently being tested. However, there are several factors in the production of substitute coatings and cements that influence the inability, to date, to produce equal quality alternatives to the asbestos products. As has been previously discussed, asbestos is unique among known raw materials in that it is a completely inert, indestructible mineral that can be processed into a fiber. This fiber partially adsorbs the vehicle into which it is placed, becoming an integral part of that medium without settling or floating. With the addition of only small amounts of asbestos fiber, a large degree of body can be added, turning a liquid into the consistency of soft butter. In comparison, glass is unabsorptive so the coating is not homogeneous, and it also floats in roof coating mediums. Rock wool also lacks absorption properties. Fiberous talcs, wollastonites, ceramics, and clays are not fibrous enough to duplicate the performance of asbestos. Most other fibers available are organic-they melt, deteriorate on aging and also are likely to have poor chemical resistance.[22]

Therefore, it seems at present that the only method of manufacturing reasonably satisfactory asbestos-free roof coatings and cements is to combine a substitute fiber (usually of less than satisfactory quality) with a variety of mineral fillers, wetting agents, plasticizers and synthetic thixotropes. With a great variety of different roof coatings, cements, and mastics, this leads to many different new formulations needed. With present tests, the end product has always been a medium containing less asphalt, tar, or other water-proofing oil and much more filler material than when asbestos is used, often leading to a lessening of waterproofing and weathering properties, and a 30 to 70 percent increase in energy requirements for manufacture.[23] In addition, many substitute formulas do not meet present Federal Specifications on asphalt roof coatings and cements, as they exceed the maximum filler content permitted. Supply considerations must also be injected into the substitute market picture. Some of the alternative raw materials are highly specialized and only produced in small volumes. These types of materials would need time to be brought up to a sufficient volume level, if increased production was feasible at all.[23]

General manufacturing considerations follow. Tremco, Inc. reports that they have a proprietary substitute that has the required affinity for asphalt to provide appropriate biological and spraying characteristics.[24] Koppers Co. has also developed an acceptable but proprietary substitute for which no information is currently available.[26] Gibson Homans Company manufactures some asbestos-free roof coatings and cements but, as they are about 15 percent more expensive and also inferior to the asbestos products, they are not marketed in the U.S.[23] However, they are shipped to Sweden where asbestos has been banned, so manufacturing performance on a large scale could be observed if a company in the U.S. thought this to be a marketable product.[22] Some Pulpex products are manufactured in a Hobart® mixer; others, with a Cowles disperser as well. This product notes that material safety data sheets should be obtained prior to the use of these products.[21]

In summary, for this product category, asbestos-free solvent based roof coatings and cements may be produced by complicated formulating techniques, but they are generally more expensive and inferior in quality and some do not meet Federal Specifications. In addition, the asbestos industry submits that asbestos used in roof coatings and cements is completely encapsulated.[26]

Automobile and Truck Undercoating--

Special qualities--The properties of asbestos that are important for automobile and truck undercoating products are: high thermal resistance, affinity for asphalt to control viscosity, high fiber density, strength, and durability. The affinity for asphalt is required to ensure complete encapsulation of fibers. Small fiber dimensions result in a high density product with soundproofing abilities. High tensile strength is needed to hold the product together and thermal resistance is required to retain this strength at the elevated temperatures experienced. Control of viscosity is also required to retain tensile strength at the elevated temperatures and to prevent unwanted flowage of the undercoating resulting in the loss of waterproofing abilities. No suitable substitute is being manufactured. A substitute should possess the qualities listed to be an adequate replacement for asbestos. Substitutes such as fiberglass, fibrous alumina, and magnesium silicate fiber do not possess the affinity for asphalt or the ability to control viscosity which make asbestos unmatched for use in undercoating products.[6] Zinc may be used to provide resistance to rusting, but, by itself, it is not sound deadening;[4] therefore it is often used in combination with asphalt/asbestos undercoating.

Product composition--A representative of Chrysler Corporation suggests that fiberglass, fibrous alumina, and magnesium silicate fiber might be used as asbestos substitutes. Zinc has also been used in undercoating.

Uses and applications--Undercoating products are used to protect the undersides of cars and trucks from wear due to road conditions and weathering from the natural elements. They also help to deaden sound transferred from the road to the driver.

Manufacturing summary--Information for substitute product manufacture was generally not available. It is known that Pulpex may be able to serve in this area.[21]

Linings and Chemically-Resistant Coatings (Asphalt- and Nonasphalt-Based)--

Special qualities--Asbestos is used in nonasphalt-based coatings resistant to alkali, acid, water, and weather. Table 65 lists substitutes for these applications, their physical characteristics and special qualities.

TABLE 65. SUBSTITUTES FOR ASBESTOS IN RESISTANT LININGS AND COATINGS[27]

	Resistant characteristics				
Name	Alkali	Acid	Water	Weather	Physical characteristics
Talc	F	G	E	E	Fibrous-platelike
Asbestos	F	G	E	E	Fibrous
Barite	G	G	G	G	Cubical, heavy
Diatomite	P	E	E	E	Porous
Silica	P	E	E	E	Hard, sharp crystals
Clay	F	G	F	G	Platelike
Mica	G	G	G	G	Platelike, used to reduce moisture vapor transfer

Key: P = Poor G = Good
F = Fair E = Excellent

Product composition--Substitutes include talc, barite, diatomite, silica, clay, and mica as listed above. In addition, a representative of Dudick Corrosion-Proof Manufacturing, Inc., states that they have a new proprietary formula for acid and alkali resistant tank linings.[28] However, at this time, no specific information on this product has been made available. Electro Chemical Engineering and Manufacturing Company has tried high temperature glass as a substitute for asbestos in asphalt mastics. It did not prove to have the necessary affinity for asphalt and therefore could not be sprayed to produce a desirable pattern.[29]

Uses and applications--Linings and coatings are used wherever there is a need to protect a product from such conditions as saltwater, salt solutions, organic acids, mineral acids or petroleum products.

Manufacturing summary--Manufacturing information for the Dudick and Electro Chemical Engineering products was not available.

Spackle and Dry Wall Joint Compounds--

Special qualities--Asbestos was used to impart lubricity, workability, water binding and pseudoplasticity to a wet mix, and, being fibrous, provided reinforcement to the cement upon drying.[29,30] However, the use of asbestos in these products was banned in 1977. Substitute products developed, such as attapulgite clay, exhibit good plasticity, stability, water retention, cohesiveness, and viscosity.

Another substitute product developed by Hercules, Inc., Delaware uses water-insoluble carboxymethylated cellulose derivatives and is said to be substantially equivalent in performance to those products currently available commercially. They are suitable for manual application by trowel or can be applied mechanically with the addition of water at the job site just prior to use.[30]

Product composition--Joint cements heretofore employed with wallboard have contained a resinous binder, limestone, clay, mica, and asbestos as the principal dry ingredients which were mixed with water, forming a dope. The new attapulgite product is a fibrous clay with a chain-like structure. The cellulose derivative is made up of a resinous binder, mica, clay, and limestone as major dry components, along with a fibrous, carboxymethylated, substantially water-insoluble cellulose derivative selected from the class consisting of cross-linked carboxymethyl cellulose (CMC) and other cellulose derivatives. Typically, a dispersant, a defoamer, a preservative, and a thickener are also added. These joint cements are marketed as fully formulated ready-to-use cement; i.e., already containing water, as well as in dry powder form to which water is added at time of use.[30]

Uses and applications--These products are used with wallboard to form seals in their construction. The use of attapulgite for this application is said to increase product price by only 12 to 13 percent. The price of the cellulose product is also competitive. This may be the best candidate for the replacement of asbestos in these products.

Manufacturing summary--Details on the manufacture of the attapulgite product were not available for this report. Hercules reports that their product is made by preparing a ready-mix formulation, to which water and binder latex are charged in a mixing apparatus. This is mixed for a short time before the dispersant, defoamer, and preservative are added. The dry ingredients (limestone, mica, clay, carboxymethylated cellulose derivative, and structure additives, if used) are dry blended and added incrementally to the stirred liquids. After the last of the dry ingredients are added, the mix is stirred for about another 10 minutes at low speed with occasional stopping to scrape down the sides of the bowl.[30]

Texture Paints--

Special qualities--Major texture paint manufacturers (Bondex International and the Synkoloid Company) indicate that asbestos is no longer used in texture paints.[12,13] This is confirmed by several minor manufacturers and distributors. This is probably a result of the Consumer Product Safety Commission ban on consumer patching compounds containing respirable asbestos because these products are manufactured by the same companies. Properties required in a substitute are resistance to vermin, heat, ozone, and ultraviolet and infrared radiation.[14] The substitute must also be available in various fiber dimensions to produce differing textures. To date, it has been found that the organic substitutes react with infrared, ultraviolet and heat radiation and ozone; hemp is often attacked by vermin, and the inorganics do not possess the fibrous structure necessary to bridge cracks. Therefore, texture is now often produced by worker's tools.[15] However, some products by Lextar--several Pulpex grades--are covered here. One is a replacement for interior textured paints, and another for ceiling texture compounds. Also being evaluated is a product for exterior block filler paints. Special qualities of the interior texture paint include: specific gravity of 0.96, melting point of 132°C, moisture content of 50 percent and essentially inert chemical reactivity.* The block filler is similar; special qualities for the ceiling texture compounds include the same specific gravity, melting point, and inert activity, but a moisture content of less than 5 percent.[21]

Product composition--Possible substitutes include fiberglass, rayon, nylon, polypropylene, polyester, and hemp fiber. Other fillers that can be used are clays, diatomite, talc, perlite, silica, mica, barite, calcium carbonate, bentonite and others. None possess the combination of properties attributable to asbestos and all yield inferior products.

*Swells in chlorinated hydrocarbons.

An example of the suggested formulation of two Pulpex products is given below:[21]

Interior textured paint (in lb/100 gal)		Ceiling texture compounds (parts)	
Water	416.8	$CaCO_3$	592
Hydroxyethyl cellulose	3.0	Diatomaceous silica	7
Dispersant	11.2	Clay	13
Mildewcide	3.0	Talc	89
TiO_2	50.0	Ground mica	89
Mica, water ground	50.0	Calcined aluminum silicate	148
Polyvinyl acetate latex	180.0	Starch	36
Diatomaceous silica	100.0	Carboxymethyl cellulose	4
Calcium carbonate	414.0	Preservative	2
Attagel® 40	15.0	Polystyrene foam chips	4
Pulpex-E,[a] grade D-V	14.8	Pulpex-E,[a] grade D-H	4
		Water	Added to desired viscosity

[a]Pulpex "E" is polyethylene pulp.

Uses and applications--Texture paints are used to give a textured appearance to ceilings and other substrates where this look is desired. As mentioned, worker's tools can perform the same function. The Pulpex products improve stipple characteristics and hiding power in interior textured paints; provide heavy body to block filler paints, reducing mud cracking and improving bridging of block imperfections; and in ceiling texture compounds, give bulk, crack resistance, and improved adhesion.[21]

Manufacturing summary--Interior texture paint substitutes made by Lextar are mixed, ground, and then mixed again until dispersed. Exterior block filler paints are mixed, dispersed under high shear, then other ingredients are added under low shear, finally mixing, until dispersed. The ceiling texture compound ingredients are dry blended in a Hobart® mixer. Resulting formulations can be sprayed with a texture spray gun.[21]

Pipe Coatings--

Special qualities and product composition--With respect to pipe coatings, there are a variety of asbestos-free product substitutes for asphalt mastic. The following materials have been used as successful pipe coatings in various applications:[31]

- Enamels - Enamels have been widely used as a protective coating for 65 years, combined with glass or felt to obtain mechanical strength for handling. Enamel systems may be designed for installation and use within an operating range of 1°C to 82°C. Enamels are effected by ultraviolet rays and hydrocarbons.

- Extruded Plastics (Polyethylene and Polypropylene - The extruded plastic coatings have been available to the industry since 1965 and their growth and acceptance has been remarkable during this period. Initial problems of stress, cracking and shrinkage have been minimized by better quality and grade of high molecular weight polyethylene resins.

- Fusion Bonded Thermosetting Powder Resins - Fusion bonded powder coatings were first introduced in 1959 and have been commercially available since 1961. These coatings are applied to preheated pipe surfaces 204°C to 260°C with and without primers. This coating is applied in a 12 to 25 ml thickness. The fusion bonded powder coatings exhibit good mechanical and physical properties and may be used above or below ground.

- Liquid Epoxy and Phenolics - There are many different liquid systems available today that cure by heat and/or chemical reaction. Some are solvent types and others are 100 percent solids. Their use is mostly on large diameter pipes where conventional systems may not be available or where they may offer better resistance to operating temperatures in the 93°C range.

- Tapes - Polyvinyl, polyethylene and coal tar tapes are widely used in the field for joint coating protection or for odd shapes or bends on mill applications. The important developments in plastic tapes have been an increase in their thickness, use of stronger resins and improved adhesion by the use of new types of adhesives and primers.

- Wax Coatings - Presently not very much is heard regarding the use of wax coatings. However, they have been in use for 48 years and are still utilized on a limited basis. Microcrystalline wax coatings are usually used with a plastic overwrap for protection.

- Polyurethane Foam Insulation- Efficient pipeline insulation has grown increasingly important as a means of operating hot and cold service pipelines. While generally used in conjunction with a corrosive coating, if the proper moisture vapor barrier is used over the urethane foam, effective corrosion protection is obtained.

- Concrete - Mortar lined and coated pipe have the longest history of use to protect steel or wrought iron from corrosion. However, today concrete as a corrosion coating is mainly limited to internal lining. The external application is applied over a corrosion coating for armor protection and negative buoyancy in marine environments.

Uses and applications--Pipe coatings are used to protect pipes from hostile surroundings. It is a difficult task to select a coating that will be an effective electrical insulator and provide other desirable characteristics which will achieve a users needs. The selection of a coating requires knowledge of the operating and installation conditions to be able to evaluate the properties of the pipe coatings required to fill these needs.

Manufacturing summary--Information on the manufacturing processes used to make the alternatives listed was not available.

COST COMPARISON

Roof Coatings and Cement

Table 66 lists costs for several fibrous materials proposed as substitutes. All of these fibers are significantly more expensive and are thought to yield an inferior product. Other roof coating data is found in Table 66a for Pulpex fiber. Here it may be seen that costs are equal, thus negating cost as a factor in roofcoating choice. In some instances, the substitution of an alternative fiber for asbestos may require manufacturing changes which would involve additional costs.

TABLE 66. COSTS OF FIBROUS MATERIALS FOR ROOFING COATINGS COMPARED WITH GRADE 7 CHRYSOTILE[1]

Fiber	Cost in $/lb ($/kg)
Chrysotile (Grade 7)	0.06-0.12 (0.13-0.26)
Fiberglass	0.40 (0.90)
Polypropylene	0.35 (0.80)
Cellulose	0.60 (1.30)
Cotton	0.20 (0.45)
Proprietary No. 1[a]	1.35 (3.00)

[a]Tremco, Inc.

TABLE 66a. PULPEX VERSUS ASBESTOS PRICES, $/lb ($/kg)

Product	Pulpex	Asbestos
Asphalt roof coating	0.13 (0.26)	0.12 (0.24)
Aluminum asphalt roof coating	0.45 (0.90)	0.45 (0.90)
Asphalt roof cement	0.11 (0.22)	0.11 (0.22)

Linings and Coatings

Several substitutes for asbestos in linings and chemically-resistant coatings are currently commercially available. Depending on the particular application, these substitutes may perform as well or better than asbestos. Cost data is presented in Table 67. In terms of cost, the asbestos substitute materials are comparable to asbestos.

TABLE 67. COSTS OF SUBSTITUTES IN RESISTANT LININGS AND COATINGS[32]

Name	Cost in $/lb ($/kg)
Chrysotile (Grade 7)	0.06-0.12 (0.13-0.26)
Talc	0.06 (0.13)
Barite	-
Diatomite	-
Silica	-
Clay	0.04-0.08 (0.09-0.18)
Mica	0.05 (0.10)

Texture Paints

There are several fiber substitutes available to replace asbestos in texture paints. A cost comparison is given in Table 68. Even the higher priced nonasbestos products cost no more than asbestos products because only a small amount of fiber (approximately 1 percent) is involved. In spite of any cost difference that might acrue, these substitutes may yield an inferior product. Texture may also be produced by workers tools, thereby eliminating the need for an asbestos substitute fiber for this application.

TABLE 68. COSTS OF SOME SUBSTITUTES FOR ASBESTOS IN TEXTURE PAINTS*

Material	Cost in $/lb ($/kg)
Chrysotile (Grade 7)	0.06-0.12 (0.13-0.26)
Fiberglass	0.05 (1.10)
Mica	0.05 (0.10)
Talc	0.06 (0.13)
Carbonate	0.04-0.08 (0.09-0.18)
Nylon	0.60 (1.30)
Polypropylene	0.35 (0.80)

*Information from nonpublished document done for OSHA-"Part I: Technological Feasibility Assessment and Economic Impact Analysis" on Asbestos Dust.

Sealants, Automobile and Truck Undercoating, Spackle and Dry Wall Joint Compounds

It has been indicated by Chrysler Corporation that potential substitutes for undercoatings cost 4 to 30 times as much as grade 7 chrysotile asbestos. No cost data was available for any of the other product categories. The use of asbestos in spackle and dry wall joint compounds was banned by the Consumer Product Safety Commission in 1977. Nonasbestos containing formulations have since become available at competitive prices.

CONCLUSION

Availability and properties of substitutes for asbestos-based sealants have been investigated for six product types:

- Sealants
- Roofing Coatings and Cements
- Automobile and Truck Undercoatings
- Linings and Coatings
- Texture Paints
- Spackle and Dry Wall Joint Compounds

The properties required for these applications span the range of properties required by most of the asbestos-based sealant products. To some degree it is possible to draw conclusions for applications not specifically discussed herein.

The first two products have generally been compounded with asphalt and asbestos. Early attempts to find a direct replacement for asbestos fibers failed because most fibrous materials are not readily wetted by asphalt as is asbestos. For sealants, it is generally felt that alternative products are available, even if their properties are not quite equal to those of asbestos. Kayocel is such a product, produced by Fillers and Abrasives, Inc. of Michigan. Asbestos-free solvent based roof coatings and cements may be produced by complicated formulating techniques, but they are generally more expensive and inferior in quality to asbestos and may not meet Federal specifications.

Commercially available asbestos-free, asphalt-based roofing products that provide the properties of asphalt-asbestos-based products are gaining market acceptance. Lextar, Tremco, Inc., Koppers Co., and Gibson Homans Co. all report the availability of products in the premarket or early commercial stages that can be used as direct replacements for asbestos in asphalt-based roofing products. Apparently these fiber substitute products are readily wetted by asphalt. In some respects, their quality is not yet known although Lextar has provided information on the special qualities of their product. It is not known whether these same products would be suitable for use in undercoatings. Chrysler Corporation has indicated that fiberglass, fibrous alumina, and magnesium silicate fiber may be used in this area, although they are much more expensive and lack special qualities.[6]

Asbestos-based linings and chemically resistant coatings are formulated both with and without asphalt. For asphalt formulations, several mineral reinforcing materials (e.g., talc, barite, diatomite, perlite, silica, clay, and mica) are available as substitutes for asbestos. Performance details are not available.

Use of asbestos in texture paints, spackle, and dry wall joint compounds has been banned since 1977. Some substitutes are listed that may provide a product of the quality of asbestos-based texture paint, although test comparisons with asbestos were not available. Attapulgite is a suitable substitute for asbestos in spackle and dry wall joint compounds. Pulpex is available for texture paints and block fillers. In addition texture may now be added by worker's tools.

With respect to pipe coatings--enamels, extruded plastics, fusion bonded thermosetting powder resins, liquid epoxy, tapes, wax coatings, polyurethane foam insulation, and concrete are all possibilities for substitution.

Overall, this category appears to have some feasible substitutes, but a quality replacement for asbestos across the board for the many applications mentioned is lacking. However, new data in this area has provided additional products in many areas which may prove capable of replacing asbestos in all areas and have already proved acceptable in some.

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SECTION 9

REINFORCED PLASTICS

ASBESTOS PRODUCT

Special Qualities

Asbestos fibers have been used in combination with plastics since the 1920's when asphalt floor tiles were first introduced.[1] Asbestos fibers, when added to polymeric materials, modify the physical and chemical characteristics of the composite. Fibers, in general, function as both fillers and reinforcing agents. The benefits of using asbestos derive from the fact that asbestos has the advantages of both a mineral and a fibrous binder carrier with reinforcing action.[2]

Asbestos is particularly useful in molding compounds because it will impart very good surface finish, toughness,* resistance to heat and fire, and less shrinkage and warpage than other fibers. Also, the addition of asbestos improves the handleability of the product during processing. For example, putty-like compounds become much less sticky.[4]

Product Composition

Asbestos fibers are used to reinforce many plastics including phenolic, urea, melamine, unsaturated polyesters, diallyl phthalate prepolymers, epoxies, silicones, polypropylene and nylon. Phenolic molding compounds (thermosetting polymers) are the major users of asbestos in reinforced plastic applications outside of floor coverings, friction materials and gasketing, which are discussed in other sections of this report. Consequently, the following discussion focuses primarily on phenolic molding compounds.

Bulk fiber is the most widely used form of asbestos in combination with plastics. Chrysotile is used in the largest quantities in plastics for molding compounds, with crocidolite, anthophyllite, tremolite, and amosite used in lesser amounts. Chrysotile classified according to the test used by the Quebec Asbestos Mining Association (QAMA) in grades 1 through 5 is normally used for its reinforcing properties. Grades 6 and 7 fibers are used for their thixotropic characteristics (to control flow), heat resistance, dimensional stability, and low cost. The crocidolite and anthophyllite varieties of asbestos are used for specialty purposes where corrosion resistance is important.[5]

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*Toughness refers to the ability of the molded material to resist impact (high strain rate) mechanical loading. The Izod test is an impact strength test which is one of several methods of characterizing toughness.[3]

A breakdown of the various chrysotile grades and crocidolite and anthophyllite asbestos used in bulk by primary plastics manufacturers in 1980 is as follows: chrysotile grades 1, 2, 5, and 7, 1400 metric tons, and crocidolite, 100 metric tons. Thus, total consumption of asbestos for plastic products was 1500 metric tons, down more than 3400 tons from 1978 figures.[6]

Today, as in the past, most of the asbestos used in plastic molding compound manufacture is chrysotile Grade 7, a short fiber that functions more as a filler than as a reinforcing agent.[2]

Rogers Corporation, one of the primary manufacturers of asbestos-reinforced phenolic molding compounds, reports that their asbestos products contain from 10 to 55 percent asbestos depending on product application.[5,*]

Uses and Applications

Asbestos-reinforced plastic molding compounds are used in a variety of applications including the electrical, electronic, automotive, and printing industries. In particular, the Rogers Corporation uses asbestos in the following products: asbestos-reinforced board material used in the printing industry as a matrix from which multiple rubber or plastic printing plates can be molded; automobile transmission reactors which are employed to direct the flow of transmission fluid; commutators for electrical motors, switches, and circuit breakers.[4] Rogers Corporation's RX 468 DN (asbestos-reinforced plastic) is General Motors' choice for molded commutators used in fan drive motors installed in its new 1980 front wheel drive (X-Model) compacts.[7] GM says the asbestos material retains its strength at temperatures over 500°F, has high impact strength and dimensional stability, and is more economical than equivalent glass-and-mineral filled materials. Asbestos-filled phenolics may also be used to make pot handles and various knobs and other components of large and small appliances, such as clothes washers and dryers, dishwashers, refrigerators, portable heaters, popcorn poppers and broilers.[8]

Product Manufacturing Summary

Manufacturing Process--

The manufacturers of asbestos-reinforced plastic products can be divided into two segments. A small number of primary manufacturers produce molding compounds in pellet or flake form, package it, and sell this granulated material to a myriad of secondary manufacturers where the final product is shaped and finished. The primary manufacturing steps consist typically of: (1) fiber receiving and storage; (2) fiber introduction; (3) dry blending; (4) resin formation; and (5) packaging and shipping. The secondary manufacturing steps usually are at a facility remote from the primary processing and consist of: (1) resin receiving and storage; (2) resin introduction; (3) forming; (4) curing; (5) finishing; and (6) product packaging and shipping to consumers.

*In addition, Rogers offers a complete line of nonasbestos reinforced molding material.

Name and Location of Manufacturers--

The most important primary manufacturers of phenolic molding compounds which currently produce asbestos-filled compounds are listed in Table 69.

TABLE 69. PRIMARY MANUFACTURERS OF PHENOLIC MOLDING COMPOUNDS[1,9,a]

Plant name	Location
Plaslok Corporation	Buffalo, NY
Plastics Engineering	Sheboygan, WI
Reichhold Chemicals	Elizabeth, NJ
Resinoid Engineering	Skokie, IL
	LaPorte, IN
	Newark, OH
Rogers Corporation	Manchester, CT

[a]Augmented by GCA telephone contact.

Production Volumes--

In 1976, 19,500 metric tons of asbestos fibers were consumed in the production of asbestos plastic molding compounds as classified by the Bureau of Mines.[10] In 1978, however, the Bureau of Mines reported that only 4,900 metric tons of asbestos were used in the production of plastics in the United States,[11] and in 1980 the figure had decreased to 1500 metric tons.[6]

SUBSTITUTE PRODUCT

Methodology

Search Strategy--

An extensive literature search was conducted to obtain information on the use of asbestos in reinforced plastics and to identify substitute products. This literature search concentrated on the use of journals to obtain the latest developments in the quickly changing reinforced-plastics industry. Upon completion of the literature study an extensive telephone survey was conducted to confirm information obtained in the literature survey and to acquire new information.

Summary of Contacts--

The following people were contacted in investigating reinforced plastics.

- Leon Meyer, Hooker Chemicals & Plastics Corporation
  Durex Division, N. Tonawanda, NY
  February 1980

- Roger Porter
  University of Massachusetts
  Amherst, MA
  February 1980

- Ronald Mount, Fiberfill
  Evansville, IN
  February 1980

- Robert Squire, NYCO
  Division of Processed Mineral Corporation
  Willsboro, NY
  February 1980

- Vincent R. Landi
  Rogers Corporation
  Rogers, CT
  February 1980

- David Shenefield
  Washington Penn Plastic Company
  Washington, PA
  February 1980

- Bill Colclough
  Fiberite Corporation
  Winona, MN
  February 1980

- Joseph Harris
  Union Carbide
  Chicago, IL
  February 1980

- Joseph Pesce
  NVF Company
  Kennet Square, PA
  February 1980

- John Ellis
  Plastics Engineering
  Sheboygan, WI
  February 1980

- Mary Ann Atchley
  DuPont
  Wilmington, DE
  February 1980

- Mr. Groane
  General Motors
  Detroit, MI
  February 1980

- Sales Manager
  General Electric
  Pittsfield, MA
  February 1980

- Donald Randolph
  U.S. Gypsum
  Chicago, IL
  February 1980

- Society of Plastic Engineers
  Greenwich, CT
  February 1980

- Society of the Plastics Industry
  February 1980

In researching this section, it was found that there are many fillers and reinforcements available to replace asbestos in phenolic molding compounds. Asbestos is not usually used unless special properties of this material are required. In order to substitute for asbestos, often two or three ingredients must be combined to achieve the same qualities. Whether the substitutes provide the required properties available in asbestos-reinforced molding compounds at a reasonable cost is debatable in some instances. However, manufacturers are finding alternatives for a majority of products previously reinforced with the shorter-fibers of asbestos in which the physical properties of the substitute product are equal to or exceed the asbestos product they replace.* All manufacturers of phenolic molding compounds have found suitable substitutes for certain products and many manufacturers have been able to completely eliminate the use of asbestos. Research and development in reinforcement technology has produced several new materials which are potential substitutes and has also improved existing substitutes. A description of materials that are currently substituted for asbestos (mostly short fiber) and those which may be viable substitutes in the near future follows.

Fiber Substitutes

Fibrous Glass--

Special qualities--Fibrous glass is the principal reinforcing material in plastics and is an integral part of most new engineering plastics. Manufacturers have chosen glass as a suitable substitute for asbestos in many applications for many years. Manufacturers are continually improving on the properties of glass reinforcements.

Fiberite has recently introduced upgraded versions of its 4000 series of glass-loaded (10 to 40 percent) compounds with heat resistance in the 260° to 316°C range. Designated the 4000F series, the improved materials are said to be based on new fiber technology that boosts physical properties in molded parts as much as 20 percent. The new glass-reinforced compounds are said to be particularly suitable for applications involving lightweight, thin-wall parts.[12]

*For the long fiber-reinforced compounds, substitution is a more difficult technical problem.[3]

Early in 1979, General Electric introduced its Genal GF-7000 series - a line of glass-reinforced, asbestos-free phenolic molding compounds formulated to meet more demanding structural and dimensional stability requirements, and to provide long-term heat resistance at temperatures up to 260°C,[13] which is comparable to heat resistance properties of asbestos-reinforced materials. Glass content ranges from 20 to 40 percent of total filler; the balance is mineral. According to General Electric, parts molded of the GF-7000 retain 80 percent of their physical properties after 20 hours of continuous exposure to 204°C.[14]

Genal GF-7021 and 7021P are medium glass-content materials that are designed to replace die-cast metals and long-fiber asbestos compounds.[14] They are especially well-suited for use in commutators, flat-iron skirts, motor housings and transmission components. Glass-reinforced phenolic such as GF-7000 series materials, significantly reduces current leakage in commutators as compared with commutators molded in asbestos-filled phenolic.

Several drawbacks in replacing asbestos fibers with glass fibers have been reported in the past, but have since been overcome with new product development. The Rogers Corporation once reported that glass fibers provided the bulk and strength needed for many applications, but, because of their brittleness, they were unsuitable for many molding applications their customers used.[4] Now, however, Rogers has developed the RX600 and 800 series of glass-reinforced products which are suitable in these applications.[3] Another prime consideration in molding a product was the resin's ability to flow. Glass fibers were at first acceptable only in very simple molds; however, they have now been adapted for use in complex molds and for fine detail requirements. In addition, the abrasiveness of glass which was thought to affect the "tool wear," or durability of processing equipment, has now been overcome.[3]

Product composition--Fibrous glass substitutes are simply made by the addition of glass fibers to products as opposed to asbestos fibers.

Uses and applications--Fibrous glass may be used in many of the phenolic molding compound applications that asbestos is used in.

Manufacturing summary--The manufacturing process used for glass phenolics is similar to asbestos; however, glass fibers are only acceptable in very simple molds (as they tend to segregate from the resin binder and fracture in complex molds) or for fine detail requirements (see Special Qualities). Glass is also abrasive, affecting the durability of the processing equipment. For certain reinforced phenolics, the use of glass may necessitate a change in processing equipment.

Carbon Fiber--

Special qualities--Carbon fibers are characterized by a combination of lightweight, high strength, and high stiffness.[15] Typical carbon composites have a Young's modulus which is one order of magnitude greater than asbestos-reinforced materials.* Carbon fibers are very fragile in comparison to asbestos and glass.[3]

Product composition-- Specific ingredients used in carbon reinforced phenolics were not available.

Uses and applications--Carbon fiber composites were originally developed to provide the aerospace industry with a strong, stiff, lightweight construction material. The composites then found their way into such sports equipment as golf clubs, fishing rods, and tennis rackets. Detroit's search for lightweight automotive components led to the use of carbon fiber composites for such parts as leaf springs, drive shafts, push rods, and side door instrusion beams. Other industrial applications include high-speed, low-inertia textile machine parts and various components of the equipment in which alignment, mechanical vibration, and fatigue are of principal concern.† Carbon fiber cannot be used as an asbestos substitute in applications requiring electrical insulation.[3]

Manufacturing summary--Manufacture of carbon-reinforced phenolics is presumed to be similar to that of asbestos phenolics. Detailed processes were not available. It is known, however, that carbon fibers require compounding with low shear mixing equipment.[3]

Aramid Fiber--

Special qualities--Aramid fiber is characterized by low density and high tensile strength and flexural modulus. It has a useful temperature range to 204°C.

Product composition--Exact specifications for this product were unknown.

Uses and applications--Introduced commercially in 1972, aramid fiber is finding broad application where lightweight, high strength and stiffness, resistance to stretch, and resistance to damage are important.[16] The fiber originally was developed to replace steel in radial tires. These properties are key to its successful use as reinforcement for plastic composites in aircraft, aerospace, marine, automotive and other industrial applications, and in sports equipment.† As with carbon fiber, aramid fibers are not likely to be utilized as an asbestos substitute in molding compounds.[3]

Manufacturing summary--Details on manufacture are not available. It is known that aramid fibers are difficult to handle in conventional compounding equipment.[3]

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*A high elastic modulus implies a large resistance to deformation or a stiff material. However, high modulus is not always desirable. This is especially true in the case of molded commutators. Toughness is sacrificed.[3]

†However, it should be noted that carbon and aramid fiber costs are prohibitive as compared to asbestos and glass.

Wollastonite--

Special qualities--Special qualities of wollastonite were not available. It is known that the hardness of wollastonite causes tool wear and harms machinability.[3]

Product composition--Wollastonite is a naturally occurring calcium silicate which is a mined, fibrous or needle-like shape material that is being used as an asbestos substitute.[8]

Uses and applications--Wollastonite is being used in combination with other additives in substitute compounds for short-fiber-filled asbestos materials. It does not provide the required mechanical reinforcement for high strength compounds.[3] The U.S. Mining Enforcement Safety Administration (MESA) has classified wollastonite as a "nuisance dust" and the National Institute for Occupational Safety and Health (NIOSH) has determined that the mineral is neither a fibrogenic nor carcinogenic substance.[8]

Manufacturing summary--The primary supplier of wollastonite is NYCO, a Division of Processed Minerals Corporation, Willsboro, NY. The other supplier is R. T. Vanderbilt Company, Incorporated, Norwalk, CT. Specific manufacturing processes are unknown.

Processed Mineral Fiber--

Special qualities--Special qualities of processed mineral fiber are unknown. However, its safety category, as covered by pertinent OSHA regulations, is that of an inert mineral dust.

Product composition--Processed mineral fiber is made from blast furnace slag and silicates.

Uses and applications--This fiber is reported to be able to reinforce a variety of plastic materials, including phenolics, nylons, polybutylene, epoxies, and polyolefins.

Manufacturing summary--This product was recently developed by Jim Walter Resources, Inc., specific manufacturing information was unavailable.

Polyethylene Fiber--

Special qualities--Polyethylene fibers are not yet currently available although they may be a viable alternative in special applications in the near future. Polyethylene fibers are high-modulus reinforcing fibers priced low enough to fill the gap between carbon and glass.[17] However, according to researchers at the University of Massachusetts, lightweight high-modulus (10 million psi) polyethylene fibers have relatively poor thermal resistance properties when compared to asbestos.[18]

Product composition--High modulus reinforcing polyethylene fibers make up this substitute.

Uses and applications--Potential use in ranges between carbon and glass.

Manufacturing summary--Not yet available.

Product Substitutes

Clay--

Special qualities--Hooker Chemical-Durez Division has produced a full line of granular and modular glass-filled, asbestos-free phenolics for many years, but the supplier has come up with a new variation - a highly heat-resistant, all-mineral-filled compound that is very competitive with glass/mineral materials.[8] Labeled Molding Grade 156, it is said to provide moldability superior to the asbestos-containing products it replaces. According to the supplier, parts molded from this product retain 50 percent of their properties after 24 hour exposure to 232°C, and 50 percent after 1,000 hours at 191°C.

Product composition--The composition of this compound is proprietary; however, it is believed to be a clay base. The properties of clay reinforcements are enhanced by adding silane coupling agents to improve flexural modulus.[19]

Uses and applications--Among the intended applications of this compound are appliance appearance components, where it provides heat resistance and dimensional stability. It is also aimed at such uses as auto carburetor spacers, sealing rings, thrust washers, speedometer sleeves, appliance terminals, probe controls, insulators, and light baffles.

Manufacturing summary--Manufacturing information was not known. The manufacturer of the product is Hooker Chemical-Durez Division.

Talc--

Special qualities--General Electric, the product manufacturer, claims that this material has the same basic properties - including impact strength, dimensional stability, and heat resistance - as their previous asbestos-filled products. GE admits that some minor product strength is sacrificed by using this new material, and that more breakage can be anticipated as compared to asbestos-filled phenolics; however, they suggest that manufacturers can compensate by building thicker walled products. Talc is good to 232°C.

Product composition--General Electric's asbestos-free Genal phenolics (apart from their new glass-filled GF-7000 series) utilize talc, in conjunction with aluminum silicates and cellulose fibers as the major reinforcement material. Like clay, the flexural modulus is improved by adding silane coupling agents.[19]

Uses and applications--The predominant use for talc is for heat resistant phenolic molding compounds in the medium temperature applications (its limit is 232°C).

Manufacturing summary--Allegedly, there is no significant difference in the price between the asbestos-filled and the Genal product, and the same processing equipment can accommodate the new material. Montana Talc Company produces a silane-treated ultra-fine particle talc for nylon and ABS plastics.

Mica--

Special qualities--Mica has proven to be a suitable substitute for asbestos in a variety of resins, however, it has had limited success when used in phenolic molding compounds. Although mica reportedly builds stiffness much more than equivalent loadings of asbestos, experiments performed by a mica producer, Marietta Resources International, reportedly showed that mica-filled phenolics cannot be exposed to elevated temperatures for long periods without blister formation. However, this company also reports that better property retention is exhibited for phenolic samples containing finer grades of mica.[19]

Product composition--Mica-based materials are expected to help solve the asbestos replacement problems in several plastic resins.[19] In the forefront is mica-filled polypropylene. Washington Penn Plastic Company recently introduced two of these compounds under its Micalite tradename. One is mica-filled polypropylene to which a small amount of chlorinated paraffin has been added; the other uses a silane coupling agent. Research work by Ford Motor Company resulted in the development of chlorinated-wax-mica-polypropylene. Addition of a small amount of powdered chlorinated paraffin increases tensile and flexural strengths, flexural modulus, and heat distortion temperature.[19]

Uses and applications--Ecoplastics, Ltd., states that mica-reinforced thermoplastics are useful in applications that require low permeability, high modulus of rigidity, high heat distortion temperature, dimensional stability and low warpage.[20] This includes use in many new industrial and automotive products.

Manufacturing summary--Detailed manufacturing processes were not available.

Calcium Sulfate--

Special qualities--United States Gypsum reports that calcium sulfate provides improved production rates, allows high loadings, and results in low densities in the finished product. However, calcium sulfate does not add reinforcing properties to molding compounds.[21] In addition, its solubility in water impairs wet electrical properties when used as an asbestos substitute.[3] Consequently, calcium sulfate is not a viable substitute in all applications. It is believed that the material could be blended with reinforcing fibers to broaden its application.

Product composition--This new material, recently put on the market, is a fine calcium sulfate that United States Gypsum's Chemical Division has introduced under their Terra Alba, Snow White, and CA-5 trade names. More specific product ingredients were not known.

Uses and applications--As this product cannot add reinforcing properties to molding compounds, it can only be used in certain applications to date, where this property is not necessary. Use could broaden if reinforcing fibers could also be added to aid in strengthening the resultant products.

Manufacturing summary--As in the products mentioned previously, specific product manufacturing processes are unknown. As for product manufacturers, in general, the manufacturers which are producing asbestos substitute molding compounds are those manufacturers which previously produced asbestos molding compounds (see Asbestos Product Manufacturing Summary). In addition, there are a variety of manufacturers that produce substitute molding compounds that, although not intended to replace asbestos, are viable alternatives. Such companies as Union Carbide, DuPont, and U.S. Gypsum produce innovative products which are potential substitutes. The exact number of manufacturers which may have a product capable of being an asbestos substitute cannot be determined under the scope of this project. However, in the description of substitute materials detailed in this report, an attempt was made to identify manufacturers of each substitute material.

The production volumes for manufacturers of asbestos substitute materials were considered proprietary information in most instances and were not provided. Consequently, production volumes of substitute materials were not available.

COST COMPARISON

There are several potential substitute fillers and/or reinforcing materials for replacing asbestos in certain reinforced-plastics applications. Several substitute materials are economically competitive with asbestos while others are not. The use of the more expensive substitute materials may be offset by the associated costs of using asbestos. However, man-made substitute materials may require more expensive manufacturing techniques to overcome problems associated with poor wettability of these fibers relative to asbestos fibers.[16] In addition, there may be a higher cost entailed in procuring man-made materials as opposed to refining asbestos.[22] A cost comparison of substitute materials with asbestos is shown in Table 70.

CURRENT TRENDS

There is a well-defined trend to replace asbestos in phenolic molding compounds, documented by both the literature and by numerous conversations with manufacturers of reinforced phenolics.[23] This movement was initiated in 1972 when General Electric Company's Plastic Division started replacing asbestos in their phenolic products with a new talc-based filler. Since this time, they have not used asbestos in their reinforced plastics and have reported that they have consistently proven asbestos-free materials meet any design criteria called for in phenolics. Through their proprietary technology, they feel that they have developed a line of asbestos-free products equal to or better than the discontinued asbestos-filled grades. The Durez Plastics Division of Hooker Chemical (who reportedly have 40 percent of the total reinforced phenolic market) has developed a nonasbestos reinforced product. By February 1979, their entire line of phenolic molding products (e.g., automotive,

TABLE 70. COST COMPARISON[5]

Substitute material (manufacturer)	Price compared to asbestos	Performance and comments
Fibrous glass	75¢/lb ($1.65/kg) vs 55¢/lb ($1.20/kg) long fiber asbestos; 50¢/lb ($1.10/kg) vs 10¢/lb ($0.22/kg) short fiber asbestos*	May be used for higher temperature applications; new glass fiber technology enhances the physical properties of the material; problems with abrasiveness of glass wearing out processing equipment; process change probable.
Genal GF-7000 glass-reinforced compounds (General Electric)	$1.25/lb ($2.75/kg)† vs $1/lb ($2.20/kg) asbestos-reinforced compounds	Same as above.
Molding Grade 156 all-mineral-filled compounds (Hooker-Durez)	51¢/lb ($1.10/kg) vs $1/lb ($2.20/kg) asbestos-reinforced compounds	Moldability superior to asbestos; good heat resistance and dimensional stability.
Talc	6¢/lb (13¢/kg) vs 5-10¢/lb (11-22¢/kg) asbestos	Loss of strength but can compensate by making thicker walled product; currently used as an asbestos substitute; limited to 232°C applications.
Mica	5¢/lb (11¢/kg) vs 12-25¢/lb (25-55¢/kg) for asbestos^	Adds dimensional stability and increases strength of plastics; high aspect-ratio mica purported to provide middle ground in cost performance between inorganic particulate fillers and fiber reinforcement; blended with higher priced substitute materials.
Micalite chlorinated wax-mica-polypropylene (Washington Penn Plastic Co.)	41¢/lb (90¢/kg) vs $1/lb ($2.20/kg) asbestos-reinforced compounds	Same as above.
Carbon fibers	$10-12/lb ($22-26.50/kg) vs 13-25¢/lb (30-55¢/kg) asbestos	For high strength applications; increases acid resistance in phenolics; also used as filler for thermoset plastics; high heat resistance; specialty applications only.
Clay	75¢/lb ($1.65/kg) vs 55¢/lb ($1.20/kg) long fiber asbestos; 50¢/lb ($1.10/kg) vs 10¢/lb (22¢/kg) short fiber	Used as filler, no reinforcement; new clay base compositions are reported to maintain the acceptable balance between heat resistance and impact strength.
Aramid fibers	$6-8/lb ($13.20-17.60/kg) vs 13-25¢/lb (29-55¢/kg) for asbestos	Used in specialty plastic reinforcements; too expensive for asbestos replacement in phenolic molding compounds; can be blended with less expensive materials.
Calcium sulfate	2-3¢/lb (4-7¢/kg) vs 13-25¢/lb (29-55¢/kg) for asbestos	Provides improved output rates, allows high loadings, and results in low densities; high heat resistance; does not add reinforcing properties to molding compounds - limited application.
Wollastonite	3-13¢/lb (7-29¢/kg) vs 13-25¢/lb (29-55¢/kg) for asbestos	Reported to be an asbestos replacement in phenolics. The material is cost competitive with asbestos. Has been classified as merely a "nuisance dust."
Processed mineral fiber	Approximately twice as expensive as asbestos	Has been accepted as an asbestos replacement in phenolics and epoxy gel coats.
Polyethylene fibers	No data	Still in development stage; high modulus but poor heat resistance properties.

*Glass- and asbestos-reinforced phenolic molding materials themselves are in the same approximate price range of $1/lb ($2.20/kg).

†Price varies for different grades and depends on quantity ordered.

^General Electric incorporates mica reinforcement into Valox 752 polybutylene terephthalate (PBT) thermoplastic polyester, in a material introduced for electrical and electronic applications. This material sells for about 90¢/lb ($2/kg).[20]

appliances, wiring, communications, electronics, and electrical switch gear) was reinforced with this new, nonasbestos material.[24] Fiberite Corporation, which was at one time a small factor in asbestos-filled phenolics, also eliminated asbestos use several years ago. Only recently has it become apparent that all remaining producers of phenolic molding compounds intend to pursue a thorough phase out of asbestos, which they hoped to accomplish by the end of 1980.[8] Rogers Corporation, Reichhold Chemicals, Plastics Engineering Company and Valite Division of Valentine Sugars, Incorporated, all now intend to discontinue using asbestos as fast as they can develop suitable substitutes for their remaining asbestos-filled grades. Only one small producer, Resinoid Engineering Corporation has said that it has no plans at the moment to drop asbestos; rather, the company appears to be taking a "wait-and-see" attitude regarding new proposed government regulations.[8] In addition, a very minor amount of asbestos-filled phenolic is being imported from Canada.[8]

This decline in overall asbestos use reflects a dramatic trend toward the use of substitute fibers. Manufacturers have reported that customers have demanded asbestos-free compounds.[13]

Plastics Engineering (reported to be the second largest producer of phenolic molding compounds) currently uses asbestos in some of their products, but they have a program to replace asbestos in all their phenolic molding compound products. This program began in 1977 and should be completed in 1 or 2 years.[25] Currently, every asbestos-reinforced product is available in asbestos-free versions which are reinforced with glass fibers, clay and talc. The asbestos-free versions are reported to have the same physical properties as the asbestos products they replace. The time required to completely discontinue the production of asbestos-reinforced materials is due to the fact that not all of Plastic Engineering's customers have made the switch to the asbestos-free versions. Customers find that they must modify their molding processes to handle the asbestos-free molding material. Nevertheless, Plastics Engineering made the decision to replace asbestos in their product because many of their customers preferred not to process compounds containing asbestos fiber in their operations.[9] After many customers converted to asbestos-free compounds, the demand for asbestos-filled compounds diminished substantially. The shrinking demand caused the need for a reevaluation and more realistic apportionment of manufacturing costs to the reduced production volume of compounds that contain asbestos. In addition, Plastics Engineering reports difficulty in obtaining an adequate and dependable supply of the type and grade of asbestos suitable for molding compounds. Plastic Engineering has urged all customers to adapt to asbestos-free compounds as soon as possible.

Reinforcement suppliers are increasing the size of their facilities to keep pace with anticipated sales growth. For example, Micro Materials has built three plants in the last few years for production of its Micro-Mix (a combination of mica flakes, glass flakes, spheres, granules, and additives), and continues to increase production by 10 to 20 percent every 4 months.

Owens Corning Fiberglass recently started up a new reinforcement plant at Amarillo, Texas, with a nominal capacity of about 90,000 metric tons. Certain-Teed Products has upgraded its facility at Wichita Falls, Texas, to 50,000 metric tons, and PPG Industries Glass Fiber Division is devoting more of its annual 118,000 metric tons output to reinforcements. Expansion is also expected from Reichold Chemicals, which took over Ferrios glass fiber operations.

Dupont recently announced a major expansion in aramid. Involved is a $200 million investment that will triple capacity (to 18,000 metric tons) at Richmond, Virginia, by 1982, and expand capacity at Laplace, Louisiana, for making aramid ingredients.[16] The buildup will increase capacity in the reinforcement grade (Kevlar 49) from 1800 to 5445 metric tons over the 3-year period.

The introduction of carbon fibers on a large scale in the aircraft industry may give a big additional boost to the acceptance of carbon reinforcements in plastics in many industries.[19] Lear Aviation Corporation is developing a prototype of a private business airplace that will be made almost entirely from carbon fiber reinforced plastic. The current price of carbon fibers is expected to be cut in half in the near future. Production is increasing as shown by Hercules, Inc., which now has a 90 metric ton/yr carbon capacity at Magna, Utah, and plans to expand to 205 metric ton/yr by 1980.[19] Union Carbide has produced a new pitch-based carbon fabric for stampable thermoplastic automotive parts.

Increased usage of wollastonite as an asbestos substitute is also anticipated. Jim Walters Resources, Inc. reports a growing list of customers in the processed mineral fiber market. A solid indication of the growth of precompounded mica-reinforced thermoplastics is the number of companies offering such materials, including Washington Penn Plastics, Fiberfill, Thermofill, A. Schulman and Ecoplastics, Ltd. of Canada.[22]

Despite the high-heat performance and mechanical properties provided by asbestos, the Rogers Corporation intends to phase out the use of asbestos as quickly as asbestos-free alternatives gain customer acceptance. They are currently searching for alternatives to all their asbestos products and report that successful substitutes are currently available for asbestos in general purpose phenolic compounds, although they do not manufacture such. Rogers manufactures only specialty thermoset compounds. They report successful substitution for asbestos in many, but not every instance.[1,3,25] Rogers Corporation has developed new glass and combination glass and cellulose reinforced products which have similar properties to asbestos-reinforced phenolics.[5] These products are being considered for several large volume programs although the asbestos substitute materials do not currently replace any asbestos products. Rogers reports that acceptance of such a substitution in the marketplace is not assured, since the cost of new products is higher (up to 15 percent) and molding characteristics are not always identical. A research breakthrough in 1978 created Roger's GP/duroid (gasketing material) products containing no asbestos, but with essentially equivalent heat resistance and sealing characteristics. Introduction of this new class of materials is now underway.[26] In addition, DAP (diallyl phthalate) molding materials, made with asbestos fibers in the past, are now being produced with other reinforcements.

Apparently there are some specialty products where no feasible asbestos substitutes have been found. The Rogers Corporation has reported that the phenolic molding materials used in commutators and rotors in electrical and automotive applications currently are reinforced with asbestos. These products function in a very dynamic environment where temperatures of 177°C and 30,000 rev/min prevail. Asbestos provides the heat resistance, dimensional stability, and moldability necessary for these applications. In their experience, no substitute for asbestos fiber exists for these applications.

Nonetheless, with the exception of specialty applications, phenolic suppliers have replaced or are in the process of substituting asbestos with other materials. Asbestos-free phenolic compounds exhibit nearly identical properties (90 to 98 percent as good, according to one supplier) at nearly identical cost.[8] It may be that asbestos will remain a reinforcement material in only specialty applications, providing exposure can be controlled to within acceptable limits. With demands of higher specifications by purchasers in the future, asbestos substitutes cannot merely equal asbestos, but must be developed to exceed the properties of asbestos reinforcement.[22]

CONCLUSION

Asbestos has been used as a reinforcing material in phenolic molding compounds because of its good physical properties which impart a good surface finish, toughness, resistance to heat and fire, minimal shrinkage and warpage, in addition to good reinforcing properties. Not every molded product requires all of the physical properties supplied by asbestos and consequently substitutes which lack some physical properties but which meet product specifications can replace asbestos. However, a majority of the products currently reinforced with asbestos require all the above-mentioned properties which asbestos supplies. In these instances, the substitute material must supply physical properties which are equal to or greater than the asbestos it replaces. New fiber technology has been developed which has boosted physical properties of substitutes such that they are comparable to asbestos. In addition, manufacturers have blended various reinforcements to achieve required properties. If the thermal insulation or tensile properties of asbestos are necessary, replacement sometimes requires using several materials together, such as a mixture of mica and an organic material. Where these special properties are not necessary, organic fillers may be used which are often cheaper than asbestos. Manufacturers often look for products with greater reinforcing and insulating properties than asbestos, due to increased demand for high-performance materials by industrial users.[22]

There is a well-established trend throughout the reinforced plastics industry to replace asbestos with alternative materials. These materials include:

- Fibrous glass
- Clay
- Talc
- Mica
- Wollastonite
- Processed mineral fiber
- Carbon fibers
- Aramid fibers

Polyethylene fibers may also be developed for future use in phenolics. In some cases it appears that these materials may even be used at a cost comparable to asbestos, while exhibiting similar properties when blended with appropriate additives. However, no one substitute material acting alone can completely replace asbestos, and there are still some specialty products where no feasible asbestos substitutes have been found. In general, reinforced plastics appear to have progressed towards the replacement of asbestos. The process of converting to nonasbestos alternatives will continue in the area of phenolic molding compounds.

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12. Telecon. B. Colclough, Fiberite Corp. with R. Bell, GCA Corporation, February 1980.

13. A. S. W., More Muscle, Higher Heat: They Power a Phenolic Molding Compound 'Revival.' Modern Plastics. July 1979.

14. General Electric Product Brochure, Genal GF-7000 Series.

15. Seymour, R. B. (1979). Fibrous Reinforcements for Plastics. 1979 Modern Plastics Encyclopedia, 170-174.

16. Telecon. Mary Ann Atchley, DuPont, Wilmington, DE, with R. Bell, GCA Corporation, February 1980.

17. Engineering Thermoplastics: Basic Performance Materials of the Future, Modern Plastics. May 1979.

18. Telecon. Roger Porter, University of Massachusetts with R. Bell, GCA Corporation/Technology Division. February 6, 1980.

19. Additives: Resin Squeeze Will Make Them More Profitable, More Useful. Modern Plastics. May 1979.

20. Fillers and Reinforcements, Modern Plastics, July 1979.

21. Telecon. Donald Randolph, U. S. Gypsum with R. Bell, GCA Corporation/ Technology Division. February 6, 1980.

22. Plastics and Floor Tiles Roundtable Discussion, at EPA/CPSC Substitutes to Asbestos Conference, Arlington, VA. July 14-16, 1980.

23. Telecon. Sales Manager, General Electric Co., with R. Bell, GCA Corporation, February 1980.

24. Telecon. Keith Smith, Hooker Chemicals and Plastics Corporation, Durez Division with R. Bell, GCA Corporation/Technology Division. February 1, 1980.

25. Telecon, J. Ellis, Plastics Engineering, with R. Bell, GCA Corporation, February 1, 1980.

26. Rogers Corporation Annual Report 1978.

SECTION 10

TEXTILES

ASBESTOS PRODUCT

Special Qualities

The specific asbestos textile products discussed in this section include:

- Fire-Resistant Materials*
- Thermal Insulation,
- Electrical Insulation,
- Packings and Gaskets,
- Friction Materials, and
- Specialty Textiles.

The strength of asbestos allows it to be processed into textiles using looms and other equipment commonly employed in the textile industry.[1] Asbestos is fireproof, thermally nonconductive, strongly dielectric, moisture, abrasion, and corrosion resistant, chemically and dimensionally stable, and flexible. In addition, asbestos is one of the few materials complying with military specifications.†

Product Composition

Asbestos used in 1980 for textiles was 200 metric tons of grades 1 and 2 chrysotile and 1700 metric tons of grade 3 chrysotile, or a total of 1900 metric tons, down from 2900 tons in 1978.[2]

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*Defined as combustible but self-extinguishing materials.

†At the Asbestos Textiles Roundtable Discussion of the EPA/CPSC Substitutes for Asbestos Conference (Arlington, Va., July 14 to 16, 1980), one party felt that asbestos was the only material to pass these specifications while a second party (from the Navy Department) stated that high temperature silica products are actually better than asbestos, having a higher temperature capability and equal durability. A substitute such as Nextel® (a 3M product) when used as a hybrid has not passed the military test.

The different forms of asbestos textiles used for the six aforementioned textile products are given in Table 71.

TABLE 71. FORMS OF ASBESTOS TEXTILES USED IN ASBESTOS PRODUCTS

Fire-resistant	Thermal insulation	Electrical insulation	Packings and gaskets	Friction materials	Specialty textiles
Yarn	Yarn	Yarn	Yarn	Yarn	Fiber
Thread	Cloth	Roving	Rope	Cloth	
Cloth	Cord	Tape	Wick		
	Rope	Thread	Cord		
	Tape	Felts	Cloth		
	Tubing	Cord	Tape		
		Lap			
		Tubing			

Asbestos yarn is composed primarily of asbestos fibers (75 to 100 percent). Cotton, nylon, polyester, and wire are added for reinforcement in some applications of yarns. Asbestos yarns are made in all of the standard ASTM grades shown in Table 72.

TABLE 72. ASBESTOS TEXTILE GRADES[3]

Grade[a]	Asbestos content by weight
Commercial	75% up to but not including 80%
Underwriters'	80% up to but not including 85%
Grade A	85% up to but not including 90%
Grade AA	90% up to but not including 95%
Grade AAA	95% up to but not including 99%
Grade AAAA	99% up to and including 100%

[a]Asbestos textile grades differ with each asbestos textile form.

Asbestos thread is produced in both plain (nonmetallic) and metallic (wire inserted) classes (A and B), the latter being noted for its great tensile strength and high thermal stability. Asbestos thread is generally furnished in Underwriters' grade.

Asbestos cloth is woven from five classes of asbestos yarns. The most widely used fabrics are woven from Class A (plain or nonmetallic) yarns and Class B (metallic or wire inserted) yarns. Other fabrics are made from Class C, D and E reinforced yarns. The different classes of asbestos cloth are listed below:

- Class A--Cloth constructed of asbestos yarns containing no reinforcing strands.
- Class B--Cloth constructed of asbestos yarns containing wire reinforcing strands.
- Class C--Cloth constructed of asbestos yarns containing organic reinforcing strands.
- Class D--Cloth constructed of asbestos yarns containing nonmetallic inorganic reinforcing strands.
- Class E--Cloth constructed of two or more of the yarns used in both Classes A through D.

Asbestos cord is manufactured in all standard ASTM grades. The diameters of asbestos cord range from 0.15 cm (0.06 in.) to 0.97 cm (0.38 in.). Asbestos rope is available in commercial grade for most general uses and in Underwriters' AA, AAA, and AAAA grades depending on service requirements. Tape is manufactured mainly as plain or nonmetallic tape and as a wire inserted product; those used in thermal insulation are manufactured in all of the standard ASTM grades. Asbestos tubing also comes in all of these grades; roving is blended with cotton or other organic fibers, producing various degrees of density to meet specific requirements of the user. This is also applied in the five standard ASTM grades. Asbestos lap comes in two styles: one is a single ribbon-like formation of fibers and the other a paralleled assemblage of the first. It comes in A, AA, and AAA grades. Felts come in all grades and are available both with or without glass cloth reinforcement; they are produced in sheets, tapes, and rolls. Wick is usually of commercial grade but other grades can be supplied on order.

Uses and Applications

Asbestos fire-resistant materials are used in a variety of applications, including welding curtains, draperies, blankets, protective clothing, hot conveyor belts, furnace shields and molten metal splash protection aprons.[3] In addition, asbestos fire-resistant materials are used in the construction field as temporary blankets or curtains. Further, they are used in the military, firefighting and aerospace fields for protective clothing and in various rocket and missile parts. Ironing board covers and theater curtains also contain these materials.

Asbestos textiles are used as thermal insulation in pipe wraps for safety protection; stress relieving pads in welding operations; protective coverings for hot glassware utensils such as pincers and tongs; coverings for diesel engine exhaust lines; flue sleeves; and braided walls in the construction of steam hoses.[2]

Asbestos textiles are employed for the insulation of wires and cables, especially those which are designed for low voltage, high-current use under severe temperature conditions. They are also used for insulation of arcing barriers in switches, circuit breakers, heater cords, and motor windings, and as sleevings for electrical appliance leads and insulated conductors where fire protection and resistance to mechanical abrasion are needed.

Asbestos textiles are used for pump packings; all purpose shaft and valve stem packings; expansion joints; manhole gaskets; seals for boilers, ovens, and furnaces; flange gaskets; and gaskets for storage tanks, cookers, and dryers.

The applications of woven asbestos brake linings are mainly found in industrial band and drum brakes contained in cranes, lifts, excavators, winches, concrete mixers and mine equipment. Woven asbestos may be used as clutch facings for industrial band, plate and cone clutches in cranes, lifts, excavators and winches. Automotive brake pads can use a woven asbestos cloth which may be reinforced with brass wire or impregnated with phenolic resin, as is commonly used in clutches.[4]

Asbestos carded fiber is the main form of asbestos textiles that can be used in specialty products. Carded fiber is used mainly in liquid filters for such products as beer, wine, oils and chemicals; and in electrolytic diaphragms. It is also used as wiping pads for molten metal and as stuffing box packing.[3]

Product Manufacturing Summary

Manufacturing Process--

There are two basic variations employed in asbestos textile manufacturing: the conventional and wet processes. The former process employs either the dry or damp method. These two methods are identical except that during the damp method the yarn is moistened either by contact with water on a roller or by a mist spray. Most textiles are manufactured by the conventional process.

In the conventional process, raw asbestos fibers of various grades are blended and mixed, with the composition of the blends and fixing of the formulation governed by the fiber characteristic, manufacturing and finished product requirements and intended use.[3] The different grades received are moved to the rear of the blender. Selected fiber sizes then enter a hopper. When filled, the hoppers deliver the blended material to the carding operation.

The carding operation combs the fibers with a relatively parallel arrangement called a fiber mat. This mat is pressed and layered into a lap. The lap is separated into thin, continuous ribbons called roving. Cotton, rayon or other material may be added at this stage to strengthen the roving.

Roving, which has been mechanically twisted and spun to give it tensile strength, forms a single yarn. This yarn may be twisted with other single yarns, wire or other material to produce plied yarn which can be coated to produce thread or treated yarns.

The wet process is based on forming single filament fibers by extrusion. The process consists of making a gelatinous mixture of fine asbestos fiber in water with a volatile dispersant. The mass is extruded through small dies. The extruded thread is then spun into various products. The product tends to hold asbestos fibers better than those produced by the conventional processes, thus reducing workplace fiber levels, but the yarn formed has the disadvantage of poor absorption and impregnation characteristics.

Asbestos tubing is made from asbestos yarns, either braided or woven. The braided style is supplied in many diameters and textures and in several wall thicknesses to meet a variety of service conditions. It can be treated as required. The woven style is manufactured in various constructions depending on specifications.

Asbestos tape is a narrow woven fabric manufactured from plied yarn containing salvage edges (the edge of the woven fabric finished to prevent raveling). The method of manufacturing tape depends on the class specified.

Asbestos rope is produced in two styles: twisted and braided. Twisted asbestos rope is made by twisting two or more strands of asbestos wick tightly together. Heavier ropes contain a binder to hold the twist. Braided asbestos rope is manufactured in three constructions: (1) by braiding one or more jackets of asbestos yarn over a case of asbestos rope or wick; (2) by braiding asbestos yarn braid over braid; and (3) by plaiting asbestos yarn into square cross section.[3]

Asbestos cord is usually twisted asbestos yarn (a predetermined number) of strands) which forms a cord of desired diameter and tensile strength. The yarns used may be sized or unsized, plain or metallic (wire inserted), or single or plied depending on the end use of the product.[3]

Asbestos textile packing is manufactured from a dry asbestos yarn that is coated with a lubricant. The impregnated yarns are braided into continuous lengths of packing and a second impregnation may follow. Variations of braided packing can be made by extruding a mixture of asbestos fiber, binder and lubricants, and then braiding lubricating asbestos yarns over the extrusion. The amount and type of lubricant and binder used in these processes varies. The formed product may then be coiled, boxed and sold. Yarn may also be used as reinforcement to elastomers such as rubber, and molded to desired shapes.[1] Asbestos wick is manufactured by loosely twisting together several strands of roving, tubing or felted asbestos.[3]

In most cases, asbestos textile materials are bound or coated with resins or elastomers before becoming the final product. The materials can also be aluminized to give a heat reflecting surface. The metallic layer can be sprayed or bonded to the cloth by a thermosetting resin.

The manufacturing process as well as the available substitutes for woven textiles used in friction materials are discussed in the Friction Materials category of this report.

Name and Number of Manufacturers--

There are three main companies which manufacture asbestos textiles used in fire-resistant materials, electrical and thermal insulation, and specialty textile products. Secondary manufacturers receive asbestos textiles in the form of yarn to manufacture the final product. Primary manufacturers are listed below.[1]

• Raybestos Manhattan Inc.	North Charleston, NC Marshville, NC
• Southern Textiles Corporation a subsidiary of H.K. Porter Co., Inc., Pittsburg, PA	Charlotte, NC
• Amatex Corporation[4,5]	Norristown, PA Meredith, NH

These three companies, and a fourth--Johns-Manville Corporation, of Manville, NJ--also manufacture asbestos textiles for packings and gasket products.

Production Volumes--

In 1980, the U.S. asbestos consumption by end use for textiles was 1900 metric tons, the majority of this total being grade 3 of the chrysotile type (1700 metric tons).[2]

Asbestos used in electrical insulation materials amounted to 8900 metric tons in 1980.[2] This asbestos fiber was used mainly in the forms of paper, roving, webbing and braid where comparatively high temperatures may occur. In 1980, the volume of asbestos used for thermal and electrical insulation materials amounted to approximately 2.5 percent of the total U.S. output of asbestos. The production volumes for individual asbestos textiles used in electrical insulation are not available.

SUBSTITUTE PRODUCT

Methodology

Search Strategy--

The search strategy included a combination of a literature review and a telephone survey of industry representatives to gather data on product specifications, uses, prices, and market trends.

Summary of Contacts--

The following company representatives were contacted for information regarding fire-resistant material substitutes.

- Mr. Bill Timmons
  Marketing Supervisor of Industrial Products
  Celanese Plastics and Specialties
  Chatham, NJ
  (201) 635-2600

- Mr. Bal Dixit, President
  Newtex Industries, Inc.
  Victor, NY
  (716) 924-9135

- Ms. Kathy Pietak
  Textile Specialist
  The Carborundum Company
  Niagara Falls, NY
  (716) 278-2000

- Mr. Bob Wilander
  Sales Manager
  Westex, Inc.
  Chicago, IL
  (312) 523-6351

- Mr. Marion Black
  Marketing Manager
  Hitco Materials Division
  Gardena, CA
  (213) 321-8080

- Mr. Barry Reznik
  Manager
  Cotronics Corporation
  Brooklyn, NY
  (212) 646-7996

- Mr. Richard Saffadi
  President
  Alpha Associates, Inc.
  Woodbridge, NJ
  (201) 634-5700

- Mr. Edmund Fenner
  Director of Environmental Services
  Johns-Manville Corporation
  Denver, CO
  (303) 979-1000

- Ms. Lucille Ellingson
  Sales
  3M Company
  St. Paul, MN
  (612) 733-1558

- Mr. Bob Chiostergi
  Textile Sales
  E.I. Dupont de NeMours and
    Company, Inc.
  Wilmington, DE
  (302) 999-3951

- Mr. Bill Maaskant
  Marketing Manager
  Amatex Corporation
  Norristown, PA
  (215) 277-6100

- Mr. Michael Storti
  Marketing Manager
  American Kynol, Inc.
  New York, NY
  (212) 279-2858

- Mr. Joseph Angelina
  Textile Products Marketing Manager
  Garlock, Inc.
  Palmyra, NY
  (315) 597-4811

- Mr. K. C. McCallister
  Marketing Manager
  Mr. A. Fazia
  Market Development Manager
  Celanese Fibers Marketing Company
  Charlotte, NC
  (704) 554-2735

- Mr. Robin Vance
  Vice President
  Fire Safe Products, Inc.
  St. Louis, MO
  (314) 423-6989

Fiber Substitutes

Special Qualities--

Fiber substitutes available in all textile applications include:

- fiber glass,
- ceramics,
- organics,
- graphite,
- carbon,
- quartz,
- cotton, and
- special wool blends.

Physical and chemical properties of these high temperature materials are compared in Tables 73 and 74 along with properties of asbestos.

TABLE 73. ASBESTOS AND SUBSTITUTE FIBER PROPERTY COMPARISON FOR TEXTILE PRODUCTS

Material (Manufacturer)	Product application	Properties: Temperature resistance[a] up to °C (°F)	Tensile strength[b] kPa (psi)	Comments	References
Asbestos	All applications requiring an incombustible high temperature fabric.	649[c] (1200)[c]	5.68×10^{6} (824,000)	Low thermal conductivity; excellent radiation stability; good flexibility; excellent resistance to moisture and corrosion; excellent spinnability; contains a minimum of magnetic or conductive fibers.	2
Glass	All applications requiring an incombustible high temperature fabric.	538 (1000)	2.17×10^{6} (315,000)	Density similar to asbestos; excellent handling characteristics; high dielectric strength; not as durable as asbestos; may produce some skin irritation; fiber diameter 0.066 mm (0.0026 inch).	2,6
Texo™, and other Fiber Glass Yarns (PPG Industries)	Fire-resistant materials; thermal insulation; packings and gaskets.	340[d] (650)[d]	2.0×10^{6}[e] (200-300,000)[e]	Dimensional stability - no more than 3% elongation under maximum stress, chemical resistance, high thermal conductivity, low moisture absorption, high dielectric strength, flame resistance.	7
Zetex™ (Newtex Industries, Inc.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	1538 (2800)	3.44×10^{6} (500,000)	Excellent strength and durability; excellent dielectric strength; dimensional stability, excellent cutting, sewing and handling; abrasion-resistant; fiber size ∿9 microns; lower (less than one-half) thermal conductivity than asbestos.	8,9
Ceramics	All applications requiring an incombustible high temperature fabric.	1427 (2600)	high	A high tensile strength silica - alumina fiber; flexible; abrasion-resistant	6
Nextel® 312 (3M Company)	Fire-resistant materials; thermal and electrical insulation, packings and gaskets.	1427 (2600)	1.72×10^{6} (250,000)	High strength retention; low shrinkage; abrasion-resistant (after 4 hours at 816°C (1500°F), it retained 100 percent of its strength); good flexibility; some skin irritation; fiber size 10 to 12 microns in diameter.	10,11
Refrasil® (Hitco Materials)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	928 (1800)	5.17×10^{5} (75,000)	Good acid resistance; good dielectric properties; excellent resistant to thermal shock; high capacity to absorb moisture; lacks abrasion resistance, fiber diameter 8 to 12 microns.	12,13
Organics					
Nomex® (DuPont Co.)	Fire-resistant materials; thermal and electrical insulation packings and gaskets.	371 (700)	6.89×10^{5} (100,000)	Abrasion-resistant; flexible; radiation-resistant; chemical-resistant; washable; low shrinkage.	14,15
Kevlar® (DuPont Co.)	Fire-resistant materials; friction materials; cables.	204 (400)	2.76×10^{6} (400,000)	High thermal stability; excellent chemical resistance; excellent cut resistance; low thermal conductivity.	15,16
Teflon® (DuPont Co.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	316 (600)	3.62×10^{5} (52,500)	High chemical resistance; low friction and adhesion; low shrinkage; great flex-abrasion resistance; radiation-resistant.	15,16

(continued)

TABLE 73 (continued)

Material (Manufacturer)	Product application	Properties: Temperature resistance[a] up to °C (°F)	Properties: Tensile strength[b] kPa (psi)	Properties: Comments	References
Kynol™ (American Kynol, Inc.)	Fire-resistant materials; packings and gaskets.	704[f] (1300)[f]	1.86×10^5 (27,000)	Low moisture absorption; acid-resistant; low toxic off gases; low shrinkage; is a carbon precursor; low abrasion.	8,17,18
P.B.I.™ (Celanese Plastics and Specialties Co.)	Fire-resistant materials.	500 (932)	2.07×10^6 (300,000)	Polybenzimidazole; nonflammable in air; little or no emittance of toxic off gases; acid-resistant; readily processed on conventional textile equipment; comfortable; good cryogenic characteristics; high moisture regain.	19,20
Fiberfrax® (Carborundum Co.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	1260 (2300)	1.72×10^6 (250,000)	Chemical-resistant; low thermal conductivity; resists oxidation and reduction; excellent resistance to thermal shock.	21,22
Carbon	Fire-resistant materials; packings and gaskets; friction materials.	1427 (2600)	Over 3.10×10^6 (450,000)	High flexibility, lightweight, good retention of fiber properties at high temperatures.	6,21,22
Celion® (Celanese Plastics and Specialties Co.)	Friction materials; packings and gaskets.	5432 (3000) (no oxygen)	3.24×10^6 (470,000)	Flexible, low shrinkage; excellent oxidative stability; excellent adhesion to organics; excellent electrical/thermal conductivity.	21,22
Celiox™ (Celanese Plastics and Specialties Co.)	Fire-resistant materials.	760 (1400)	2.10×10^5 (30,500)	Lightweight, flexible, high moisture regain, low density, readily converted into carbon	23,25
Quartz					
Alphaquartz® (Alpha Associates)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets.	Over 1204 (2200)	8.69×10^5 (126,000)	Thermal stability; elastic; excellent resistance to thermal shock; easily impregnated; excellent abrasive characteristics; high purity; transparency to electromagnetic and radio waves.	26,27,28
Cotton (Westex, Inc.)	Fire-resistant materials.	232 (450)	8.62×10^5 (125,000)	Flame-resistant; is coated and treated; washable; fiber diameter 0.020 to 0.030 mm (0.0008 to 0.0011 inches).	29

[a]Temperatures depend upon product application.

[b]Figures are for fibers only, and are not necessarily related to fabric strength.

[c]Wire inserted asbestos textiles.

[d]Retains 50% of tensile strength at this temperature.

[e]At 72°F and 50% R.H. based on fiber area.

[f]Carbonizing temperature range.

TABLE 74. CHARACTERISTICS OF HIGH TEMPERATURE MATERIALS[30]

Property	Chrysotile asbestos cloth	Fiberglass cloth	Alumino-silicate products	Aluminum borosilicate cloth	Aromatic polyamide cloth
Maximum Continuous Use Temperature (°C)	600	538	1260	593	-
Degradation Temperature (°C)	up to 1700	700-760 melting point	1790 melting point	1145 melting point	-
Cloth Tensile Strength (lbs)	50-200	500-600	65-100	500-600	-
Fiber (tensile) Strength (MN/m^2)	3100 average	1700	2760	3447	-
Fiber Diameter (μm)	Fiber 0.03-100 Fibril 0.02	14.7	2-3 average	9	-
Fiber Length (mm)	Fiber 1-80 Fibril 0.25-5	152-254	40-250	continuous filament	-
K value in Btu in./hr ft^2 °F	0.7 at 212°F	0.51 at 500°F	0.40-0.70 at 500°F	0.42 at 500°F	0.45 at 500°F
Chemical Resistance	Most chemicals Exceptions: HF, strong acids at elevated temperatures	Most chemicals Exceptions: HF, phosphroic acid, strong alkalies	Most chemicals Exceptions: HF, H_3PO_4, strong alkalies	Most chemicals Exceptions: HF, H_3PO_4, strong alkalies	Most commonly used chemicals, solvents Exceptions: strong acids and alkalies

Product Composition--

The specific compositions of the fiber substitutes are listed in conjunction with the manufacturing process section.

Another potential substitue should be noted for this category. Fibercoat by Textured Products was specifically developed for use as fireproof upholstery and wall covering fabrics. As this product is noted for many applications, it was covered extensively in the Paper section "Electrical Insulation: and should be referred to there by the reader.

Uses and Applications--

At a recently held conference concerned with the availability of substitutes for various asbestos products, a supplier of asbestos-free textiles stated, ". . . It is very safe to say that there is a replacement for every asbestos textile product right now."[31] In general, replacement of asbestos must be made on an application-by-application basis, taking into consideration such factors as cost, performance, and service life.

Asbestos thermal insulation, which is used principally for its heat resisting properties, can be replaced by fiberglass for the lower range of temperature conditions [up to 540°C (1000°F)], or by ceramics over higher ranges.[1] High strength is not usually a critical thermal insulation requirement.

In applications such as electric insulation sleeving for cables and battery separators, direct replacement with fiberglass is usually satisfactory; fiberglass is not suitable for applications where severe flexing is involved. For cable and wire insulation up to 530°C (990°F), ceramic materials may be used with glass filament inserts to maintain high temperature strength.[3] Quartz products also can be substituted for asbestos in electrical insulation at elevated temperatures.

Manufacturing Summary--

Manufacturers--Manufacturers of nonasbestos textile materials are listed in Table 75. In addition, Table 75a provides a list of weavers and fabricators of one substitute product--Fiber Glass Yarn--and which product type(s) each makes; i.e., industrial tapes, fabrics, etc.*

*For completeness, gaskets and packing products were included on this list, and referenced here in the gaskets and packings section of this report.

TABLE 75. MANUFACTURERS OF NONASBESTOS TEXTILE FIBERS[a]

Manufacturer	Location	Fiber produced
Owens-Corning	Toledo, OH	Fiber glass
Hitco Materials Division	Gardena, CA	Fiber glass (Refrasil®)
Newtex Industries, Inc.	Victor, NY	Fiber glass (Zetex™)
PPG Industries	Pittsburgh, PA	Fiber glass (Texo™)
3M Company	St. Paul, MN	Ceramic (Nextel® 312)
Carborundum Co.	Niagara Falls, NY	Ceramic (Fiberfrax®)
Celanese Plastics and Specialties	Chatham, NJ	Carbon (Celiox™) Carbon (Celion®) Organic (PBI™)
Alpha Associates, Inc.	Woodbridge, NJ	Quartz (Alphaquartz®)
E.I. DuPont de Nemours and Co., Inc.	Wilmington, DE	Organic (Nomex®, Kevlar®, Teflon®)
American Kynol Inc.	New York, NY	Organic (Kynol™)
Westex, Inc.	Chicago, IL	Cotton

[a]From telephone contact and product literature.

TABLE 75a. WEAVERS AND FABRICATORS OF TEXTURED AND OTHER FIBER GLASS YARN PRODUCTS[7]

	Asbestos replacement								
	General industrial fabrics	Industrial tapes	Specialty industrial fabrics	Electrical sleeving tapes, cordage	Fiber glass screening	Vinyl-coated yarns	Fabrics	Ropes, packings and gaskets	Tapes and tubing
Amatex Corporation, Norristown, PA			•				•	•	•
Auburn Manufacturing Co., Mechanic Falls, ME									•
Atkins & Pearce Company, Cincinnati, OH				•					
Baycor, Atlanta, GA					•	•			
Belding Corticelli Fiber Glass Fabrics, New York, NY	•								
Bentley-Harris Mfg. Co., Thermal Design Group, Lionville, PA				•				•	•
Burlington Glass Fabrics Company, A Division of Burlington Industries, Rockleigh, NJ	•	•					•		
Carolina Narrow Fabric Company, Winston-Salem, NC		•		•					•
CHEMFAB-Material Technologies Division, North Bennington, VT			•						
Clark-Schwebel Fiber Glass Corp., White Plains, NY	•						•		
Darco-Southern, Inc., Independence, VA							•		•
Davlyn Manufacturing Co., Inc., Chester Springs, Pa.								•	•
Engineered Yarns, Inc., Coventry, RI						•			
FIL-TEC, Inc., Hagerstown, MD		•					•	•	•
Garlock, Inc., Palmyra, NY							•	•	•
Hi Temp Textiles, Greensboro, NC								•	•
Hesgon Company, Brownsville, TX		•		•					
Hexcel Corporation-Trevano Div., Dublin, CA			•						
Intec, Inc., Buena Park, CA								•	•

(continued)

TABLE 75a (continued)

	Asbestos replacement								
	General industrial fabrics	Industrial tapes	Specialty industrial fabrics	Electrical sleeving tapes, cordage	Fiber glass screening	Vinyl-coated yarns	Fabrics	Ropes, packings and gaskets	Tapes and tubing
Mutual Industries, Inc. Philadelphia, PA		•		•					•
Newtex Industries, Inc., Victor, NY							•	•	•
North American Textiles, Detroit, MI	•		•						
Oxford Mills, A Div. of Root Industries, Mt. Wolf, PA					•	•			
Phifer Wire Products, Inc., Tuscaloosa, AL					•	•			
Quinco Fabrics, Inc., Auburn, ME			•						
Raybestos Industrial Products, North Charleston, SC			•				•	•	•
I. Sommers Narrow Tape Corporation, East Stroudsburg, PA		•		•					
Southern Textile Corp., Charlotte, NC		•	•				•	•	•
J.P. Stevens & Company, Glass Fabrics Dept., New York, NY	•	•							
Johnathan Temple, Inc. Hackensack, NJ				•					
Uniglass Industries, Div. of United Merchants, Inc. New York, NY	•	•							
Warwick Mills, Greenville Mill Div., New Ipswich, NH			•						

Manufacturing process--The manufacturing processes used to form some of the nonasbestos textile materials are listed below.

- Fiber Glass--manufactured from a silica-based product that is carded and formed into yarns. These yarns are sold to secondary manufacturers who may impregnate or chemically and physically alter the fiber glass according to their customers' needs.[32] An example of product composition of an "E" (electrical) glass form is given in Table 75b, based on percent by mass:

TABLE 75b. COMPOSITION OF E-GLASS FIBER SUBSTITUTE[7]

Silica	54.0%
Calcium oxide	20.5%
Alumina	14.0%
Boron oxide	8.0%
Soda	1.0%
Calcium fluoride	1.0%
Magnesia	0.5%
Total minor oxides	1.0%
Bare glass composition	100.0%
Plus binder	0.5-2%

- Refrasil®--manufactured by leaching out the low melt elements (such as sodium, potassium, boron, lithium) from fiber glass with hydrochloric acid, and forming silica.[12]

- Zetex™--proprietary process; received as a yarn, woven and treated before becoming a fire-resistant material.[8] No process changes required from asbestos textile manufacturing steps.

- Fiberfrax®--carded with an organic carrier such as rayon and made into various fire-resistant materials.[21]

- Cotton--treated and cured in an ammonia chamber before becoming a 100 percent durable, flame-resistant fabric.[29]

- Quartz--manufactured by processing pure quartz crystals into extruded filaments which are formed into yarn which is then plied and woven into fabrics.[26]

- Carbon--manufactured by sintering either rayon or polyacrylonitrile fibers to produce extremely strong fire-resistant fibers.[6]

- Kynol™--a phenol formaldehyde polymer formed as stable fibers and subsequently cross-linked.[6,17]

- Teflon®--a perfluorinated polyethylene manufactured by polymerizing tetraflouroethylene. Teflon particles are dispersed in a viscous rayon dope and extruded in a rayon matrix. The rayon is burned off, leaving a continuous Teflon filament.[6,33]

- Kevlar®--an aromatic polyamide manufactured by reacting paraphenylenediamine with phthaloyl chloride.[6,16]

- Nomex®--an aromatic polyamide manufactured by condensing metaphenylenediamine with isophthaloyl chloride as a stable fiber, continuous filament or as short fibers.[6]

Production volumes--The exact production volumes of some of the textile materials are proprietary. However, available information is listed in Table 76.

TABLE 76. PRODUCTION VOLUMES OF NONASBESTOS TEXTILE MATERIALS[8,12,23,26]

Manufacturer	Substitute	Production volume kg/yr	(lb/yr)
Celanese Plastics and Specialties	Celion®	45,000	(100,000)
Newtex Industries Inc.	Zetex™	225,000-450,000	(500,000-1,000,000)
Hitco Materials Division	Refrasil®	135,000-225,000	(300,000-500,000)
Alpha Associates, Inc.	Alphaquartz®	36,000	(80,000)

Product Substitutes

Special Qualities--

Physical and chemical properties of several nonasbestos textiles that are presently marketed are compared in Table 77.

Product Composition--

The composition of substitute products is included under Manufacturing Summary.

Uses and Applications--

Discussion of the available substitutes for asbestos textiles used in packings and gaskets are contained in the Packings and Gaskets category of this report. This category includes the substitute contacts and manufacturing summaries, asbestos cost comparisons, current trends, and conclusions.

Substitutes for carded fibers used in liquid filters and electrolytic diaphragms are discussed in the Beverage Filter and Specialty Papers Sections of the Paper Products Category of this report. Substitutes for stuffing box packings are discussed in the Packings and Gaskets category.

TABLE 77. SUBSTITUTE PRODUCT PROPERTY COMPARISON

Substitute product (Manufacturer)	Product application	Properties: Temperature resistance[a] up to °C (°F)	Properties: Tensile strength[b] kPa (psi)	Comments	References
Thermo-Sil™ (Garlock, Inc.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets	538 (1000)	2.17×10^6 (315,000)	Resists organic solvents and most acids and alkalies; resists abrasion and wear; moisture and weather resistant; dimensionally stable; high dielectric strength; low dielectric constant; soft and flexible.	32,34
Durette® (Fire Safe Products, Inc.)	Fire-resistant materials	593 (1100)	4.83×10^5 (70,000)	Better heat stability than Nomex ; high abrasion resistance; good acid resistance; high tear resistance; excellent dimensional stability.	35
Thermo-Ceram™ (Garlock, Inc.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets	1260 (2300)	1.72×10^6 (250,000)	Excellent resistance to mechanical vibration and stress; resists attack from most chemicals; no loss of strength from water evaporation at high temperatures; low thermal conductivity and excellent electrical resistance.	36
Norfab® (Amatex Corp.)	Fire-resistant materials; thermal and electrical insulation; packings and gaskets	343 (650)	-	A combination of synthetics, excellent workability; lightweight; high abrasion resistance; flexible; good chemical resistance. Amatex also offers Thermoglass, which will not burn or smoulder, has excellent dimensional stability, high tensile strength, chemical resistance, excellent electrical properties, flexibility, and meets U.S. Coast Guard Requirements for Incombustible materials and Government MIL specifications. Applications for such a product include use as a cloth, tape, tubing and rope.	37,38
SILTEMP® (Haveg Industries, Inc.)	Thermal and electrical insulation; packings and gaskets	1649 (3000)	-	Meets MIL Spec I-24244; approved for use in nuclear applications; substantial reuse factor compared to asbestos.	39
Preox (Celanese Plastics and Specialties Co.)	Thermal and electrical insulation; packings and gaskets	-	-	Thermally stabilized polyacrylonitrile; flexible; electrically nonconducting; water absorbing; carbonizes at high temperatures. Emits toxic cyanide gas at 800°F.: exposure level undetermined.	40

[a]Temperatures depend upon product application.

[b]Figures are for fibers only, and are not necessarily related to fabric strength.

Manufacturing Summary--

Manufacturers--Manufacturers of nonasbestos textile products are listed in Table 78.

Manufacturing process--The manufacturing processes for some of these materials are listed below.

- Durette® - manufactured by chlorinating woven Nomex fabrics.[6]
- Thermo-Sil™ - fabrics and tapes woven, and tubing braided, from texturized fiberglass yarn.[34]
- Thermo-Ceram™ - fabrics and tapes are woven, and tubing braided, from wire-reinforced ceramic yarn, containing a rayon carrier fiber.[36]
- Norfab® - manufactured by blending together synthetic fibers in a unique process. Nor-Fab series 400 is produced as yarn (plain and reinforced), roving, filler, tapes, braided and twisted ropes and cord.[41]

Production volumes--The exact production volumes of these products are proprietary.

COST COMPARISON

Table 79 provides a cost comparison between asbestos fibers and several available substitutes. There are many substitutes that do not use fiber as a basic unit of comparison. These include Alphaquartz®, Zetex™, Fiberfrax® and PBI™. Product cost is a function of both fiber cost and the amount of fiber required to produce the product. Thus, if a lower weight of a substitute fiber can be used to produce a product, the substitute product may cost less than the asbestos product.

Alphaquartz® is more expensive than asbestos at \$36 to \$45/kg (\$80 to \$100/lb) for quartz wool and yarn, and \$1.20 to \$1.50/m[1] (\$4 to \$5/ft) for quartz mat.[26]

Zetex™ is currently more expensive than asbestos at \$3.65 to \$12.80/m (\$4 to \$14/yd) or \$0.90 to \$2.27/kg (\$2 to \$5/lb) depending on the type of product required.[8] However, production costs are almost identical to asbestos except in the safety garment field, where they may be higher by about 20 percent.

Fiberfrax® costs \$3.50/kg (\$7.75/lb) for 1.3 mm (0.5 inch) rope.[21]

There is a possible market for an organic material called PBI™ which will cost \$9 to \$13.50/kg (\$20 to \$30/lb) for fabric. However, with all factors

TABLE 78. MANUFACTURERS OF NONASBESTOS TEXTILE PRODUCTS[32,34,35,37-40]

Manufacturer	Location	Product (or fiber used)
Garlock, Inc.[a]	Palmyra, NY	Fiber Glass (ThermoSil™) Ceramic (ThermoCeram™), Texo™
Celanese Plastics and Specialties	Chatham, NJ	(Preox)
Fire Safe Products, Inc.	St. Louis, MO	Organic (Durette®)
Amatex Corp.[a]	Norristown, PA	Synthetic (Norfab®), Texo™
Haveg Industries, Inc., a subsidiary of Hercules, Inc.	Wilmington DE	(SILTEMP®)
Southern Textile Corporation,[a,b] a subsidiary of H.K. Porter Co., Inc.	Charlotte, NC	Glass fabrics, aramid fibers, Texo™
Davlyn Manufacturing Co.[a]	Chester Springs, PA	Texo™
FIL-TEC[a]	Hagerstown, MD	Texo™
Newtex[a]	Victor, NY	Texo™

[a]Companies reported by phone contact with Russell Smith, PPG Industries, (Texo™), 12/17/81, with N. Krusell, GCA. They produce yarn from Texo fiber that PPG manufactures.

[b]Asbestos Magazine, March 1981, p. 34.

TABLE 79. COST COMPARISON BETWEEN ASBESTOS FIBERS AND SUBSTITUTES USED IN TEXTILES[a]

Product	Approximate cost per kilogram (pound)	Reference
Asbestos	\$0.45-0.50 (1.00-1.10)	6
Fiber Glass	0.50 (1.10)	6
Texo™	\$0.50-0.85 (1.12-1.87)[b]	42
Kevlar®	2.50-2.70 (5.50-6.00)	15
Nomex®	2.70-2.95 (6.00-6.50)	15
Teflon®	3.15-4.50 (7.00-10.00)	15
Refrasil®	3.15-5.40 (7.00-12.00)	12
SILTEMP®	2.70-4.95 (6.00-11.00)	39
Norfab®	1.36-1.82 (3.00-4.00)	40
Durette®	3.60 (8.00)	35
Nextel® 312	13.50 (30.00)	10
Kynol™	2.00-2.25 (4.50-5.00)	18
Celiox™	4.50 (10.00)	23
Celion®	11.25 (25.00)	23
Zetex®	0.90-1.35 (2-5)	8

[a]Prices vary with product style and quantity.

[b]The basic yarn prices here vary from \$1.29-1.87/lb for "ETDE" Texo with most less than \$1.50 to a range of \$1.12-\$1.23/lb for "6-filament," a coarser and therefore a bit less expensive product.[42]

considered (the fabric being half the weight of asbestos and possessing a longer service life) PBI™ could amount to a cost of only three times that of asbestos.[23]

CURRENT TRENDS

A downward market is forecasted for asbestos fire-resistant materials. Many large manufacturers of asbestos fire-resistant materials are currently manufacturing substitutes such as fiberglass and ceramics along with their asbestos products. Many government specifications for fire-resistant materials are being revised for health reasons, thus encouraging sales of various substitute products.

Sales of asbestos insulation have dropped drastically from 1973 to 1980.[1,2] At current consumption rates, asbestos insulating materials are less than 1 percent in value of the total market for all insulation materials.[1] There is a decreasing trend in the use of asbestos thermal insulation because of economic as well as health disadvantages.

The low conductivity of substitute electrical textile materials gives them appreciably better insulating value than asbestos on the basis of both weight and surface area. Lower densities give these materials further economic advantages over asbestos. These advantages along with increased health concerns explain the continuing decrease in the use of asbestos for insulating purposes. Concern with asbestos emissions has prompted many manufacturers of asbestos textiles used in electrical insulation to turn to viable substitutes such as Fiberfrax®, Nomex® and Refrasil®.

Specific trends for some of the nonasbestos textile materials are listed below.

- Celion®, Celiox™ - viable replacement by 1980; potential 450,000 kg/yr; (1,000,000 lb/hr) plant by 1982.[23]
- Zetex™ - high probability of overtaking asbestos market; need 4,500,000 kg/yr; (10,000,000 lb/yr) plant (300 to 400 workers) to compete with asbestos.[8]
- Refrasil® - could replace 27 percent of asbestos market, with a possible \$20,000,000 to \$30,000,000 business.[12]
- Durette® - by 1990, could have a viable substitute market in specialized protective clothing.[35]

CONCLUSION

There are a number of viable substitutes for asbestos textile materials that are well suited to replace asbestos in nearly every application.

These include: Fiberglass, Kevlar, Nomex, Teflon, Refrasil, Siltemp, Norfab, Durette, Nextel, Kynol, Celiox, Celion, Zetex, and Fiberfrax. In addition, other products are still in developmental stages. Many of these substitutes have better property advantages for textile applications than asbestos. Although more costly in most cases, these alternatives are already on the marketplace, providing a nonasbestos choice for consumers. As in the other categories mentioned where viable substitutes exist, the choice of substitutes involves consumer education and exceptance towards a changeover from the established product. As there are some occasions where the substitute products are more applicable for a particular job, their use may result in longer product life, leading to lower overall cost and public acceptance. The small number of asbestos textile applications for which no satisfactory alternative exists at present include lamp and stove wicks, wipes for molten metal, diaphragms for some of the electrolytic cells and some filter cloths.[3]

In the future, the market for nonasbestos, fire-resistant materials will undoubtedly improve. The Department of Interior has projected a zero demand for asbestos in textiles by the year 2000.[43] The performance of high temperature application substitute materials has proven that these materials not only compare with, but often exceed the performance characteristics of asbestos. With the substitute materials currently on the market, and assuming new developments of asbestos replacement products in the future, asbestos consumption in fire-resistant materials will drop significantly. Sales of asbestos insulation products have already shown this drop in their drastic decrease in sales over the past few years.

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22. The Carborundum Company. Fiberfrax® Product Bulletins. C736-A-G. Niagara Falls, NY. p. 1-10.

23. Telecon. Timmons, B., Marketing Supervisor, Celanese Plastics and Specialties, Chatham, NJ. (201) 635-2600, with T. Henderson, GCA/Technology Division, January 28, 1980. Notebook No. 07, Phone call No. 05.

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25. Celanese Plastics and Specialties Co. Celiox™ Fibers Bulletin. Chatham, NJ. November 1979.

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SECTION 11

MISCELLANEOUS USES

INTRODUCTION

This section combines information on several minor uses of asbestos fibers, including:

- drilling muds,
- shotgun shell base wads,
- asphalt/asbestos cement,
- foundry sands,
- sprayed-on insulation, and
- artificial fireplace ashes and artificial snows.

The total fiber consumption for this category was 10,400 metric tons of asbestos in 1980. For the products noted here, drilling muds consumes the majority of asbestos, 4900 m.t.; a complete breakdown of the remaining 5500 m.t. was not available. Each section includes a brief introduction to the product. In general, methodology, contacts, and special qualities are given for each section. In addition, manufacturers and production volumes are given, along with substitutes, trends, and conclusions. The section on Drilling Muds contains extensive information on substitutes and costs. This section had the most data to offer as asbestos is still used in drilling muds whereas it has been banned in products such as artificial fireplace ashes, artificial snows, and sprayed-on insulation.

DRILLING MUDS (FLUIDS)

Asbestos Product

Drilling muds, also called drilling fluids, are used when wells are drilled by the rotary method. This method involves a drill bit which is turned by a drill pipe extending down to the bit from the surface of the ground. The machinery for rotating the pipe is located at the ground surface (see Figure 3).[1] The drilling mud is pumped down through the drill pipe and the drill bit and then returns through the annulus between the drill pipe and the well bore hole.[1] As the fast moving drilling mud passes through the bit and back up the annulus, it cools and lubricates the bit and picks up the drilled cuttings, carrying them to the surface. The bottom of the hole is thus left clean for the drill bit. At the surface, the drilling mud passes through screening equipment which removes the chips of rocks ground away by

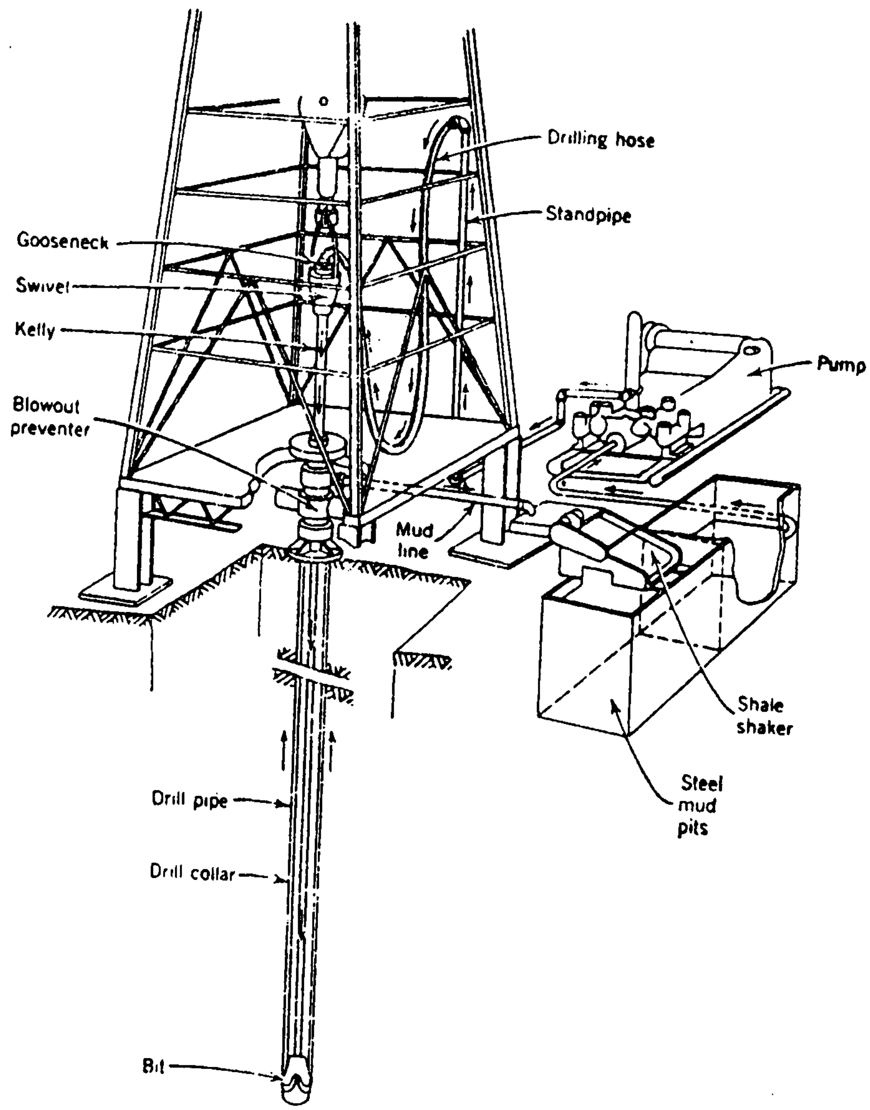

Figure 3. A circulatory system for a rotary drilling rig.[1]

the drill bit. The mud is replenished with new additives and is recirculated back through the drill pipe to the drill bit. The process is repeated until the desired depth is attained.[2]

Drilling muds typically contain anywhere from 3 to 12 different additives out of over 150 minerals and chemicals which are appropriate for drilling mud applications. When drilling begins, mud additives are dumped into a hopper where they are blended with water. The mixture then goes to a tank near the well and is pumped from this tank through the drilling system.[2]

Special Qualities--

Asbestos is used in drilling muds to increase the carrying capacity of the mud (the ability of the mud to bring up cuttings) without significantly increasing the mud viscosity. This is a useful property since it is easier to pump a less viscous fluid which results in more power available at the bit and a faster drilling rate. Additionally, asbestos acts as a loss-circulation material; that is, a material added to drilling mud to plug all passages, cracks, and cavities in the drill hole to prevent the loss of the drilling mud.*

Uses and Applications--

In the field, asbestos is added to the drilling fluids through a mud hopper or large funnel. Asbestos is used in concentrations normally ranging from 1 to 2 1/2 kg per barrel [1 barrel = 159 liters (42 gallons)] of mud.[4] However, values as low as 0.2 kg per barrel[5] and as high as 9 kg per barrel have also been reported[6] depending upon the desired characteristics of the drilling mud. Initially, a volume of drilling mud ranging from 150 to 200 barrels is prepared and as drilling progresses, additional quantities are prepared as needed. Under typical conditions, the drilling mud is prepared once every 8-hour shift. The amount of asbestos added each time is normally less than 230 kilograms (500 pounds).*

The choice of whether or not to use asbestos in a drilling mud is a function of the individual well site and depends upon the specific job, soil characteristics, materials being drilled for, and cost effectiveness.

Product Manufacturing Summary--

Manufacturing process--One manufacturer of asbestos used in drilling muds (Johns-Manville) processes the asbestos in the following manner. The asbestos is extruded, highly moisturized (12 to 15 percent) and then pelletized, thus binding the fibers together. The manufacturer claims that this process produces an asbestos product with negligible fiber release when it is used to make drilling muds.[7]

Name and number of manufacturers--The asbestos product described above is sold under the trade name of FLOSAL® and marketed by Drilling Specialties in Bartlesville, OK.[5] Approximately 1.6 million kilograms (3.5 million pounds) per year of FLOSAL® are made and marketed in the United States.[8] The other American manufacturer of an asbestos product for use in drilling muds is Union Carbide Corporation. This product is marketed by Montello Company of

*Source is an unpublished OSHA document on Asbestos.

Tulsa, OK, under the trade name Super Visbestos® and is advertised as being sheared, wet-refined, pelletized, chrysotile asbestos.[9] Information about annual production rates was given for Super Visbestos® but, upon further consideration, the Montello Company considered this information to be proprietary and it is not listed in this report.[10] The Johns-Manville Company mines their asbestos in Canada and the asbestos used by Union Carbide is mined in California. NL Inudstries, Inc. of Houston, Texas, was also contacted as a potential (but unconfirmed) manufacturer of drilling muds and their components, but chose not to divulge any information on the subject.[11]

Production volumes--Approximately 9,900 metric tons (10,000 tons) of asbestos fiber were used in 1978 in drilling fluids.[12,13] Current production is estimated to be 4,900 metric tons annually.[14]*The shorter grades of chrysotile fiber are normally used, in either pelletized or loose fiber form.[15] Because the two American manufacturers both produce a pelletized form of asbestos for drilling muds, the loose fiber form is assumed to come from non-American manufacturers.

Substitute Products

Methodology--

Search Strategy--Information on the use of asbestos in drilling muds and substitute products was obtained from a literature review and contact with manufacturers and suppliers of asbestos and substitute products.

Summary of Contacts--Trade Associations, manufacturers of both asbestos and substitute products, and product distributors were contacted. All are listed below.

Trade Associations

- Mr. Bob Pigg, Asbestos Information Association, Arlington, VA, January 1980.
- Mr. Bill Sallens, Petroleum Equipment Supplier's Association, Houston, TX, January 1980.
- Mr. Steve Chamberlain, American Petroleum Institute, Washington, DC, February 1980.

Manufacturers

- Dr. Harry Rhodes, Union Carbide Corporation, Niagara Falls, NY, February 1980.
- Mr. Edmund Fenner, Johns-Manville Corporation, Denver, CO, January 1980.
- Mr. Don Peteherych, Kelco Division, Merck Company, Houston, TX, January 1980.

*At this date, the figure is most likely to be still less, given the 1980 downward turn in asbestos consumption for all categories.

Product Distributors

- Mr. Nile Copeland, Dresser Industries, Magcobar Division, Houston, TX, January 1980.
- Mr. Phil Theis, Milwhite Company, Inc., Houston, TX, January 1980.
- Mr. E. E. Clear, Drilling Specialties, Bartlesville, OK, January 1980.
- Mr. Hal Marple, International Drilling Fluids, Houston, TX, January 1980.
- Mr. Gregg Jackson, Brinadd Company, Houston, TX, January 1980.

Other

- Dr. George Binder, Exxon Production Research Company, Houston, TX, January 1980.

Special Qualities--

Asbestos serves a dual function in drilling muds. It increases the carrying capacity (acting as a viscosifier) and also acts as a loss-circulation material. No single substitute except perhaps bentonite or attapulgite clays serve both functions, but a variety of substitutes can be used as loss-circulation materials. These materials are both added to the drilling mud to serve the functions that asbestos would perform. Loss-circulation material substitutes can be used to obtain similar results to those seen with asbestos fiber. With viscosifiers, each substitute product may have a specific application and must be chosen according to the requirements at the drilling site. Asbestos has a universal application as a viscosifier, whereas substitute viscosifiers must be chosen for the specific application.

The temperature of circulating drilling mud in oil wells is normally 52°C to 60°C with a maximum temperature at the bottom of the hole of 149°C and sometimes as high as 204°C. Asbestos can be used at temperatures over 316°C before it breaks down.[15] Polymers can generally be used at temperatures of up to 149°C, although new copolymers have been demonstrated at temperatures of from 260°C to over 371°C.[5,16] Bentonite, attapulgite, and other clays cannot withstand temperatures as high as asbestos, but can normally be used in most drilling applications up to 177°C to 204°C. Bentonite is the most widely used viscosifier for freshwater drilling systems, and attapulgite is the most common viscosifier for saltwater drilling systems.*

Asbestos performance degrades readily from mechanical shear forces. Xanthan gum polymer can be subjected to high mechanical shear without degradation.[6] Clays, such as attapulgite, have the advantage of actually increasing viscosity at higher shear forces.*

*Source is an unpublished OSHA document on Asbestos.

Uses and Composition--

There are two types of products that may be substituted for asbestos in drilling muds--viscosifiers and loss-circulation materials. Each is described below.

Viscosifiers--Depending upon the characteristics of soil and water into which a well is being drilled, a number of viscosifying agents can be added to the drilling mud. These viscosifiers give the drilling mud carrying capacity to bring up the drilled rock pieces. Frequently, a combination of viscosifiers is added to the drilling mud to provide a synergistic effect on the carrying capacity of the drilling mud or to meet the specific needs at the site. Each site is different and therefore the types and concentrations of the viscosifiers are variable. Table 80 provides a listing of substances which act as viscosifying agents and can be used as substitutes for the viscosifying qualities of asbestos.[13,17]

TABLE 80. VISCOSIFIERS USED IN DRILLING MUDS[9]

Bentonite	Guar gum
Attapulgite clay	Mined lignin
Sepiolite clay	Polyacrylamide dispersion
Ferrochrome lignosulfate	Polysaccharide organics
Synthetic cellulose	Sodium acid pyrophosphate
Sodium carboxymethyl cellulose	Sodium hexametaphosphate
Carboxymethyl hydroxyethyl cellulose	High temperature stable clay
Hydroxyethyl cellulose	Nonfermenting starch
Carboxymethyl cellulose	Organophilic clay
Natural polymers	Pregelatinized potato starch
Xanthan gum biopolymer	Pregelatinized corn starch
Calcium magnesium silicate	Polyanionic cellulosic polymer
Magnesium smectite	Gelling agent
Sodium tetraphosphate	Asphaltic gelling agent
Nonionic polymers	Blended polymers
Anionic polymers	

The most commonly used viscosifier is clay, such as bentonite clay or attapulgite clay.* In addition, the use of polymers as viscosifiers has gained wide acceptance in recent years. World Oil's 1978-1979 Guide to Drilling, Workover, and Completion Fluids contains a list of 263 trade names (including blends) for polymers used in drilling fluids.[9] The polymers are either synthetic or natural. The natural polymers include starch, guar gum, and Xanthan gum. The synthetic polymers include cellulosics, acrylates, acrylamides, and maleic anhydride derivatives.[18]

*Source is an unpublished OSHA document on Asbestos.

Most polymers sold are used for the same applications in which bentonite or asbestos is used.[5] The Xanthan gum polymer (frequently referred to by its trade name XC polymer) is the polymer most frequently compared with asbestos and cited as a good substitute.[5,6,13,19]

Loss-Circulation Materials--Another function of asbestos in drilling fluids is to act as a loss-circulation material; i.e., a material to seal cracks, holes, or extremely permeable streaks in the formation through which the drilling fluid is lost. When the zones into which the drilling fluid is lost contain large cracks and holes, the materials added to prevent the loss of drilling fluid are very coarse grained and normally have high compressive strength such as coarsely broken walnut shells. When drilling fluid is lost into formations containing medium-size cracks and holes, medium-grained materials that are granular, fibrous or flaked, such as walnut shells, bagasse, and cellophane flakes, are added.[1] For formations with fine cracks and tiny holes, fine grain materials, such as mica flakes or shredded leather, are added. Since the size of the cracks and holes is not normally known, it is common practice to add several loss-circulation materials together, to cover the range of crack or hole sizes.[1]

There are many low cost substances that can be used as loss-circulation materials instead of asbestos. The 1979 World Oil Guide to Drilling, Workover, and Completion Fluids lists over 50 substances that are used as loss-circulation materials.[9] A literature source also lists over 50 substances which have been used as loss-circulation materials and classifies them under the categories of granular, fibrous, and flaky.[1] This list is shown in Table 81.[1] Normally, the cheapest and most readily available loss-circulation material in the vicinity of the drill site is used.

COST COMPARISON

The number of materials which are used as viscosifiers is too large to permit a cost comparison of each one. For some of the most common viscosifiers, a cost comparison with the asbestos product is presented in Table 82.[4,5,17,20]

Table 82 shows that asbestos is generally the cheapest of the common substances used as viscosifiers in drilling muds. The bentonite and attapulgite clays are cheaper per pound but, because more material must be used, the cost is somewhat higher. The polymers generally cost between $1.00 and $9.00 per pound, but less is used per barrel than for asbestos, so the cost is more competitive.

Table 83 shows cost data for some common loss-circulation materials.[17] On a cost basis, there are many loss-circulation materials which compare favorably with asbestos.

TABLE 81. LOSS-CIRCULATION MATERIALS[1]

Granular	Fibrous	Flaky
Beans	Cotton	Chopped cellophane
Coarse treated bentonite	Bagasse	Cork
Crushed rock	Flax shive	Mica
Cracked corn cobs	Wood fiber	Ground corn cobs
Crushed gilsonite	Textile fiber	Vermiculite
Ground plastic	Mineral fiber	Paper, high wet strength
Ground nut shells	Leather	Fish scales
Ground coke	Glass fiber	Wheat bran
Ground tires	Peat moss	Gutta-percha flakes
Peas	Tree moss	Polystyrene flakes
Rice	Feathers	Linseed hulls
Peach pits	Beet pulp	Rice hulls
Walnut shells	Hay	Cottonseed hulls
Polystyrene foam	Excelsior	
Asphalt	Hog hair	
Cellular plastics	Manure	
Pecan shells	Copper wool	
Almond shells	Sponges	
Ground formica	Aspen fibers	
Cracked wood	Cedar fibers	
	Redwood fibers	

TABLE 82. COST COMPARISON OF DRILLING MUD VISCOSIFIERS[4,5,17,20]

Material	Cost $/lb ($/kg)	Amount used lb/barrel (kg/barrel)	Cost ($/barrel)	Reference
Asbestos	0.40 - 1.00 (0.88 - 2.20)	2 - 5 (4.40 - 11.00)	0.80 - 5.00	4,5
Bentonite	0.08 - 0.10 (0.18 - 0.22)	20 - 40 (44.00 - 88.00)	1.60 - 4.00	4
Attapulgite	0.16 - 0.20 (0.35 - 0.44)	15 - 20 (33.00 - 44.00)	2.40 - 4.00	4
Sepiolite	0.20 - 0.25 (0.44 - 0.55)	5 - 10 (11.00 - 22.00)	1.00 - 2.50	4
Xanthan (XC) polymer	7.00 - 9.00 (15.45 - 19.85)	0.5 - 2 (1.10 - 4.40)	3.50 - 18.00	4
Carboxymethyl cellulose	3.60 (7.95)	0.25 - 2 (0.55 - 4.40)	0.90 - 7.20	5
Polysaccharides polymer (DF-VIS)	5.00 (11.00)	1 - 2 (2.20 - 4.40)	5.00 - 10.00	17
Hydroxyethyl cellulose	1.00 (2.20)	8 - 9 (17.65 - 19.85)	8.00 - 9.00	20

TABLE 83. COSTS OF COMMON LOSS-CIRCULATION MATERIALS[17]

Material	Cost in $/lb ($/kg)
Asbestos	0.45 (1.00)
Cellophane flakes	0.41 (0.90)
Mica	0.33 (0.73)
Nut shells	0.32 (0.70)
Bentonite	0.10 (0.22)

CURRENT TRENDS

The use of asbestos in drilling muds has decreased from an estimated 9,900 metric tons per year in 1978 to an estimated current annual use of less than 4,900 metric tons per year.[13,14]

The most common polymer substitute for asbestos is Xanthan gum (XC) polymer. This polymer has no known adverse health effects and has, in fact, been approved by the Food and Drug Administration as a viscosifier in products for human consumption, such as beer, ketchup, and salad dressing.[15,19]

The other common substitute viscosifiers are bentonite and attapulgite clays. In addition, Lextar of Wilmington, Delaware, reports that it's product-Pulpex-a polyolefin pulp, is a potential replacement in oil well drilling muds. Its use is currently being investigated, and at this date, information is considered proprietary.[3]

CONCLUSION

Adequate substitutes are available to replace both functions of asbestos in drilling muds; i.e., to provide carrying capacity (viscosifier) and to act as a loss-circulation material. A large number of substitutes exist for the loss-circulation material needs at a competitive cost. The substitute materials which are viscosifiers are the bentonite, attapulgite,and sepiolite clays and a variety of polymers. The clays are competitive with asbestos in cost. The polymers are more expensive than asbestos, but less material is necessary to make up the drilling mud, resulting in a cost-per-barrel figure that is still more expensive, but nevertheless competitive. The use of asbestos in drilling muds is not mandatory and probably not even necessary in most applications, as adequate substitutes exist at a competitive cost. As with other mud additives, the type and amount of asbestos substitute will vary between drilling sites. Since no typical mud formulation exists, a direct comparison between asbestos and nonasbestos drilling muds cannot be made.

SHOTGUN SHELL BASE WADS

Asbestos is used to manufacture base wads for shotgun shells. Both a literature search and telephone contact were used to gather information for this section. Most of the data presented here was furnished by Ted McCawley of Remington Arms Co., Bridgeport, CT.[22]

Base wads are formed from a mixture of about 36 percent by weight of asbestos, 54 percent wood flour and 10 percent wax which is pressed to form the required shape. Only one shotgun shell manufacturing plant (operated by Remington Arms Co. in Bridgeport, CT) is known to use asbestos.[22] In the past, approximately 450 metric tons per year of asbestos was consumed in shotgun shell base wad production. This amount is expected to decrease in the future.

The Remington Arms Co. is currently phasing out the use of asbestos in shotgun shell base wads. The manufacturer is going to a one-piece polyethylene shell which is a more stable shell in addition to being less costly. The Remington Co. reported that they will have converted 95 percent of the asbestos-containing shotgun shells to one-piece asbestos-free shells by the end of 1980; i.e., currently). The remaining 5 percent of the asbestos-containing shells will be converted to asbestos-free shells by the end of 1981.[22]

ASPHALT/ASBESTOS CEMENT

This section includes the composition and special properties of asphalt/asbestos cement as well as a summary of the contacts made during the course of this report. Appropriate conclusions are noted.

Special Properties and Product Composition

Asphaltic cement consists of aggregates cemented together with ordinary paving grades of asphalt such as AC-10 and AC-20.[23] The idea behind adding asbestos to asphaltic cement was to increase the amount of asphalt that could be put into the mix, which would increase the strength of the material and increase the life of the pavement.[24] While there is some indication that asbestos might improve the quality of asphalt cement, the prevailing opinion appears to be that if there is actually anything to be gained by adding asbestos, it isn't enough to make it worthwhile. A spokesman for the National Asphalt Paving Association said that there was evidence that asbestos might actually be an agent contributing to cracking.[23]

The following contacts were made in the course of investigating the use of asbestos in asphalt cement:

- Mr. Charles Foster, Consultant
  National Asphalt Paving Association
  6811 Kenilworth Avenue
  Riverdale, MD 20804 (301) 779-4880

- Mr. Miguel Leman
  Johns-Manville Corporation
  Ken-Caryl Ranch
  Denver, CO 80217 (303) 979-1000

- Mr. John Tidewell
  Federal Highway Administration
  Federal Building
  Raleigh, NC 27611 (919) 755-4346

- Mr. Durwood Barber
  North Carolina Division of Highways
  Materials Test Unit
  Highway Building
  Raleigh, NC 27611 (919) 733-3563

- Mr. Harold Schmitt
  Federal Highway Administration
  P.O. Box 1915
  Sacramento, CA 95809 (916) 440-2428

- Mr. Harold Plate
  ASARCO, Inc.
  120 Broadway
  New York, NY 10005 (212) 732-9500

- Mr. James McGee
  Arizona Department of Transportation
  206 S. 17th Avenue, Room 176A
  Phoenix, AZ 85007 (602) 261-7386

- Mr. Tom O'Neil
  Maryland State Department of Highways
  Highway Maintenance
  Baltimore, MD 21201 (301) 383-4108

None of the individuals contacted was aware of any intentional use of asbestos in asphalt paving in the United States. The only place asbestos is known to be used in North America is Canada.[25]

FOUNDRY SANDS

The make-up of foundry sands was investigated as to asbestos content, use-to-date, and possible substitutes. Also included in this section is information on insulating sleeves and a complete list of contacts for this section. Methodology consisted of a literature search as well as a number of telephone calls to various industry spokespersons.

Principal contacts were:

- Mr. Ezra Kotzin
  American Foundryman's Society
  Des Plaines, IL (312) 824-0181

- Mr. Gary Mosher
  Industrial Hygienist
  Des Plaines, IL (312) 824-0181

- Mr. Phillip Berg
  Industrial Hygienist
  Asbestos Information Association
  Arlington, VA (202) 979-1150

- Mr. S. Kuhn
  Johns-Manville Regional Sales Office
  Atlanta, GA (404) 449-3300

- Mr. A. Penters
  Sales Manager
  Whitehead Brothers Co.
  Florham Park, NJ (201) 377-9100

- Mr. H. Manvel
  Pennsylvania Foundry Supply and Sand Co.
  Philadelphia, PA (215) 333-1155

Foundry sands are used to make expendable molds for metal castings. The sand is used with a bonding agent to give the mold the necessary strength required for castings. The mold is filled with metal through a system of channels called runners or gates. In addition, there is a system of risers which ensure that the mold is properly filled and compensates for shrinkage.

Asbestos is actually an undesirable material in foundry sands since it lowers the refractory point of the sand mold. For this reason, asbestos is not used in foundry sands for making molds for the production of castings.[26] Personnel from the American Foundryman's Society as well as suppliers of foundry sands and asbestos stated that asbestos is not used in foundry sands at this date.[27-30]

Asbestos has been used in the past as a filler in the formulation for the manufacturing of insulating sleeves for risers on castings. However, due to Occupational Safety and Health Administration (OSHA) standards for airborne asbestos in the workplace, asbestos use for insulating sleeves or risers has ceased.[26,27]

Substitute materials for asbestos fibers used in insulating sleeves on risers for castings include any inert mineral material that can: (a) withstand high heat, (b) insulate, and (c) does not crystallize with water at high temperatures. The materials used to manufacture the insulating sleeves for risers on castings are proprietary, but include such mineral compounds as vermiculite, perlite, and diatomaceous earth.[26]

SPRAYED-ON INSULATION

The use of asbestos in sprayed-on insulation was regulated in 1973 by the National Emission Standard for Asbestos (40 CFR 61) promulgated by the U.S. Environmental Protection Agency. This standard limits the amount of asbestos in spray-on materials used to insulate or fireproof buildings, structures, pipes, and conduits to less than 1 percent asbestos on a dry weight basis. This standard effectively eliminated the use of asbestos as sprayed-on insulation. The 1 percent limitation prevents the use of asbestos while allowing the use of other materials in which asbestos is a trace contaminant. In 1978, the standard was revised to limit the use of sprayed-on asbestos for decorative purposes to materials containing less than 1 percent asbestos.

Prior to 1973, it had been common practice to coat pipes, ducts, boilers, tanks, reactors, turbines, furnaces, and structural members with sprayed-on asbestos materials.[31] The typical form of asbestos used was chrysotile, although amosite was used in applications such as shaped, block-type gagging for high temperature pipes. At present, however, the major source of asbestos fiber emission is during demolition of existing structures and manufacturing equipment. The National Emission Standard for Asbestos requires removal of asbestos insulation before demolition with adequate wetting of all exposed asbestos during the removal process.

Substitute materials exist for the applications in which sprayed-on asbestos was formerly used. Both cellulose fibers and rock wool can be sprayed-on to equipment or structural members to provide insulation.

Cellulose from processed paper (with fire retardant and adhesives added) is used to make the cellulose material which is sprayed-on for insulation. The fire retardants are impregnated into the cellulose to give an Underwriter's Laboratory Class 1 fire rating.[32] The sprayed-on cellulose installed cost is approximately \$3.22 to \$5.38 per square meter (\$0.30 to \$0.50 per square foot) with a 2.54 cm (1 in.) thickness and has an insulating R value of approximately 1.46 to 1.77 per cm (3.7 to 4.5 per inch). The cellulose material has been tested for potential health hazards and no health hazards are thought to exist with the manufacturing or use of the product.[32,33]

Rock wool (also referred to as mineral wool and slag wool) can be used in sprayed-on applications for insulation or fireproofing.[34] The rock wool is considered to be noncombustible[35] and no health hazards associated with its use have been demonstrated.[34] Rock wool has an insulating R value of approximately 1.50 to 1.57 per cm (3.8 to 4.0 per inch) and installed costs are between \$4.30 and \$8.61 per square meter (\$0.40 to \$0.80 per square foot) with a 2.54 cm (1 in.) thickness.[34,35] The mechanical and insulation properties of rock wool may be inferior to asbestos.

ARTIFICIAL FIREPLACE ASHES AND ARTIFICIAL SNOWS

Artificial Fireplace Ashes

Between 1971 and 1976, over 100,000 logs for gas-burning fireplace systems were reported sold which were frosted or treated with asbestos-containing materials.[36] At approximately 1/2 pound (0.23 kg) of asbestos per log, approximately 5 tons (4.5 metric tons) of asbestos, mostly chrysotile, were sold annually for artificial embers.[12] In mid-1977, manufacturers stopped producing the product in anticipation of a subsequent consumer ban by the Consumer Products Safety Commission. The ban of artificial emberizing materials (ash and embers) containing respirable free-form asbestos became effective December 15, 1977. Manufacturers of artificial gas log emberizing material are currently using four substitutes in their products: vermiculite, rock wool, mica, and synthetic fiber.[37]

Artificial Snows

Health considerations have nearly halted the use of asbestos in artificial snows.[12]

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SECTION 12

DISCUSSION, RESULTS, AND CONCLUSION

DISCUSSION

Results achieved in this analysis of asbestos substitute development and performance have been determined by the methodology employed and the availability of data. The methodology involved:

- gathering a brief description of each asbestos product, including a definition of special qualities required for each application and a product manufacturing summary,
- expanding these characteristics to include related nonasbestos products,
- comparing the cost of the asbestos product to the substitute options,
- delineating trends and drawing conclusions for substitution possibilities for each asbestos product category.

To gain the information described above, the following methods of data gathering were employed:

- collecting and reviewing available data in the form of reports, brochures, literature searches, etc.,
- contacting manufacturers, users, suppliers, and national trade associations of both asbestos and nonasbestos products by phone,
- obtaining current thoughts and opinions as well as product brochures on the status of substitute development through the EPA/CPSC Substitutes for Asbestos Conference, Arlington, Virginia, July 1980,
- reviewing patent information.

In addition, the final report was revised to include comments from asbestos and substitute product industry sources, such as the Asbestos Information Association (A.I.A.), Bendix Research Laboratories and Victor Products.

This served both to update the original text as well as to amend and expand it where necessary. As inquiries were not limited to a single type of source, this assessment reflects both published technical data and expressions of user criteria for product selection.

Descriptions of asbestos product uses consisted of defining, as concisely as possible, the purposes served by each category of products. To a certain extent this led to the inclusion of market segments not unique to asbestos products and provided an early indication of possible substitute products.

Availability of data and willingness to discuss the performance of asbestos products and substitute products seems to be a function of both a product stage of development and its marketing. Five classifications may be noted:

- established products marketed by many manufacturers
- established products marketed by a limited number of distributors
- recently developed products with a captive market
- products under development
- fibers under development

For each of these classifications, the availability of the following types of data varies: product composition, technical performance specifications, performance record, and market statistics.

For established products marketed by many manufacturers all data are readily available. Product manufacturers and distributors do not benefit by restricting the publication of data. Markets are well characterized and well known. Included in this classification are: asbestos-cement pipe, vinyl-asbestos floor tile, and asbestos-cement sheet.

For established products marketed by a limited number of distributors, marketing data and detailed performance data are not readily available. Included here are several products in the miscellaneous category.

Recently developed products with captive markets tend to have proprietary compositions and manufacturing technologies. Properties are known and performance statistics available. Investments in development efforts can be large. Data on the extent of commercialization are often considered proprietary. This classification includes friction products and, to some extent, plastics.

For products under development general performance claims tend to be available and occasionally some composition data are available. Manufacturing technologies are closely guarded and only limited publishable data are available. Candidate manufacturers tend to aggressively promote their products and will furnish data on projected manufacturing capacities.

For fiber substitutes under development, available data tend to be speculative.

The final step was the assessment of available data to determine whether substitutes exist, and whether performance and cost data are available. Costs were often obtained by telephone contact; they are as up-to-date as possible but should be used for comparison purposes only.

RESULTS

Substitute availability, performance, and cost data are presented on a category-by-category basis. Category discussions are subdivided as necessary.

Asbestos Paper Products

Paper products have been grouped into nine subcategories:

- flooring felt
- roofing felt
- beater-add gaskets
- pipeline wrap
- millboard and rollboard
- electrical insulation
- commercial papers
- specialty papers
- beverage and pharmaceutical filters

Asbestos has been used in paper products to add dimensional stability, moisture, rot, and corrosion resistance, heat resistance, electrical resistance, strength and resilience. In flooring felts, asbestos has virtually replaced organic and jute felt backings, and is now so well established that there are no acceptable alternatives at present, although some are under development. Nonasbestos beater-add gaskets have made a significant entrance into the marketplace in just the past year and a half, changing this category from one in which only limited alternatives existed, to one where the substitute product promises to become competitive with asbestos in only a short time. In most of the other paper product categories, suitable alternatives to asbestos are available. Organic felt, fiberglass felt, and single-ply membrane systems may replace asbestos roofing felt. In pipeline wrap applications, saturated fiberglass, extruded epoxys and resins, and plastic coatings are all viable alternatives, although saturated asbestos pipe wraps are currently the preferred protection system for oil and gas pipelines due to their time-tested durability and relatively low cost. However, the market for pipeline corrosion protective materials is competitive, and the relatively new substitute materials just becoming commercially available may displace asbestos. For millboard and rollboard products, ceramic boards have been developed which generally equal or better the asbestos board product, though at significantly higher price. Other replacements in this area are also under development. Substitutes to asbestos in electrical insulation are also available, but, again, the cost is higher. In general then, it may be seen that adequate substitutes are available in many of the paper product categories, though not all, and that they are specific to certain applications and often are more expensive.

Friction Materials

Friction materials are used in automotive, truck, airplane, railroad, and industrial brakes and clutches. They require appropriate coefficients of friction, the ability to withstand high temperatures, dimensional stability, strength, durability and a lack of abrasion characteristics. Asbestos meets these requirements, as do a number of materials which may be used as substitutes, although substitute products may not be used in all of the applications for which asbestos has been developed. Substitutes include glass fiber, steel wool, mineral wool, carbon fiber, cermets, semimetallic friction materials, potassium titanate fibers, aramid fibers, vermiculite and silicon nitride. As friction applications vary, so do the materials most appropriate for each use. Semimetallic and cermet friction materials may be used in direct asbestos substitute applications, semimetallic in disc brake pads (it is projected that in 5 years nearly all original equipment disc brakes in passenger cars and light trucks will use semimetallic friction materials) and cermets for aircraft brakes (95 percent of all new commercial aircraft use cermets). Most railroad and metro systems have now replaced any existing asbestos with an alternative such as these also. Currently, all drum brake linings contain asbestos. However, research in this area is ongoing and nonasbestos drum brake linings may become available at some future date. Research is also underway to provide nonasbestos heavy-duty truck and industrial brakes, as well as vehicle and industrial clutches. To date, asbestos is the best material which has been found to provide the properties necessary in these latter products. For certain industrial machinery with a long service life and for which asbestos friction materials are a required component (often custom fabricated in small volumes) it is unlikely that substitute products will be developed for machines currently in service.

Asbestos Cement Pipe

Pipe in use as sewer or waste conduits must be strong, resilient, flexible, durable, inert and fire-resistant. Asbestos fibers are used to make A/C pipe products as they impart these characteristics. However, alternatives are also available in the form of plastic pipe, concrete pipe, vitrified clay pipe, glass-reinforced concrete pipe, ductile iron pipe and various fiber substitutes. Each of these alternatives offers different qualities--ductile iron is more suited for situations involving shock loads, vibration and ground movement; vitrified clay is cheaper for nonpressure applications; for small pipe diameters, iron as well as plastic and vitrified clay offer strong competition, with A/C pipe most suitable for mid-range diameter (6 to 24 inches). Therefore, for pipe products, economics appears to be the main factor influencing choice; similar properties to asbestos may be obtained from commercially available alternatives, and many areas of the country specify nonasbestos piping, simply because of special parameters found in different pipe materials.

Asbestos Cement Sheet

Asbestos imparts high tensile strength, flexibility, resistance to heat, chemical inertness and a large aspect ratio (ratio of length to diameter) to this product. It also gives A/C sheet sufficient wet strength so that it may be molded into complex shapes at the end of the production process. A/C sheet products thus may include: flat sheet, corrugated sheet, siding shingles, and roofing shingles. Substitutes for A/C sheet thus vary with the product; in general it appears that A/C sheet still maintains command of specific markets where its unique properties make it outstanding (e.g., laboratory table tops although even in this area, alumina sheet and laminated hardboard may be adequate replacements), whereas, for more general use, substitute products are readily available. Both flat and corrugated sheets may be replaced with glass-reinforced cement sheet, which is superior to A/C sheet in some respects, such as overall strength characteristics and impact resistance. Cement/wood board may also be used in place of flat sheet; this product has been available in Europe for a number of years. Alumina-silica products, galvanized steel, masonry, and reinforced plastics are also alternatives to the sheet products. A/C siding shingles may be substituted by hardboard, siding shingles, paneling, wood shingles, aluminum, stucco, and brick. Roofing shingle replacements include unreinforced concrete, asphalt and fiberglass shingles. Many of these products are comparable to or even less expensive than the asbestos product. Therefore, it appears that A/C sheet may continue to dominate specific applications, such as lab tables and the overseas construction market, but readily available, competitive, substitute materials will fill other niches that were once almost solely those of A/C sheet.

Vinyl Asbestos Floor Tiles

Floor tiles must be tough, dimensionally stable, long lived, economical, moisture resistant, smooth surfaced, and easy to clean. To date, only asbestos offers this combination of properties. Although products such as asbestos-free vinyl tile are available, they not only cost more (as seen with pipe products, this could be overcome with other unique properties, if it was the only problem) they also lack durability, resilience, flexibility and wear resistance, which makes them inappropriate for any heavy duty use applications. Thus, to date, V/A floor tiles continue to command 91 percent of the resilient floor covering market.

Gaskets and Packings

Gaskets and packings are composed of asbestos, an elastomeric binder, and in the case of some packings, a lubricant. Asbestos has been used not only because it is heat resistant, resilient and strong, but also because it is relatively chemically inert which is important for many chemical applications. However, research on substitute materials has recently brought products to a forefront which surpass asbestos in these qualities and others. Replacements on a fiber-for-fiber basis include silica, carbon, Kevlar, ceramic, and teflon fibers. Material substitutes also exist, in the form of Gylon, NuBoard, and Victor Products brands for gasket applications. No single substitute fiber material possesses all of the qualities attributable to asbestos; however, for any particular application, a substitute fiber can often be employed to achieve the desired combination of properties. It appears that many gaskets and packings manufacturers are currently using or switching to alternative products and buyers are specifying such products. Both health concerns and a growing awareness of substitute capabilities have caused this trend. Although asbestos combines versatility and low cost and may be uniquely suitable to some situations, it does have negative qualities also and a virtually endless list of potential substitutes exists, any one or combination of which could act to replace asbestos in the gaskets and packings marketplace. In general, compressed asbestos sheet gasketing can be replaced with substitute materials at present, with the added expense to the customer at applications under 260°C. Graphite, sheet metal and other gasketing materials can replace asbestos at higher temperatures but often at greater cost. New packing materials appear to be more than viable alternatives, offering less abrasion and thus lower operating and maintenance costs. It appears that only sales and engineering resistance stands in the way of a total switch-over to nonasbestos packings.

Paints, Coatings, and Sealants

Asbestos is used in paints, sealants and coatings because it is strong, resistent to corrosion and heat, deadens sound, is waterproof, has the required viscosity and consistency, is durable and economical. It also has a unique affinity for asphalt which enables its use in roofing coatings and cements and automobile undercoatings. As a result of this property, asbestos-free, asphalt-based coatings which duplicate the characteristics found in asbestos products have been slow to develop. Although more expensive and sometimes of inferior quality to asbestos they are now available in countries such as Sweden where asbestos has been banned, and, to a more limited degree, in the U.S.

Nonasphalt based coatings made up of several minerals may be used as substitutes for asbestos. These include talc, barite, diatomite, silica, clay and mica. More information on performance of such products will become available as they are further developed and tested. For pipe coatings, asbestos-free alternatives include enamels, extruded plastics, fusion-bonded thermosetting powder resins, liquid epoxy and phenolics, various tapes and wax coatings, polyurethane foam insulation, and concrete.

Other products which once contained asbestos, such as texture paints, spackling and drywall joint compounds are now banned such that asbestos-free products are coming online as replacements. Other compounds such as the polyolefin pulp "Pulpex" by Lextar or worker's tools are now used to provide texture and attapulgite may be an alternative to asbestos in spackle and dry wall joint compounds. Fiberglass, fibrous alumina, and magnesium silicate fiber (containing asbestos) may be used to replace asbestos in automobile and truck undercoatings, but they are much more expensive and do not display the properties required of asbestos (affinity for asphalt and viscosity control).

Reinforced Plastics

Asbestos fibers have been used in combination with plastics since the early 1920's. When added to polymeric materials, asbestos acts to modify both the physical and chemical characteristics of the composite. Fibers function both as fillers and reinforcing agents. Asbestos combines the advantages of both a mineral and fibrous binder carrier with reinforcing action. It also imparts good surface finish, toughness, resistance to heat and fire, and less shrinkage and warpage than other fibers. In addition, it improves the ability to handle the product during processing. There are a wide variety of fillers and reinforcements available as potential substitutes to asbestos in phenolic molding compounds. All manufacturers have found suitable substitutes for certain products and many have been able to completely eliminate the use of asbestos. Viable substitutes include: fibrous glass, clay, talc, mica, carbon fibers, aramid fibers, polyethylene fibers, calcium sulfate, Wollastonite, and processed mineral fiber from blast furnace slag and silicates. While most of these materials are already economically and physically competitive with asbestos, the others probably will become so as the lack of expensive asbestos dust collecting systems and similar properties at reasonable prices offset the fiber replacement cost. In general, it appears that there is a well-established and indeed much progressed trend throughout the reinforced plastics industry to replace asbestos with alternative materials. Although there may still be some specialty products which require the use of asbestos, the trend towards nonasbestos products will continue. In fact, it can be said that, generally, producers of phenolic molding compounds intend to phase-out the use of asbestos in most areas, as soon as nonasbestos developments gain customer acceptance. Only in some specialty applications (including national defense items) will asbestos then be required.

Textiles

Textiles may be broken down into six different categories: fire-resistant materials, thermal insulation, electrical insulation, packings and gaskets, friction materials, and specialty textiles. In each application, asbestos fibers have been used for strength, processing ability, heat and acid resistance, high tensile strength, resistance to abrasion, and durability. Substitutes for many of the applications include fiberglass, ceramics, organics, graphite, carbon, quartz, cotton, and special wool blends. Many large manufacturers of asbestos textile materials are currently manufacturing substitute products such as fiberglass and ceramics along with their asbestos products.

Government specifications, such as for fire-resistant materials, are being revised due to health concerns, which acts to encourage the sale of various substitute products. The viable substitutes cover a wide range of products, although they are in most cases more costly than asbestos. Thermal insulation products using asbestos have been loosing their share of the market to fiberglass and ceramic materials; electrical insulation substitutes which are suitable are readily available; packings and gaskets and friction materials appear to have adequate alternatives; and specialty textiles using asbestos have been decreasing, although there still may remain a small number of minor applications such as lamp and stove wicks for which no satisfactory alternative appears to exist at present, even though substitute product manufacturers claim that replacements exist for every asbestos textile product. Overall, nonasbestos textile products, although higher priced, appear to be readily available to step into the one time asbestos-dominated market.

Miscellaneous Uses

Miscellaneous uses of asbestos include:

- drilling muds
- shotgun shell base wads
- asphalt/asbestos cement
- foundry sands
- sprayed-on insulation
- artificial fireplace ash and artificial snows

Asbestos has been used in these applications for various reasons--it increases the carrying capacity of drilling muds without significantly increasing the mud viscosity, and also acts as a loss-circulation material for the mud; it is added to asphalt cement to increase the amount of asphalt that can be put into the mix, thus increasing the strength of the material and the life of the pavement (this is no longer thought to be a worthwhile trait); and it acts as a fire-resistant filler in sprayed-on insulation. Health considerations have since caused a ban on sprayed-on insulation and artificial fireplace ashes. Both cellulose fibers and rock wool are now used in place of asbestos in sprayed-on insulation. Foundry sands no longer use asbestos as it is undesirable since it lowers the refractory point of the sand mold; it also appears to be undesirable in asphalt/asbestos cement as it may contribute to cracking. In shotgun shell base wads, asbestos use is currently being phased out. The sole manufacturer is quickly shifting to a one piece polyethylene shell which is more stable in addition to being less costly. As for drilling muds, asbestos use is decreasing due to health concerns. Adequate, cost competititve substitutes are available to replace both functions of asbestos in drilling muds--the carrying capacity and as a loss-circulation material. In general, the miscellaneous uses of asbestos are small, and nonasbestos products are being developed to fill in voids where asbestos has been phased out. In some cases, the asbestos product simply does not warrant production in the marketplace any longer, and thus is not replaced at all.

CONCLUSION

In certain product categories, data were limited. In part this reflects the difficulty inherent in obtaining accurate and complete information on a large and complex sector of the economy. Production volume data for many asbestos and substitute products could not be obtained except as gross composite estimates. Technical details concerning exact composition or manufacturing methods were closely guarded in some cases. Nevertheless, it has been possible to determine whether acceptable products are available in the marketplace.

With the exception of a few specific applications, each asbestos product category has commercially available alternatives. These alternatives are listed in Table 84. Required characteristics of the asbestos product substitutes, including availability, performance characteristics, cost, and additional comments, are summarized in Table 85. Resilient floor coverings constitute a major asbestos product category for which an economically viable direct substitute product is not available. For any particular application, the variety of available substitutes is a function of many factors including:

- customer preference
- product performance
- economics
- labor union demands
- regulatory controls
- construction trends (e.g., sewer construction)

In light of these complexities and changes over time it will be advisable to consider such factors when applying the data of Tables 84 and 85. In other words, these tables represent present conditions in a rapidly changing market.

Definition of the properties required in each application has frequently shown that asbestos products are "overqualified" for many applications. That is, not all of the properties imparted by asbestos are required for all applications. Often, a single asbestos product is employed for a range of applications differing in severity. The result is that inexpensive substitutes may be available for mild service conditions, whereas more expensive substitutes are required for severe service applications.

In no case is there a fiber or material alternative that can completely replace the special qualities of asbestos in every use; instead, a wide range of alternatives are offered, each fitting only a small niche in the range of

TABLE 84. POTENTIAL SUBSTITUTE PRODUCTS*

Asbestos product category	Potential substitutes
1. PAPER PRODUCTS	
a. Flooring felt	• "Backless" sheet vinyl • Foam-cushioned backings • "Place and press" vinyl tile squares • Carpet, wood, etc.
b. Roofing felt	• Organic felt • Fiberglass felt • Single-ply membrane system
c. Beater-add gaskets	• Ceramic paper • Teflon • All-metal • Silicone rubber
d. Pipeline wrap	• Saturated fiberglass • Coating materials-enamels, wax, etc.
e. Millboard	• Fiberglass • Mineral wool • Ceramic boards
f. Electrical insulation	• Aramid paper • Cellulose • Fiberglass
g. Commercial papers	• Ceramics • Cellulose • Fiberglass
h. Specialty papers	• Plastics • Cellulose • Aluminum • Steel • Ceramics • Fiberglass
i. Beverage filters	• Cellulose • Glass
2. FRICTION PRODUCTS	
a. Automobile brakes	• Semimetallics • Hybrids
b. Heavy-duty truck brakes	• Semimetallics
c. Railcar brakes	• Cermets • Carbon composite • Rubber polymer
d. Aircraft brakes	• Cermets • Carbon composite
e. Industrial brakes	-
f. Vehicle clutches	-
g. Industrial clutches	-

(continued)

TABLE 84 (continued)

Asbestos product category	Potential substitutes
3. A/C PIPE	• Cast and ductile iron • Steel • Reinforced and nonreinforced concrete • Plastic - (PVC) • Vitrified clay • Glass (GRC) and carbon fibers
4. A/C SHEET	• Cement/wood board • Glass - GRC • Plastic - reinforced concrete sheet • Polypropylene layered cement sheet • Aluminum sheet • Masonry, galvanized steel, wood
5. FLOOR TILES	• Cellulose fibers • Synthetic polyolefin pulp • Solid vinyl tile; vinyl blends • Rubber tile • Wood, carpet
6. GASKETS AND PACKINGS	• Silica, ceramic, graphite, aramid, teflon fibers • Inorganic and inert fibers, bonded • Fluorocarbon particles • Precursors to carbon fibers and rayon
7. SEALANTS	
a. Asphalt-based	• Volatiles and ash • Cellulose • Fiberglass, polypropylene, polyesters, acrylics, cotton
b. Nonasphalt-based	• Talc, barite, diatomite, silica, clay, mica
8. REINFORCED PLASTICS	• Fibrous glass, carbon fiber, aramid fiber, Wollastonite, processed mineral fiber, and polyethylene fiber • Clay • Talc • Mica • Calcium sulfate
9. TEXTILES	• Glass • Ceramics • Organics • Carbon • Quartz • Cotton

(continued)

TABLE 84 (continued)

Asbestos product category	Potential substitutes*
10. MISCELLANEOUS	
a. Drilling muds	• Bentonite or attapulgite clay • Xanthan gum polymer • Corn cobs, peat moss, vermiculite, etc.
b. Other	• Polyethylene for shotgun shells • In the other categories, asbestos is either undesirable or banned

*Corresponds to Table 85.

TABLE 85. SUBSTITUTE PRODUCT CHARACTERISTICS

Asbestos product category	Availability	Performance characteristics	Costs	Comments
1. PAPER PRODUCTS				
a. Flooring felt	Under development	--	--	Material substitutes such as carpet readily available, fiber felt substitute still under development
b. Roofing felt	Commercially available	Meets all requirements	Comparable	Some substitutes pre-date asbestos; best covering varies with roof.
c. Beater-add gaskets	Commercially available	Meets many requirements	Higher	Substitute development quickly underway.
d. Pipeline wrap	Commercially available	May be less durable	Higher	Asbestos pipeline wrap presently preferrred.
e. Millboard	Commercially availabile	Meets many requirements	Higher	Substitutes not available for all applications.
f. Electrical insulation	Commercially available	Meets all requirements	Higher	Extensive substitute products available.
g. Commercial papers	Commercially available	Meets some requirements	Much higher	Substitutes not available for all applications.
h. Specialty papers	Commercially available	Meets all requirements	Comparable	Durability may not equal asbestos.
i. Beverage filters	Commercially available	Meets most requirements	Higher	For haze removal, asbestos still superior.
2. FRICTION PRODUCTS				
a. Automobile brakes	Commercially available	Meets all requirements	Comparable	Proprietary composition
b. Heavy-duty truck brakes	Commercially available	--	--	--
c. Railcar brakes	Commercially available	--	--	--
d. Aircraft brakes	Commercially available	Meets all requirements	Higher	All new brakes cermet; some asbestos still in use.
e. Industrial brakes	Under development	--	--	Many diversive uses.
f. Vehicle clutches	Under development	--	--	--
g. Industrial clutches	Under development	--	--	--
3. A/C PIPE	Commercially available	Meets all requirements	Comparable	Several available substitutes.
4. A/C SHEET	Commercially available	Meets most requirements	Some higher	Substitutes for high temperature applications more costly.
5. FLOOR TILES	Commercially available	Less durable	Higher	Currently, no substitutes comparable to asbestos.
6. GASKETS AND PACKINGS	Commercially available	Meets most requirements	Variable	Equipment redesign required in certain cases.
7. SEALANTS				
a. Asphalt-based	Under development	Expected to be less durable	Comparable	Specially treated cellulose fibers.
b. Nonasphalt based	Commercially available	Meets some requirements	Generally higher	Asbestos banned in some products.
8. REINFORCED PLASTICS	Commercially	Meets most requirements	Variable	Many manufacturers have already switched to substitutes.
9. TEXTILES	Commercially available	Meets most requirements	Higher	Substitutes available for most applications.
10. MISCELLANEOUS	Commercially available	Meets most requirements	Some higher	Some asbestos products banned; drilling mud substitutes may be much more expensive.

applications for which asbestos has come to be counted on. Although costs of substitute products are generally higher, other considerations may act to increase the asbestos product cost, while at the same time increased production of substitute products may drive their costs down, effectively negating the current cost gaps by bringing nonasbestos products and their individual properties into wide acceptance and use.

It seems likely that, at least in the near term, there will be a core of products requiring asbestos. This includes products which cannot function without asbestos-containing components unless they are redesigned. Thus, substitutes for these products are not available for the replacement parts market but they might be available for the original equipment market. Also included in this core are products for which no technically and economically acceptable substitutes have been found for all applications; e.g., vinyl asbestos floor coverings.

Products such as specialty papers, roofing felts, A/C pipe, and aircraft brakes are, to some extent, being displaced by products which have been available for several, and sometimes many, years. Many of the available substitute products fulfill some but not all of the requirements placed on asbestos fibers. Asbestos still provides the most complete haze removal of any beverage filter; it is presently the preferred pipeline wrap due to the length of time it has been on the market; it is the single best component of tough vinyl floor tile; it is sometimes unique in high-temperature A/C sheet applications; and it is a low cost viscosifier in drilling muds.

Nonasphalt-based sealants, many A/C sheet products, gaskets and packings, reinforced plastics, and textiles fall somewhere in-between - substitutes are available, but often the cost is higher, the product lacks the durability attributed to asbestos, or certain applications may not be filled by the non-asbestos product. Products still in the development stage include flooring felts, various types of brakes and clutches, and asphalt-based sealants.