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LIFE CYCLE OF ASBESTOS IN COMMERCIAL AND INDUSTRIAL USE INCLUDING ESTIMATES OF RELEASES TO AIR, WATER AND LAND

Final Inhouse Report

February 1982

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SECTION 5

FRICTION MATERIALS

INTRODUCTION

Friction materials are used in clutches for transmitting torque, in brakes for slowing or stopping motion, and in torque limiters. Besides their well-known use in autos, trucks, buses, and railroad cars, friction materials are also found in other applications where motion must be controlled, ranging from bulldozers and tractors to typewriters, tape recorders, and parking meters.

Automobile brake linings have used asbestos since 1908 when Herbert Frood demonstrated that a combination of pure woven asbestos spun on brass wire combined with a specially developed bonding agent resulted in a product with excellent durability and heat resistance. By the first World War, woven asbestos brake linings were in common use on passenger cars, commercial vehicles, and military transports. In 1921, a vulcanized combination of ground-up waste, bonded asbestos, and a rubber-type binder was used to manufacture the first molded brake block, but molded blocks were not widely accepted until after the second World War. Disc brake pads were originally developed for aircraft landing wheel brakes in 1944 and have become more universally used in the intervening years.

Clutch facings followed a similar pattern of introduction. Impregnated cotton replaced leather in automotive clutch facings in 1905 and was, in turn, superseded by asbestos. Today, clutch facings of wire covered with asbestos yarn are widely used and continued progress is being made in die cast and molded clutch facings.[1]

In 1980, an estimated 43,700 metric tons of asbestos, about 12 percent of the United States fiber consumption, was used in the manufacture of friction materials.[2] Five companies dominate the United States friction material market, but foreign competition is becoming more of a factor.[3]

Figures for production volumes were not available but a breakdown of the estimated value of asbestos-bearing friction materials produced in 1979 is given in Table 19. These data were derived by projecting 1972 figures provided by Meylan[4] to 1979 costs. As shown, brake linings are by far the largest component (58.9 percent) of the asbestos friction material industry. Consequently, this section emphasizes the production processes and emissions associated with brake linings, placing lesser emphasis on other products in the friction materials group.

TABLE 19. VALUE OF ASBESTOS FRICTION MATERIAL SHIPMENTS (IN MILLIONS OF 1981 DOLLARS)[a]

Final product	Total product shipments, including interplant transfers		Percentage of total (1981)
	1981	1972	
Brake linings			
Woven, containing asbestos yarn, tape or cloth	$ 27.8	$ 10.2	4.9
Molded, including all non-woven 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 non-woven 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 from Meylan, et al. (1972), p. 61,[4] using September 1981 Engineering and Mining Journal cost index factors.

PRODUCT DESCRIPTION

Composition

Many raw materials, including some whose exact roles are regarded as proprietary information, are used in varying quantities in the manufacture of friction materials. The major or foundation constituent of practically all friction materials is asbestos fiber, which can range from 15 to 79 percent of the final product by weight depending on end use.[5] In 1980, chrysotile grades 3 through 7 accounted for all of the estimated 43,700 metric tons of asbestos used to produce friction materials.[2] Fiber sizes and types may be mixed or calcined to improve performance.

Asbestos is used because of its thermal stability, relatively high friction level, and reinforcing properties, but asbestos alone does not offer all of the desired properties. Therefore, other materials known as property modifiers and binders are added. Different types and amounts of modifiers are used to provide desired levels of effectiveness, wear, fade, recovery, and noise. Binders hold the disparate materials together. The average composition of a typical automobile brake lining is shown in Table 20. Individual product mixes vary considerably from these averages. Manufacturers refuse to release their exact product compositions due to proprietary considerations but some details are available in patents. Several examples are given in Table 21.

Table 22 lists binders and property modifiers used in automobile brake linings. Phenolic-type resins are the most commonly used binders because of their high binding efficiency and ability to withstand pyrolytic breakdown. Other resin binding systems are based on elastomers, drying oils, or combinations.

A wide range of materials are used in friction materials as property modifiers. In general, property modifiers can be divided into two classes, nonabrasive modifiers and abrasive modifiers. Nonabrasive friction modifiers can be classified further as being either high friction or low friction material. The most common high friction material is friction dust, a cured resinous material derived from cured or polymerized cashew shell liquid, a phenolic compound. When heated with hardening agents such as hexamethylene tetramine or formaldehyde, it polymerizes becoming sufficiently hard to be granulated. Other friction dusts are different combinations of cured resins, polymers, fillers, and cashew resins. Ground rubber is normally used for noise, wear, and abrasion control in particle sizes smaller to or slightly coarser than those of the cashew dusts.[4]

Low friction nonabrasive modifiers like carbon black, graphite, petroleum, coke flour, or other carbonaceous material may be added to lower the coefficient of friction and reduce noise. Normally the materials are added as fine powders or particles although graphite is occasionally used as coarse particles or pellets.[4]

TABLE 20. AVERAGE BRAKE LINING COMPOSITION (WEIGHT PERCENT)[a]

Material	Automobile	Truck
Asbestos	55	33
Resins and polymers	28	48
Oxides and pigments	9	16
Metals	3	2
Carbon, graphite, etc.	5	1
Total	100	100

[a]Lunch, quoted by Meylan,[4] et al.

TABLE 21. BRAKE LINING COMPOSITIONS FROM PATENT LITERATURE (WEIGHT PERCENT)[4]

Lining No. 1[a]		Lining No. 3[b]	
Asbestos	55	Asbestos	35
Barite	10	Barite	2.5
Phenolic resin binder	20	Graphite	7
Brass	5	Brass	13
Magnesium carbonate	8	Phenolic resin	7
Limestone	8	Lead oxide	11.5
Organic calcium powder	10	Buna N rubber	8
		Naphtha	7
		Copper sulfide	12.5
		Methyl ethyl ketone	4
Lining No. 2[c]		**Lining No. 4[d]**	
Asbestos	60	Asbestos	50
Phenolic resin	15	Tarry residue	12
Nitrile rubber	3	Barite	20
Cashew dusts	12	Phenolic resin	20
Calcium fluoride	7	Graphite	2
Copper iodide	3		

[a]Sakata, et al., 1974 (Hitachi).

[b]Keller, 1969 (Abex).

[c]Toyota Central Research and Development Labs, 1971.

[d]Mitchell, 1974 (DuPont)

TABLE 22. PROPERTY MODIFIERS IN FRICTION MATERIALS[4]

Binders	Property modifiers	Use function
Phenolic-type resins	Graphite	Lower friction coefficient and noise
Natural rubber	Coke	Lower friction coefficient and noise
Buna N rubber	Coal	Lower friction coefficient and noise
Nitrile rubber	Carbon black	Lower friction coefficient and noise
Tire scrap	Gilsonite	Lower friction coefficient and noise
Pitch	Friction dusts	Lower friction coefficient and noise
Cork	Rottenstone (SiO_2)	Remove decomposition deposits
Gilsonite	Quartz (SiO_2)	Remove decomposition deposits
Elastomers	Wollastonite ($CaSiO_3$)	Remove decomposition deposits
Drying oils	Brass Chips	Remove decomposition deposits
	Zinc and compounds	Remove decomposition deposits
	Aluminum	Remove decomposition deposits
	Limestone ($CaCO_3$)	Improve wear resistance
	Clays	Improve wear resistance
	Silicas	Improve wear resistance
	Barite ($BaSO_4$)	Improve wear resistance
	Lead and compounds	Lubricant to prevent grabbing
	Antimony compounds	Not available
	Calcium compounds	Not available
	Copper and compounds	Not available
	Barium hydroxide	Not available
	Potassium dichromate	Not available
	Magnesium carbonate	Not available
	Iron oxide	Not available
	Cryolite (Na_6AlF_3)	Not available
	Fluorspar (CaF_2)	Not available
	Cardolite	Not available
	Nickel	Not available
	Sulfur	Not available
	Molybdenum sulfide (MoS_2)	Lubricant
	Calcium fluoride	Lubricant

Abrasive modifiers improve brake lining wear resistance at minimum cost but simultaneously increase noise and decrease mating surface compatibility. In organic materials such as whiting (ground limestone), barite (barium sulfate), clays, silicas, and metals or metal oxides may be added to brake linings in small amounts and fine particle sizes to provide desired characteristics. For example, brass chips in heavy-duty friction materials break up undesirable surface films while a small amount of zinc chips can assist in recovering normal performance following a fade. Particle size is limited to 100 mesh or finer because large, hard particles groove and wear mating surface.[4]

Clearly, a wide range of components may be present in any automobile or truck brake lining depending on anticipated application and use patterns. When material variations are combined with manufacturing variations, it is clear that brake linings can vary greatly from company to company, even when intended applications are identical. Thus, emissions during production and use can vary greatly from lining to lining.

Uses and Applications

Friction materials are used wherever motion must be controlled. Friction materials are used in clutches for transmitting torque, in brakes for slowing or stopping motion, and in torque limiters. Although use in automobile brakes is the most important application commercially, asbestos friction materials are used in buses, trucks, railroad cars, military vehicles, and construction equipment as brakes and clutches. Friction materials are also used in farm tractors, presses, hoists, forklift trucks, machine tools, shuttle cars, mining equipment, chain saws, drilling equipment, spinning and knitting equipment, X-ray machines, tape recorders, typewriters, bicycle brakes, snow blowers, washing machines, and parking meters.

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. Disc 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
- Strength

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

Asbestos is used in friction materials because of the properties listed in Table 23. The most important properties are thermal stability, reinforcing abilities, relatively high friction, fiber flexibility, and relatively low cost.

TABLE 23. UNIQUE PROPERTIES OF ASBESTOS APPLICABLE TO FRICTION MATERIALS[3,7]

Properties	Comments
Fibrous form	Flexibility contributes to forming characteristics. Fibers interlace and interlock, enhancing strength. Flexibility reduces wear at friction interfaces.
Fine fiber diameter	Provide 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). Stable for short period of time at T around 1000°C. 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.

SUBSTITUTES

Most large manufacturers of friction materials have active research and testing programs working toward the development of asbestos-free brakes. Incentives to change from asbestos to some other material are numerous. Some new nonasbestos products are at the stage of consumer testing and their manufacturers are optimistic regarding their future use. Possible alternatives which have been considered include:

1. Glass Fiber - Overall strength is lower than that of asbestos, but strong enough for friction material applications. Unfortunately, at the temperatures reached by braking operations, glass fiber melts, even in depths below the operating surface.

2. Steel Wool - Compared to asbestos, the overall strength is lower and the cost is much higher.[8,9]

3. Mineral Wools - Overall strength is very low and brittle to the extent of limiting mixing processes.

4. Carbon Fiber - The main properties of carbon fibers are good. A major consideration is cost which is a great deal higher than 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. Carbon fiber has high thermal stability and low density making it especially attractive for aircraft brakes.[8,9]

5. Sintered Materials or Cermets - These materials are now being used to manufacture brake linings for railroad cars and airplanes. Cermets have extremely high thermal stability. The wear resistance is not good enough for automobile use and the cost is too high. Both carbon fibers and cermets are stable to 700°C (1290°F). High thermal conductivity can excessively heat hydraulic brake fluid causing erratic performance. However, this problem may be avoided by proper design.[10]

6. Semimetallic Materials - Semimetallics are stable to temperatures of 400°C (750°F) and exhibit excellent wear resistance.

7. Potassium Titanate Fibers - The National Aeronautics 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 for lightweight cars and trucks was developed which utilized potassium titanite fibers with the DuPont trade name FYBEX. However, unfavorable toxicological effects and other market considerations caused DuPont to withdraw FYBEX from the market.[3]

8. Aramid Fibers - These are being researched for use in high performance clutch facings in automatic transmissions. They do not possess the flexural or physical strength of asbestos, and the fibers are not easily dispersed as they tend to clump together.[3]

9. Vermiculite - Delaminated vermiculite is used in friction materials which are commercially available throughout Europe. It maintains strength at high temperatures, is compatible with phenolic resins, require little attention in manufacturing methods, and may be used with asbestos to help reduce asbestos content.[11]

10. Silicon Nitride - 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 composites eventually adopted.[11]

11. Others - Various other fibers have been used in phenolic binders, such as aluminosilicates (wollastonite). All have drawbacks and none are yet as good as asbestos, especially for high-temperature applications such as disc brake pads.[11]

Borg Warner Corporation and Abex Corporation (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. Raybestos-Manhattan has tested a wide range of materials in an attempt to find a substitute for asbestos. Fibrous glass, mineral wool, wollastonite, potassium titanate fibers, heat resistant organic mineral fibers and natural organic fibers such as cotton and sisal have been considered. Except for wollastonite and the natural organics, the fibers are more expensive than asbestos. Unfortunately, the less expensive fibers lack the heat resistance and fiber strength needed in brakes. Another problem is that many of the fibers tend to break up in the milling process and would require some process modification. Although Raybestos stated publicly in May 1979 that the company would "halt the manufacture of brake linings and other parts that contain asbestos"[12] 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.[13] 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 all friction materials is not expected in the foreseeable future.

Cermet or sintered metals, a copper or iron matrix of material reinforced with steel fiber and various ceramic and metallic property modifiers, are used primarily in heavy-duty applications where high torque capacities and longer life are desired. In many applications, cermet products outperform asbestos products. One example is the aircraft brake market where cermet's market share continues to grow. Currently, 95 percent of all new commercial aircraft use cermet brakes. The remaining 5 percent are carbon composite.[13]

Semimetallic or resin bonded metallic brakes are presently used in heavy-duty automotive applications such as police cars and taxis. While their performance is supposedly superior to asbestos brake linings, semimetallic brake linings tend to perform erratically at different temperatures, fade, and produce more noise than asbestos linings. 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.[3] Approximately 20 percent of passenger cars using disc brakes are equipped with semimetallic disc brakes as original equipment and it is estimated that in 5 to 10 years, most original equipment disc brakes in passenger cars and light trucks will be semimetallic.[14]

General Motors has used a hybrid disc brake consisting of one semimetallic and one organic asbestos lining in some mass produced passenger cars. The asbestos lining insulates the brake fluid from heat generated by the semimetallic surface during braking, but never actually touches the motor surface. In effect, the asbestos content of the brakes is reduced. Compared to asbestos-lined disc brakes, the hybrid brakes have a higher coefficient of friction, higher heat resistance, and wear longer but are more noisy and more expensive. While some industry sources feel that hybrid disc 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.[3]

The friction material in disc brakes is formed into an intrinsically stronger shape than in drum brakes and consequently needs less fibrous reinforcement. Asbestos is used in many disc brakes to reduce thermal shrinkage and withstand thermal shock, but asbestos-free semimetallic disc brakes have been developed for automotive uses. A typical composition is given in Table 24.

TABLE 24. COMPOSITION OF AN ASBESTOS-FREE DISC BRAKE PAD (IN VOLUME PERCENT)[4]

Carbon	45
Iron powder	25
Steel fiber	10
Phenolic resin	20

Semimetallic disc brakes, originally designed and produced by Bendix Corporation and now also manufactured by two other companies, are expected to increase their market share relative to asbestos disc brakes. In fact, it is projected that in 5 years nearly all original equipment disc brakes made for passenger cars and light trucks will be made with semimetallics. American automobile manufacturers have targeted 1983 as the last model year asbestos disc brakes will be used.[14]

As for drum brake linings, a nonasbestos product for passenger cars is not available commercially at this time. 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, synthetics, cotton, ceramic, carbon, natural materials, glass, and mineral fibers. For model year 1980, commercial nonasbestos lining was not available for drum brakes; however, Bendix Corporation is apparently very close to marketing this kind of product. American automobile manufacturers have targeted 1985 as the last model year asbestos drum brakes will be installed as original equipment.

The use of cermet brake linings may increase once the problem of their interaction with hydraulic brake fluid can be solved. With all of the current research into brake lining substitutes, a nonasbestos product for more universal use should become available in the future.

Primary Manufacture

Plants manufacturing friction products contain a diverse collection of machinery. Typically included are grinders, mixing vats, mills, molds, extruders, curing ovens, lathes, metal stampers, presses, paper machines, conveyors, and drill presses. Chemical operations, such as preparation of specific resins, may also be performed onsite. The exact mix of machinery at any given plant depends upon the manufacturing processes in use. Friction materials can be molded using either a dry mix or a wet mix process, woven like textiles, or formed like papers.

Overview of Manufacturing Process--

In the first steps of manufacturing friction materials, bags of asbestos are typically dumped into mixers that blend the formulations in either a wet or dry state depending on product specifications. A fluffing device may also be used. Next, the mix is fed through a compression molder (dry) or an extruder (wet), to form strips that are cut and bent into various widths and lengths. A release compound is added to prevent sticking. Dry-mixed formulations, which include a small amount of solvent, are transferred to pressing molds where slabs are formed, sometimes after a preheating step. Slabs are then hot pressed, causing resin in the slabs to flow, binding the mixture upon curing. The slabs are sawed into specific parts and sent to a curing oven.

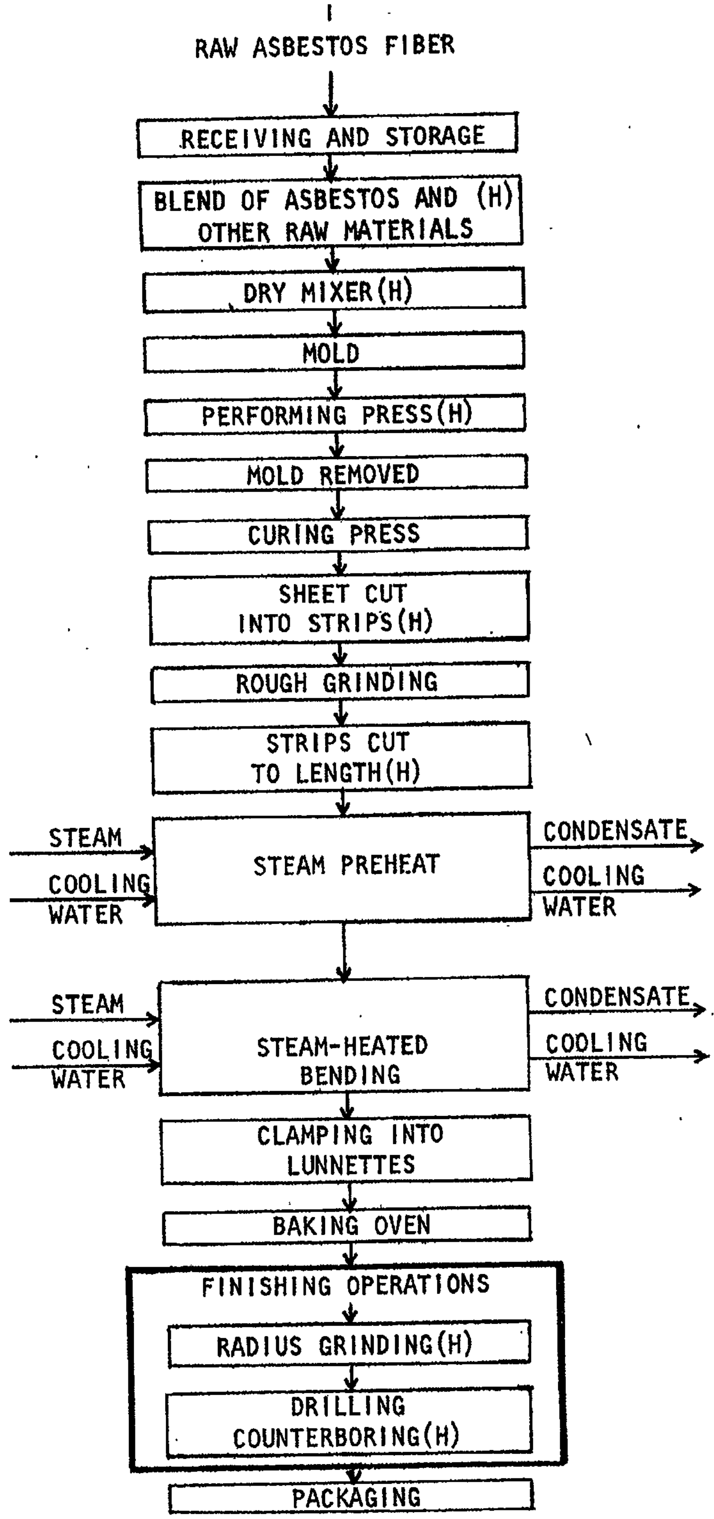
Dry Mix Molding Process--

The steps typically employed in manufacturing friction materials using the dry-mix molding process are shown in Figure 6. Asbestos fibers, metallic constituents, bonding agents, and other additives are weighed, mixed, then placed into a metal mold and formed into a uniform sheet using a preforming press. The mold is removed and the material is heated sufficiently in a curing press to allow the resin to flow and set. Only partial curing occurs during this step. The material is then cut to product-sized segments and rough ground. The resin is then softened by a preheating step after which the proper arc is formed by steam-heated bending. In the final curing step, the segments are placed in compression molds (lunnettes) and baked at a pressure of 1,000 to 2,000 psi. This converts the resin to a permanent thermoset bond so that the desired arc will be retained. Finishing steps, including sanding and grinding to the correct thickness, edge grinding, drilling holes for rivets, inspecting and branding are required before the brake linings can be packaged.

Wet Mix Molding Process--

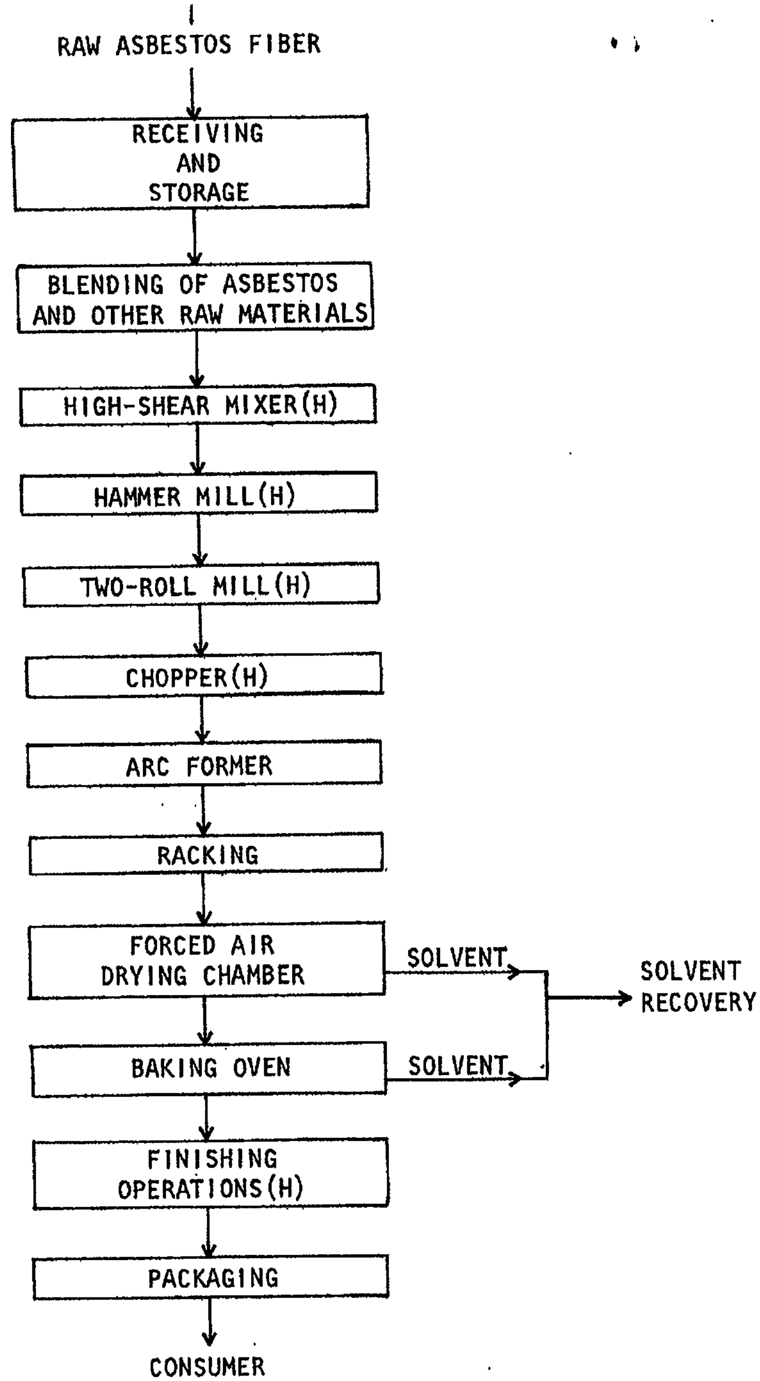
Figure 7 shows the major steps in the manufacture of wet-mix molded brake linings. The term "wet mix" is actually a misnomer since the ingredients of the molded lining are relatively dry. The term arises from the use of a wet solvent in the process.

The raw materials are blended in the proper proportions, mixed and then sent through a hammer mill in order to ensure homogeneity. The mixture is then forced into the nip of two roll formers where it is compressed or extruded into one continuous strip of friction material. A chopper cuts the material to the proper length after which an arc former is used to give the



Note: (H) - Indicates hooded
operations.

Figure 6. Dry-mixed molded brake lining manufacture.[15]



Note: (H) - Indicates hooded operations.

Figure 7. Wet-mixed molded brake lining manufacture.[15]

material the desired brake lining shape. The linings are placed in racks, air dried and baked to remove any remaining solvent before final finishing operations.

In an alternative process, arc-formed linings are placed in metal molds and baked in an oven prior to finishing and inspection. Another variation has automatically measured volumes of the raw material mixture dropped into disc brake molds where pressure is applied, shaping the contents which are removed and baked after finishing.

Molded Clutch Facings--

Molded clutch facings are produced in a similar manner, as Figure 8 illustrates. Asbestos fiber, a rubber friction compound and a solvent are combined in a mixer and then conveyed through a two-rolled mill which compresses the mixture into a continuous strip of material. A punch press is used to cut the material into doughnut-shaped pieces. Scraps from this process are mixed and then fed back into the two-roll mill while punched sheets are racked, placed in drying ovens and then into baking ovens for final curing and solvent extraction. Oven dried sheets are finished, inspected and packaged. Finishing operations include sanding, edge grinding, drilling and dusting.

Paper Products--

Some friction materials can be classified as paper products based on their method of manufacture. In particular, discs for automatic automotive transmissions are punched from rolls of asbestos paper formed on a Fourdrinier or cylinder machine. The forming process is discussed in detail in Section 4, Asbestos Paper Products. Since transmission discs are annular, much of the paper produced becomes scrap. About 70 percent of a roll is wasted in cutting and must be recycled. In a later step the paper discs are sprayed with a phenolic resin, heated, and bonded to steel wafers. The product transmission plates, steel cores with friction material on either side, are then ground, inspected, and packaged.

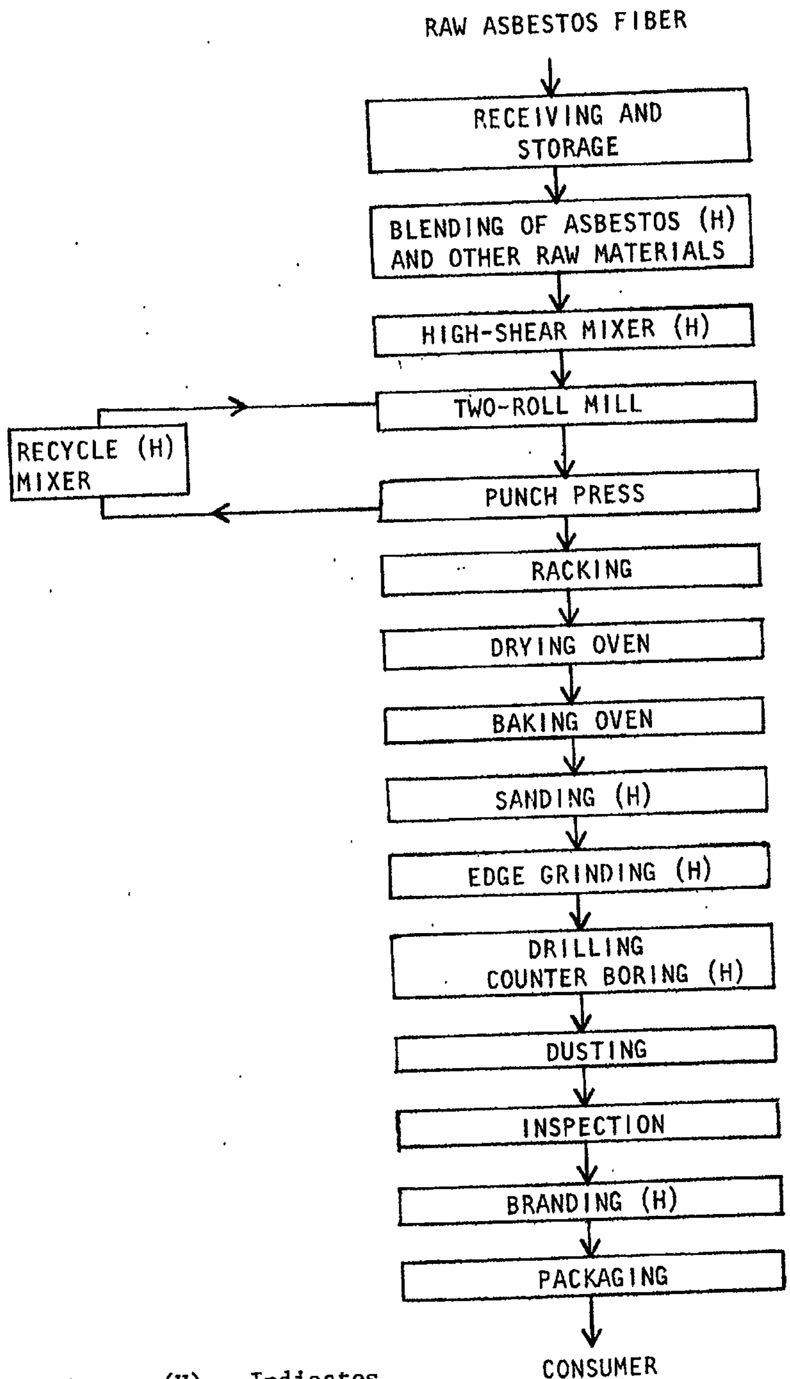
Die Cast Clutch Facings--

Larger clutch facings are frequently die cast. Raw materials which include asbestos and perhaps rubber and metallic oxides impregnated with resin are mixed, then brought to the work station. A worker measures out the necessary amount and pours it into a mold where it is pressed to the required density. After drying, the form is gear cut and bonded to a metal backing. The face is then ground with a pattern designed specifically for the eventual product application.

Woven Products--

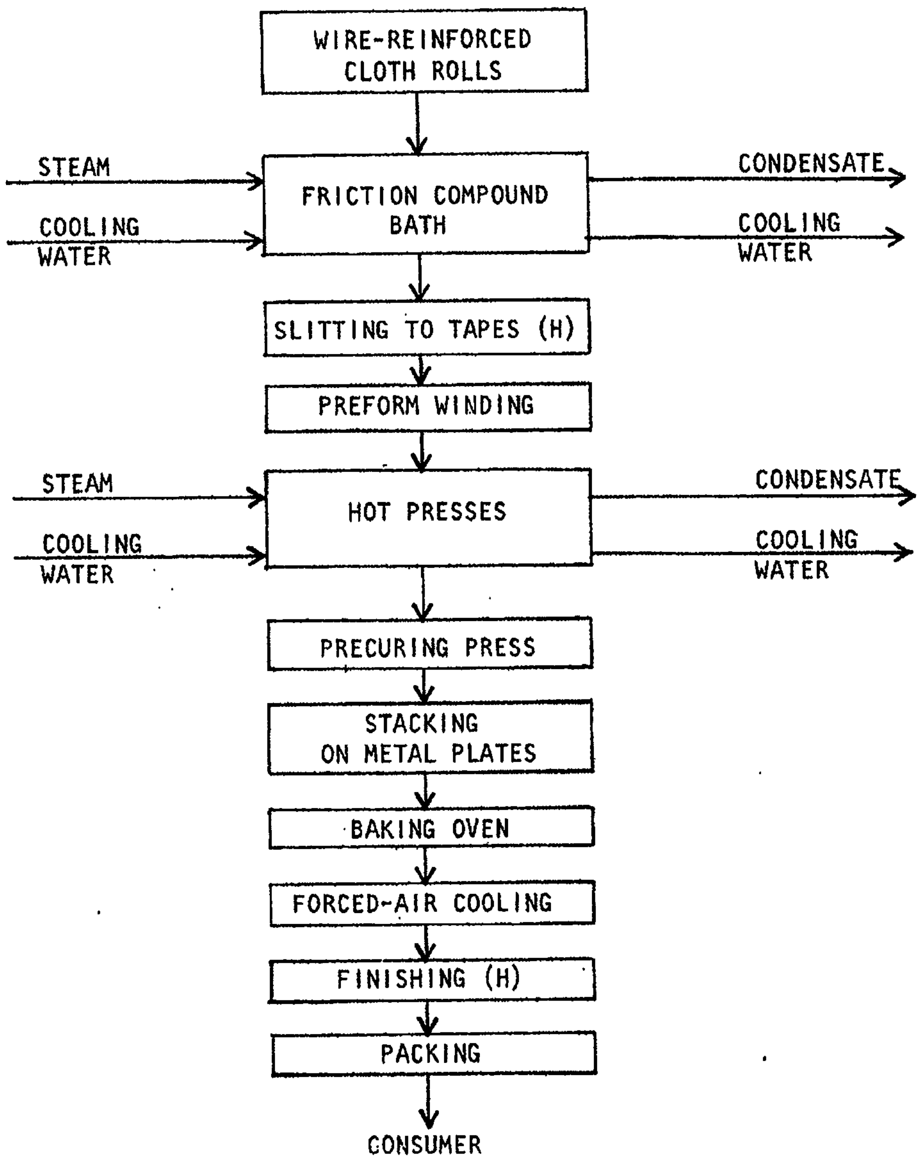
Woven clutch facings are frequently classified as being asbestos friction products. Figure 9 shows the press used in their manufacture. More detail on woven products is available in Section 12, Textiles.

Woven clutch facings and brake linings are manufactured from high strength asbestos fabric that may be reinforced with wire. The fabric is predried in an oven or by autoclave before being impregnated with resin in one of several



Note: (H) - Indicates hooded operations.

Figure 8. Molded clutch facing manufacture.[15]



Note: (H) - Indicates hooded operations.

Figure 9. Woven clutch facing manufacture.[15]

techniques. The fabric may be immersed in a resin bath, exposed to the binder in a pressurized autoclave, mixed with resin before being wound into yarn or pressed beneath a roll whose surface is covered with resin. Once solvents are evaporated from the fabric, it is made into brake linings or clutch facings.

Brake linings are made in a manner similar to that described earlier: woven clutch facings are made differently. Treated fabric is cut into tape width strips by a slitting machine before being wound around a mandrel to form a fabric roll. The roll is placed in a steam-heated press, baked in an oven to cure the resin in the clutch facing, then finished, inspected and packaged in the by now familiar sequence.

Secondary Manufacture

Some brake pads are sold to secondary manufacturers. The division between primary and secondary manufacturers, however, is not particularly important since secondary manufacturers perform a subset of the tasks generally considered the preserve of primary manufacturers. Secondary manufacturers take brake pads, rivet or bond them to brake shoes, inspect them, and package them as the final product. Any defective assembly could discredit their properly built products.

Manufacturing Plants and Production Volumes

The manufacture of friction products is highly labor intensive, with many processing and handling steps. Because of the labor intensive production process, differences between large and small manufacturers are limited to the variety of products formed and the number of work stations devoted to each. There are presently a large number of friction material manufacturers but many of the smaller firms have extremely limited product lines.

Table 25 lists the U.S. manufacturers of asbestos-bearing friction materials including, if known, their respective friction product sales in 1975 and the products they manufacture. Both larger diversified companies such as Raybestos-Manhattan and smaller, single plant companies are included in this list. The first eight companies listed on this table accounted for 75 to 85 percent of the total estimated sales of asbestos friction products in 1975, a pattern consistent with the industry's historical trends. From 1954 to 1967, the eight largest companies together accounted for 86 to 91 percent of the industry's value of shipments.[4]

ASBESTOS RELEASE

For friction materials, release of asbestos fibers will be discussed for four general areas: during manufacture, use, replacement, and disposal. Under manufacture emissions is included workplace concentrations, for various areas, human exposure to airborne asbestos, water emissions, and solid waste. Replacement emissions discuss release as a part of the automotive aftermarket which includes refacing and rebuilding, repackaging and general repairs. Disposal emissions are included within the manufacturing emissions sections (i.e., solid waste, etc.). An input/output figure is shown first to help detail the path of these emissions.

TABLE 25. U.S. MANUFACTURERS OF ASBESTOS-BEARING FRICTION MATERIALS[9,16-37,55]

Company	Plant location(s)	Products: Brakes: Automobile and light truck	Products: Brakes: Heavy duty truck	Products: Brakes: Railcar	Products: Brakes: Industrial	Products: Clutches: Vehicle	Products: Clutches: Industrial	Comments	Estimated 1978 sales[a] ($ million)
Raybestos-Manhattan, Inc.[16] RM Friction Materials Co.	Stratford, CT; Mannheim, PA; Crawfordsville, IN; Fullerton, CA	Drum, disk	Disk, segment block			✓	✓		165.0
Bendix Corporation[17] Automotive GRP	Troy, NY; Cleveland, TN; Southbend, IN	Drum, disk	Block			✓	✓	Brakes - machine tools, off-highway equipment.	94.5
Abex Corporation[17] Friction Products Group	Cleveland, OH; Troy, MI; Winchester, VA	Drum, disk	Block	✓					66.6
General Motors[17] Delco-Moraine Div., Inland Div.	Dayton, OH	Drum, disk							16.2
H. K. Porter Company[18] Thermoid Div.	Huntington, IN	Drum, disk			✓				26.5
Chrysler Corporation[17] Cycleweld Div.	Trenton, MI	Drum, disk							-
Borg Warner Corporation[19]	Bellwood, IL	Drum, disk				✓			-
Nuturn Company[20] (formerly World Bestos Co.) Maremont Corp., Grizzly Products, Div.	Nashville, TN; Paulding, OH		Block						21.5
National Friction Products Corporation[21]	Logansport, IN				✓	✓	✓	Off-road vehicles, cranes, shovels, travel trailers, mobile homes, plant machinery, appliances.	12.0
Auto Specialties Manufacturing Company[22]	St. Joseph, MI	Drum, disk			✓		✓	Off-road vehicles, agricultural equipment.	0.66
Stanico Industries[23]	Houston, TX				✓		✓	Off-road equipment, winches, cranes, drilling rigs	8.7
Friction Products Company[24]	Medina, OH		Block		✓	✓	✓		4.0
Royal Industrial Brake Products, Inc.[25]	Danville, KY	Drum, disk						Assembly of parts from Canadian manufacturers.	16.0
Reddaway Manufacturing Company[26]	Newark, NJ				✓	✓	✓		3.0
Molded Industrial Friction Corporation[27]	Prattville, AL		Block					Tractors and trailers.	3.6
Wheeling Brake Block Manufacturing Co.[28]	Wheeling, WV; Bridgeport, OH		Block						4.0
Force Control Industries[28]	Fairfield, OH			✓	✓			Disk and plate brakes, railcar and diesel engine brakes, tramways, off-road vehicles.	-
Brassbestos Manufacturing Corporation[29]	Patterson, NJ	Drum, disk						Rebuilt.	8.3
Auto Friction Corporation[30]	Lawrence, MA	Drum	Drum						26.5
Gatke Corporation[31]	Warsaw, IN				✓		✓	Custom manufacturing.	12.0
Lasco Brake Products Company[32]	Oakland, CA	Drum, disk	Block						3.8
MGM Brakes, Incorporated[33]				✓	✓			Off-road vehicles, buses, railcars, mining equipment, towing vehicles	<1
Carlisle Corporation[34]	Ridgway, PA		Block	✓				Buses, off-road vehicles	28.2
Thiokol Chemical Corporation[35]	Trenton, NJ	Drum, disk						Rebuilt only.	9.7
P. T. Brake Lining Company Inc.[36]	Lawrence, MA	Drum	Block						-
Eaton Corporation[37]	Kenosha, WI		Block, disk		✓				-
Scan-Pac Manufacturing Company[55]	Menomonee Falls, WI								2.8

Input/Output

Figure 10 shows estimates of process and disposal emissions for the asbestos friction materials industry. These figures are based on Levine's[38] 1974 estimates projected to 1980 U.S. Bureau of Mines consumption figures. Potential sources of emissions include blending mixing, cutting, milling, chopping and finishing operations. Of the 43,700 metric tons of raw asbestos fiber processed in 1980, approximately 42,525 m.t. are incorporated into the product and 1111.9 m.t. are sent to disposal as vacuum cleaner and baghouse dust. An estimated 10.9 metric tons escape through a control device (typically a baghouse). Levin's[38] atmospheric emissions estimates are based on gross assumptions with a reported uncertainty of at least an order of magnitude. Meylan's[4] estimates of emissions are generally 1 to 3 orders of magnitude less. Atmospheric emissions from disposal, based on GCA estimates, are shown to total 2.2 metric tons per year for the friction materials industry. This last estimate, which follows Levine's[38] 1974 data, also takes into account the Asbestos NESHAPS regulations adopted in 1975 regarding the disposal of asbestos-containing waste material.

During Manufacture

Workplace Fiber Concentrations--

Table 26 shows the time-weighted average exposures at different points in the friction material production process. These figures are based on 12 plants which consumed approximately 35,000 m.t. of asbestos in 1975 and made up about 60 percent of the friction products segment during that year. Data was obtained by Weston[39] in a survey using industry questionnaires and is of questionable validity as industries may tend to report biased figures. In addition, the range of data reported is extremely broad, indicating questionable sampling and counting procedures.

TABLE 26. TIME-WEIGHTED AVERAGE FIBER CONCENTRATIONS OF OPTICAL MICROSCOPE VISIBLE FIBERS GREATER THAN 5 μm IN FRICTION PRODUCTS MANUFACTURING PLANTS[39]

	Fiber count	
Process step	Range (fiber/cc)	Typical (fibers/cc)
Receiving and storage	0.25 - 2.5	1.0
Fiber introduction	0.4 - 4.6	2.5
Mixing	0.2 - 8.0	2.3
Forming and rolling	0.5 - 22.0	3.3
Curing	0.5 - 3.5	1.5
Finishing	0.6 - 7.4	2.0
Adjustment and printing	0.7 - 1.0	1.0
Inspection	0.1 - 15.0	2.0
Packaging	1.0 - 2.0	1.5

*Based on plants representing 50 percent of asbestos friction material production.

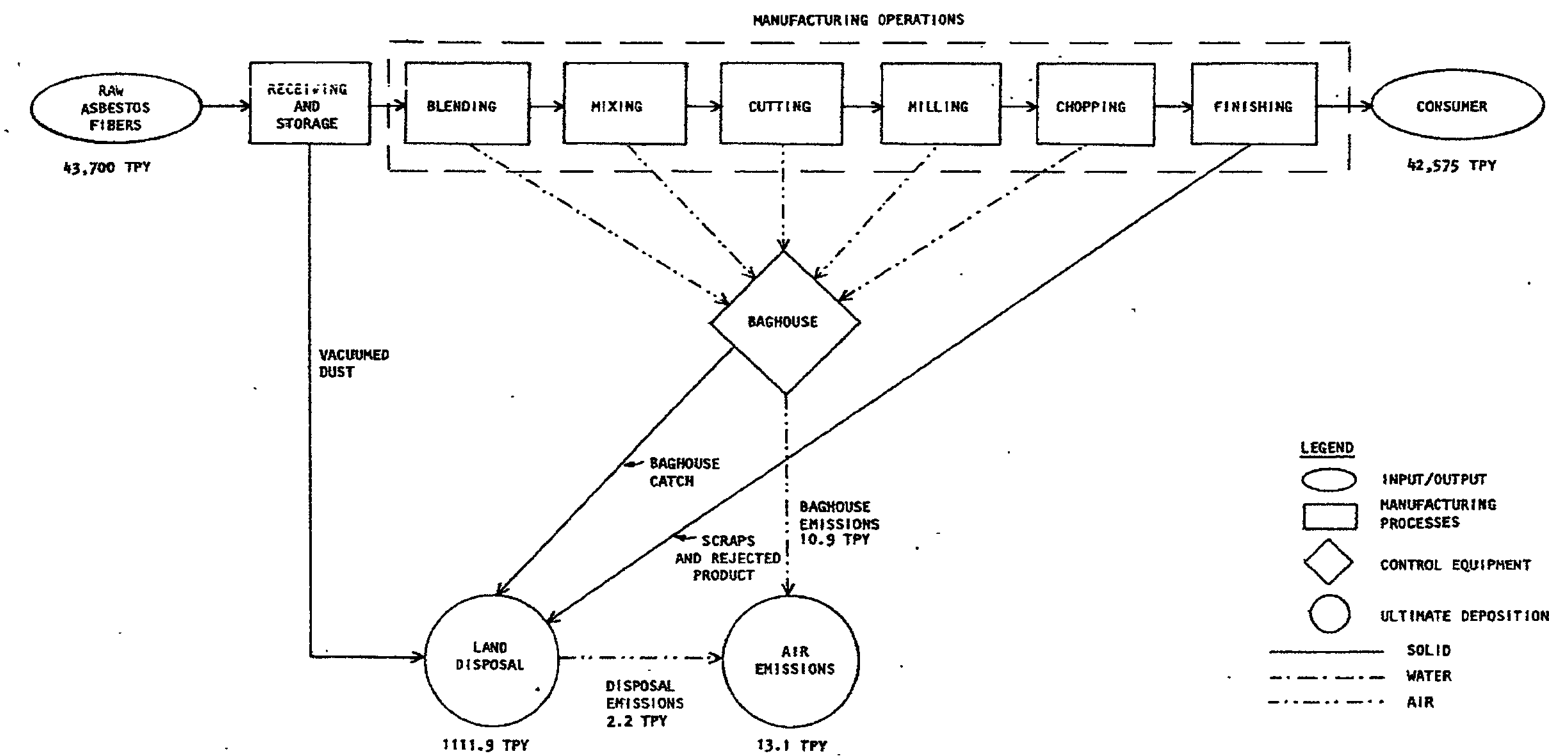


Figure 10. Input/output estimates for the asbestos friction materials industry in metric tons.

A review of the data collected indicates that in addition to variations in sampling and counting procedures there are many reasons for the wide variations in the range of fiber counts. The largely individual manual techniques and worker practices introduce considerable deviations, as does the percentage of asbestos in the product which may range from 30 to 70 percent by weight.

Receiving and storage--Exposures during receiving and storage in asbestos friction material production are identical to receiving and storage exposures in all other primary asbestos industry segments. Consequently, the range reported for asbestos paper, 0.25 to 2.5 fibers/cc TWA and the typical value, 1.0 fibers/cc TWA, are equally valid for friction materials.[39]

Fiber introduction--Bags of the raw material may be manually opened and dumped into hoppers for transport to mixers. Fiber levels during this operation are higher than those in papermaking fiber introduction, ranging from 0.4 to 4.6 fibers/cc TWA for friction materials as opposed to a 0.3 to 2.8 fibers/cc TWA range for papermaking. Typical fiber levels exhibit a similar difference, with 2.5 fibers/cc typical of fiber introduction for friction products and 1.9 fibers/cc typical for papermaking.[39]

It is not clear why such a difference should exist, since the processing step is similar. Perhaps the fact that in some paper applications it is not necessary to dump the fiber out of a bag contributes to lower typical values in papermaking. However, this characteristic should not affect the range reported since some paper applications require that the asbestos be removed from the bag.

Mixing--The combined raw materials may be mixed either dry or wet, depending on product specifications. The state in which mixing occurs greatly influences the workplace fiber levels, since fibers in water are unlikely to become airborne, while dry fibers can easily be dispersed. Fiber levels of 0.2 to 8.0 fibers/cc TWA were reported with 2.5 fibers/cc TWA considered to be typical.[39]

Forming or rolling--The product of the mixing stage is fed to a compression molder or an extruder, again depending on the required product. Levels of 0.5 to 22.0 fibers/cc TWA were recorded; a level of 3.3 fibers/cc TWA was considered typical.[39] The higher exposure levels are caused by the manual handling of the dry preform mix, which is conveyed in open carts, scooped by hand, weighed, and poured into a block mold where it is mechanically pressed into the shape of the finished product.[38]

Curing--Some formulae require a heating step that causes resins to flow and bind the mixture. In the curing step fiber levels ranged from 0.5 to 3.5 fibers/cc TWA. A fiber count of 1.5 fibers/cc TWA was typical.[39]

Finishing--Parts taken out of the curing oven undergo a number of steps to produce the final product. These machine-assisted manual finishing steps may include grinding, sawing, drilling, blanking, tapping, and boring. Fiber levels in finishing were typically 2.0 fibers/cc TWA, although reported values ranged from 0.6 to 7.4 fibers/cc TWA.[39]

Adjustment and printing--After finishing, the friction products are dusted, adjusted, and printed. Fiber levels in this operation are consistently close to 1.0 fibers/cc TWA. The range of exposures during this process is very narrow, 0.7 to 1.0 fibers/cc TWA.[39]

Inspection--Generally considered to be an examination of the finished product, inspection encompasses different activities in different plants. Some plant inspection stations only examine the finished product; if the product is defective or needs more comprehensive finishing it is returned to the finishing area or rejected entirely. Other plants have additional equipment in the inspection area so that any defect in the product can be rectified immediately. Consequently, fiber counts recorded in inspection areas vary widely from 0.1 to 15.0 fibers/cc. Usually, the fiber level will be toward the low end of the range, with 2.0 fibers/cc TWA considered typical.[39]

Packaging--Even workers involved in packaging the final product are exposed to fibers. The range of reported fiber levels in packaging was 1.0 to 2.0 fibers/cc TWA with 1.5 fibers/cc TWA considered typical.[39]

Emissions to Air--

The maximum allowable exposure over a 40 hour week for workers in the asbestos industries has been set at 2 f/cc.* Workers are exposed to an average fiber count of 1.9 f/cc,* with fiber counts as high as 22 f/cc* being reported (see Table 26). The values reported reflect levels recorded in or before 1975 and are probably higher than present day concentrations. With greater worker awareness and increased employer concern, along with the regulatory activities of OSHA, it is very likely that friction product worker exposure concentrations are well below the 2 fiber/cc limit. Documentation in the open literature to substantiate this belief, however, is not available.

With a workplace fiber count of 1.9 f/cc, workers can be expected to inhale 119† billion fibers per year.[40] Estimates of nonoccupational exposure to asbestos have been made using a binormal continuous plume dispersion model with assumed plant emissions. The affected population was assumed to be those people living within a 5 km radius of a friction material manufacturing plant. The atmospheric asbestos concentration around the plant was estimated to be 23,000 f/m^3† and the annual amount of asbestos inhaled was estimated to be 125 million fibers† per person. This compares to a mean ambient urban exposure of 5,000 fibers/m^3† with an average annual inhalation of 27.4 million fibers per person.[40]

Release to Water--

Water is not used directly in the production of friction materials except for those products formed on paper machines from a 2 to 3 percent solids slurry. Water usage and consequent water pollution associated with this process is discussed in Section 4, Asbestos Paper Products. Despite the term

*Optical-microscope-visible fibers >5 μm in length.

†Electron-microscope-visible fibers.

"wet mix" used in the description of one of the manufacturing processes it is actually dry because no wastewater is generated. Solvents are used to make the mix of raw materials more pliable; no excess water is used and no floor drains are present.

Wastewater is generated in some solvent recovery operations and in wet dust collection equipment used to control dust throughout the plant. Solvent recovery wastes normally have very low suspended solid levels. A typical solvent recovery operation has been reported to have 0 mg/l suspended solids in its waste stream.[41] Wastes from wet dust collection have significantly higher solids concentrations.

Wastewaters from wet dust collectors are slurries of dust from plant operations, and are characterized principally in terms of suspended solids. Clearly, the concentration will be a function of the amount of dust generated and the water flow rate which can vary from 1.9 to 37.9 liters per minute per 28.3 standard cubic meters of air per minute. Plant air systems served by wet scrubbers range from 283 to 7079 scmm, resulting in discharges of 189,250 to 2,838,750 liters per day.[41] Units are for the most part equipped for partial recirculation. Sludge, or settled slurry is discharged to a settling lagoon where it becomes a solid waste problem. In a typical plant using wet collection, about 1566 kg of asbestos are collected annually. About 95 percent or 1488 kg are removed as sludge by clarification. The sludge is disposed of by landfilling while the remaining 78 kg of asbestos are discharged to surface waters.[4]

Release to Land--

Most of the solid waste generated in the manufacture of friction material is produced in grinding. In the past, grinding dust was collected for use as solid fill in marshlands and low-lying areas. It is now trucked to sanitary landfills for disposal but as the hazards of asbestos have become better known, fewer and fewer landfills are willing to accept asbestos-containing materials for disposal.

Estimates of the percentage of asbestos lost in grinding and drilling range from 12.7 percent to 30 percent,[41,42] but even with the high cost of raw materials, asbestos in these scraps is not recovered for reuse. Once the binders and resins have set, it is uneconomical to break them down to salvage the fibers.

In most cased baghouses are used to collect grinding and drilling dusts. It has been estimated that wastes can amount to as much as 12.2 tons/month for a plant producing 40,000 brake shoes per day.[4] Based upon a total asbestos consumption of friction materials of metric tons in 1980, 1,112 tons of asbestos would be lost in product waste. Baghouses would collect about three-fourths of this total, or about 834 tons, while the remainder, 278 tons, would be collected by vacuum cleaners and as damaged product.[4]

During Use

During vehicle operation friction material, whether used as a disc pad, drum lining or clutch facing, engages with a metal rotor to form a sliding friction couple which converts the kinetic energy of rotating members into heat, absorbs heat and dissipates it to the surroundings. Emissions are generated by wear. Asbestos fibers are pulverized into small particles which are either trapped in the brake or clutch housing, fall to the road or are emitted to the atmosphere. Most of the asbestos, however, is heated sufficiently to cause chemical conversion to olivine or forsterite.

A number of articles have discussed asbestos emissions from brake linings. Table 27 summarized the published data. A detailed discussion of the reported information is provided in reference 4.

Jacko and DuCharme reported[42] that approximately 33.6 million kilograms of asbestos in friction material wear away annually. Based on their experimental finding that only about 0.2 percent of the debris is not converted to some other substance, total annual asbestos emissions were estimated to be 71,759 kilograms. Of this amount, 85.6 percent or 61,426 kilograms were estimated to drop out on to the ground, 11.2 percent or 8,037 kilograms was estimated to be retained within the brake or clutch housing and only 3.2 percent or 2,296 kilograms was believed to become airborne.

Rohl, et al.[49] performed a similar calculation based on a separate analysis of friction material wear debris, but otherwise retaining all of Jacko and DuCharme's assumptions. Their best estimates of the total annual asbestos emission were that 1,329,039 kilograms of asbestos dropped out, 172,367 kilograms were retained in brake and clutch housings, and 49,896 kilograms become airborne.

Elevated levels of asbestos were found in a study by Bruckman and Rubino[52] in which airborne asbestos concentrations were monitored at three Connecticut toll plazas. Asbestos concentrations were found to vary between 3 ng/m^3 and 41 ng/m^3. A nearby large industrial asbestos user was suspected of influencing the highest measured concentration. Although no correlation was made between vehicular traffic and the asbestos concentration it was concluded that the decomposition of brake linings is a significant source of airborne asbestos fibers.

During Disposal

Friction materials are usually replaced before they are completely worn out. Most passenger vehicles reportedly use a set of asbestos-containing brake linings every three to four years.[53] Asbestos-containing friction products are disposed of in the form of worn brake linings, disc pads, and clutch facings. These materials may be discarded as scrap pieces separated from any metal component which can be reused or scrapped along with the machinery they were a part of such as automobiles.

Because of the means by which they are manufactured, asbestos fibers are bound within the pieces even though they are worn. During disposal, asbestos material should not be released from the worn pieces due to the lack of sufficient energy to dislodge the fibers bound in the friction material matrix. Ultimately, the nonfriable friction material is either incinerated or landfilled.

TABLE 27. SUMMARY OF PUBLISHED DATA - ASBESTOS EMISSIONS FROM BRAKE LINING USE[42,48]

Publication source	Method used to collect emission or debris samples	Method used to determine asbestos content of emission debris samples	Asbestos particle size distribution	Asbestos content of emission or debris
Lynch, 1968[43]	Laboratory simulations utilizing brake-testing machines or dynamometers. Samples collected on 0.8 μ pore size membrane filters.	Electron micrographs	Not discussed	<1%, except under severe-stress conditions
Hatch, 1970[44]	A dust cloud was generated by using compressed air jets to remove dust from brake linings in an auto repair garage. Samples were collected by means of a hand pump located in center of dust cloud.	Not stated	94% of fibers fell in 2-5 μm length category. Only 6% were longer than 5 μm	~1%
Hickish and Knight,[45] 1970	Samples were collected directly from debris remaining as brake dust and from membrane filters exposed during brake cleaning operations utilizing compressed air. Filter pore size is not given.	Not stated	Not discussed	1.6% and less
Bush et al., 1972[46]	Laboratory simulations utilizing a disc brake assembly mounted on an inertial dynamometer. Samples were collected on suitable filter paper.	Neutron activation	Not discussed	~44% (this figure is not accurate; see discussion)
Anderson et al., 1973[47]	Laboratory simulations utilizing a disc brake assembly mounted on a dynamometer. Air samples of wear debris collected down wind of disc brake.	Transmission electron microscopy	Test results and and procedures precluded a size distribution estimate	~0.02%
Jacko and DuCharme,[42] 1973 (contains same data as Jacko et al., 1973)[48]	Samples were generated by operating a standard American car under typical driving conditions in Detroit, Michigan. More abusive conditions, such as fade tests, were also included. Brake and clutch assemblies were enclosed by specially designed collectors. Samples were collected from (1) dropouts during use, (2) dust retained in lining assemblies, and (3) airborne samples collected on membrane filters.	Optical and electron microscopy	30% of fibers were from 0.25-0.50 μm in length; 60% were longer than 0.5 μm	0.25% overall average (an independent check done by Batelle Labs give a figure of 0.171%)

(continued)

TABLE 27 (continued)

Publication source	Method used to collect emission or debris samples	Method used to determine asbestos content of emission debris samples	Asbestos particle size distribution	Asbestos content of emission or debris
Rohl et al., 1976[49]	Ten samples of automobile brake drum dusts were collected from maintenance shops in the New York area.	X-ray diffractometry Transmission electron microscopy, selected area electron diffraction, and electron microprobe analyses	 80% of fibers were shorter than o.4 μm length	2-15%; average of 3-6% Consistent with, but lower than, quantitative determination made by X-ray diffractometry; no percentages are given
Alste et al., 1976[50]	Samples were taken from fresh and worn brake linings and from the atmosphere near a freeway.	Electron microscopy	Majority were ≤ 2 μm in maximum linear dimension	No percent figure given, however, conclusion was that major effect of braking appears to be in separating bunches of fibers and reducing their average length, but not in altering their crystal structure
Rohl et al., 1977[51]	This is basically a reprint of the Rohl et al., 1976 study with the inclusion of brake wear test samples obtained from Europe and Australia.			The mean weight percentage ranged from 1.4% in Australia to 2.5% in France

Emissions in Automotive Aftermarket

The automotive aftermarket in which asbestos exposures may occur is divided into three major sections: refacing or rebuilding of friction materials, repackaging of friction materials, and general brake repair and service.[39]

Refacing and Rebuilding--

The major difference between refacing operations and plants in the primary friction materials segments is that no raw asbestos fiber is handled in the smaller rebuilding plants. Therefore, the control problems are not as acute. Most rebuilt asbestos-bearing parts plants have had local controls for a long time. Asbestos exposure levels measured at three of these establishments were reported by NIOSH during the American Industrial Hygiene Conference in New Orleans in May 1977 and are presented by process step in Table 28.

Repackaging--

Repackaging operations in the automotive aftermarket consist of manually transferring asbestos friction material products from one container to another at a location other than the facility where the friction material was produced. Asbestos exposures for this sector have been reported to range from 0.2 to 0.6 fibers/cc TWA.[4]

General Repairs--

From the existing data on asbestos exposure levels during brake repair work, it appears that an establishment using compressed air for blowing residual dust from brake lining assemblies may exceed the 10.0 fibers/cc ceiling limit under the current OSHA standard. Data reported by Rohl[49] on asbestos emissions during brake lining maintenance indicated that a peak exposure of 29.8 fibers/cc had been encountered 0.9 to 1.5 meters from the workplace. These data are presented in Table 29.

TABLE 28. ASBESTOS FIBER[a] EXPOSURE LEVELS IN REBUILDING BRAKE AND CLUTCH ASSEMBLIES[54]

Facility	Fibers/cc TWA			
	Receiving and cleaning	Bonding and riveting	Cutting and grinding	Inspection and packaging
A				
Mean	1.1	0.6	1.1	0.7
Range	0.4 - 4.8	0.2 - 1.4	0.8 - 1.6	0.8 - 1.1
Number of samples	15	20	6	4
B				
Mean	4.0	2.7	5.0	
Range	1.0 - 7.6	1.1 - 5.8	1.5 - 9.3	—
Number of samples	5	6	6	
C				
Mean	1.3		0.8	
Range	1.2 - 1.3	—	1.5 - 9.3	—
Number of samples	2		6	

[a]Fibers 5 to 100 μm were counted using phase contrast microscopy according to the NIOSH method.

TABLE 29. FIBER LEVELS[a] DURING BRAKE LINING MAINTENANCE[49]

Distance from workplace (meters)	Peak exposure (fibers/cc)
0.9 to 1.5	6.6 to 29.8
1.5 to 3.05	2.0 to 4.2
3.05 to 6.1	0.4 to 4.8
Background samples	0.1 to 0.8

[a]Fibers 5 to 100 μm were counted using phase contrast microscopy.

CONCLUSION

Between 1978 and 1980 there has been a 41 percent decline in the amount of asbestos consumed to manufacture friction products. The decline can be attributed to a slowdown in automobile sales and the increasing use of asbestos substitutes. Atmospheric release of asbestos fibers during primary manufacturing, by far the largest source of emissions in this category, is estimated to have declined to 13.1 tons per year in 1980 from 21.6 tons per year in 1978. Asbestos containing solid waste is estimated to have declined from 1,876 tons to 1,112 tons between 1978 and 1980. Process wastewater discharged from friction products manufacturing plants is not expected to be laden with asbestos fibers. Wastewater from wet dust collectors employed to control fiber release, however, will contain asbestos material. About 95 percent of the asbestos material suspended in the control device wastewater is removed as sludge by clarification. The sludge is typically disposed of by landfilling with the remaining five percent discharged to surface waters. The decline in asbestos releases that has been estimated between 1978 and 1980 is expected to continue through 1981, coinciding with the turndown in the economy and an increased interest in asbestos substitutes.

Beyond 1981, the outlook for the use of asbestos in friction materials 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 brakes. Further uncertainty is introduced by the American automobile manufacturers' avowed intentions to eliminate asbestos from original equipment brakes by the 1985 model year. If a successful substitute is found, asbestos consumption in friction materials will drop precipitously.

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