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ASBESTOS

A MATERIALS SURVEY

BY OLIVER BOWLES

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United States Department of the Interior—1959

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BY OLIVER BOWLES

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON 25, D. C.

September 15, 1958

Hon. Leo A. Hoegh
Director
Office of Civil and Defense Mobilization
Washington 25, D. C.

Dear Mr. Hoegh:

The Materials Survey on Asbestos, originally published in February 1952, under an agreement with the National Security Resources Board, has been revised. Copies are being forwarded to you.

This is the first Materials Survey to be revised under the terms of the April 15, 1955, agreement between the Department of the Interior and the Office of Defense Mobilization, which assigned responsibility to Interior for preparation and revision of Surveys covering 45 mineral commodities.

Manuscript revisions proposed by reviewing officials of the Office of Civil and Defense Mobilization have been incorporated in the Survey.

Sincerely yours,

Thomas H. Miller
ACTING
Director

Foreword

Materials Surveys are designed to bring into a single document all the fundamental data needed by war or defense personnel with major responsibilities with respect to Survey subjects. The Surveys dealing with metals and minerals summarize the demand-supply position in the United States and include information on production, imports, consumption, exports, capacity, interchangeability, substitutes, possibilities for expansion, and pertinent history, usually in some detail back to 1935. The properties of the commodity are described. Exploration, mining, milling, and processing methods and domestic and foreign resources and reserves are discussed. An extended presentation of the structure of the industry covering major corporations, transportation service, processing facilities, interrelationship to other industries, pertinent laws and taxation policies, tariffs, Government controls, special labor problems, and history of wartime control experiences is included. Other special data are presented for particular commodities.

The first edition of Materials Survey—Asbestos, prepared by the Bureau of Mines, was published in February 1952. The present report, prepared in the Division of Minerals under the direct supervision of G. W. Josephson, Chief, Branch of Construction and Chemical Materials, is a revision of the earlier Survey, made in accordance with the agreement between the Office of Defense Mobilization and the Department of the Interior dated April 15, 1955, that revisions of the Surveys should be made periodically. Such revisions are essential because conditions governing production and consumption are constantly changing. New deposits may be discovered and exploited while other deposits may be depleted. Changing economic factors may curtail production in certain areas and expand it in others. Thus, production patterns may shift, the emphasis varying from point to point, from country to country, and even from continent to continent.

Similarly, in the field of utilization, substitution of alternate materials for a mineral commodity may increase; on the other hand, new and wider uses for the mineral may be developed. New equipment designs or new processes may increase or diminish the quantities of the mineral needed for specific uses. Changes in specifications or results of research may contribute to modifications in the use pattern.

Copies of the original Asbestos Survey were sent to many competent reviewers with a request for comments or corrections. Numerous respondents in the United States and in several foreign countries furnished supplemental or corrective data that have been incorporated in the revision. The revised manuscript was reviewed in whole or in part by specialists in the Bureau of Mines, the Geological Survey, the Department of Defense, and industry. Grateful acknowledgment is made to the reviewers of both the original and the revised report for their cordial and constructive response.

CHARLES W. MERRILL,
Chief, Division of Minerals.

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ASBESTOS¹

A MATERIALS SURVEY

BY

OLIVER BOWLES²

Summary and Introduction

"Asbestos" is a name applied to a group of naturally fibrous minerals. Because it has the fibrous characteristics of silk or cotton and at the same time will not burn and has other advantageous properties as well, asbestos has specialized uses for which no adequate substitutes are yet available. Asbestos furnishes a major raw material for a great variety of essential products, the manufacture of which constitutes a vast industry.

Asbestos generally occurs in irregular veins scattered throughout rock masses. Most of the fiber-bearing rock is mined in huge open-pit or underground workings. The fibers are separated from the rock and sorted into groups, according to length, in large, complex mills. The longer fibers are shipped to textile plants, where they are further fiberized and prepared in special machines and are used for spinning into yarn and weaving into unburnable cloth that has many important uses. The shorter fibers, which are much more abundant than the long ones, are used in asbestos-cement building materials in heat-insulating products and for a multitude of other applications. These processes and uses are covered in considerable detail in later sections of this report.

This report gives primary consideration to the types and grades of asbestos that are of greatest importance in the program of military preparedness—namely, the spinning grades of chrysotile, both foreign and domestic, and the amosite and crocidolite obtained only from foreign sources.

ESSENTIALITY OF ASBESTOS

The United States has developed the greatest asbestos-products industry in the world. The value of such products manufactured in 1953 was \$345 million and in 1954, \$323 million. These products are not only vital to building construction and industry but are absolutely essential to certain other important fields of use. For example, virtually all brake lining and clutch facings of automobiles, trucks, or other mobile equipment used in peace or war consist essentially of asbestos. Hence, a shortage of asbestos used in friction materials would tend to immobilize highway transport. Also, there is no known substitute for asbestos used in steam packings. Accordingly, a shortage of such products would interfere seriously with many lines of industrial activity. Satisfactory replacements for the amosite variety mined only in South Africa for felted insulation of marine turbines can be obtained only at exorbitant prices. Crocidolite (blue asbestos), mined in Africa and Australia, is regarded as a necessary constituent of asbestos-cement pipe.

¹ Work on manuscript completed January 1958.

² Former consultant commodity specialist, Bureau of Mines (deceased).

Many other examples might be cited to indicate the essentiality of asbestos to our modern way of life and to any program of military preparedness.

SHORTAGE OF DOMESTIC SUPPLIES

This great asbestos-products industry has been built up under conditions of overwhelming dependence upon foreign supplies of raw asbestos. Domestic mines furnish only 6 to 8 percent of our requirements of all grades and an even smaller percentage of the important strategic grades. Canada and Africa are the principal foreign sources. Canada supplies most of the short-fiber demands of the United States and a major part of the longer textile-grade fibers. Africa formerly supplied a low-iron asbestos essential to important military needs where fireproof electrical insulation is involved, but such supplies are now obtained chiefly from British Columbia, Canada. Africa is our only source of the asbestos variety amosite, which is of first importance as lightweight insulation on ships and airplanes. Africa is the principal source of crocidolite (blue asbestos), which has certain special uses. Bolivia supplies small quantities and is the only source of crocidolite in the Western Hemisphere.

UPWARD TREND OF BOTH WORLD DEMAND AND SUPPLY

The asbestos-products industries of the United States are expanding greatly to pace growing industrial activity; therefore the domestic demand for raw asbestos is increasing steadily. British and continental European needs are also expanding. Central European asbestos-products industries, stagnant during World War II, have revived, and increasing quantities of African and Canadian fibers are being shipped to European markets. Australian demands are also rising substantially. Canadian and African production facilities recently have been greatly enlarged, and further increases are expected. Supplies of fiber adequate to meet growing world needs appear to be ample for the near future, but the long-term prospect is less definite.

ADEQUATE INFORMATION AN IMPERATIVE NEED

The procurement of necessary supplies is a problem of worldwide scope, and in every war emergency asbestos assumes top priority among strategic minerals. It is of paramount importance, therefore, that a thorough knowledge should be gained of the composition and properties of asbestos, its uses and requirements for each use, grades and specifications, the degree of essentiality of each application, the nature and extent of sources of supply throughout the world, mine and mill capacity, reserves, transportation facilities, political and commercial control, world requirements by countries, import and export data, allocation of supplies, fiber beneficiation, possibilities of synthetic asbestos manufacture, use of substitute materials, past war controls, war history, and various other problems that may appear. The purpose of this report is to furnish information on as many as possible of these pertinent questions.

CHAPTER 1. VARIETIES AND COMPOSITION OF ASBESTOS

VARIETIES

There are several varieties of asbestos, differing considerably in composition and physical properties. The most important commercially is chrysotile, which constitutes about 95 percent of total world production. Its wide use is due to the fact that its fibers are generally strong and flexible and therefore can be applied to many uses, such as manufacture of textiles and steam packing, for which weak and brittle fibers are not adapted.

Species of asbestos other than chrysotile fall in the amphibole group of minerals. The only varieties having significant use are anthophyllite, tremolite, amosite, and crocidolite. Fibers of anthophyllite and tremolite are generally weak and brittle, and their uses are limited. Sales are small, and only small quantities of these materials enter international trade. Amosite and crocidolite are mainly African varieties exported to the United States and other countries in considerable quantities for specialized uses.

CHRYSOTILE ASBESTOS

Chrysotile is a hydrous magnesium silicate having a composition represented by the chemical formula $3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$. It is a fibrous form of the mineral serpentine. Antigorite is a platy form of serpentine of no commercial value.

In recent work Shaw (5)³ indicates that both OH, the hydroxyl radical or water of constitution, and H_2O , the water of crystallization, are present in chrysotile. To indicate the dual nature of the water content, he writes the chemical formula $(\text{OH})_6\text{Mg}_3\text{Si}_2\text{O}_{11} \cdot \text{H}_2\text{O}$. He claims also that in fibers from different locations the proportions of these two forms in which water occurs may vary. Thus, in Canadian chrysotile a greater part of the hydration is water of crystallization, while in the Rhodesian chrysotile the hydration is due largely to the hydroxyl radical. He expresses the view that such a difference in chemical constitution may explain in part the superior electrical resistance of the Rhodesian fiber.

The composition of chrysotile, however, is not rigidly fixed according to either of the for-

mulas given above. Minor quantities of iron, nickel, manganese, or aluminum may replace part of the magnesium. Such small replacements may result in some modifications in the physical properties of the fibers. Furthermore, these properties are influenced to some extent by the presence of impurities; but, in general, chrysotile is more constant and dependable in quality than other varieties of asbestos. Chemical analyses of representative samples of asbestos are given in Bureau of Mines Bulletin 552 (7).

AMPHIBOLE ASBESTOS

The amphibole group of minerals was formerly believed to consist of anhydrous silicates of magnesium, calcium, iron, and other elements. However, in 1916 Schaller (2), using five exact analyses of tremolite, showed, by calculating the molecular ratios, that water was an integral part of the composition of tremolite and derived the formula $2\text{CaO} \cdot 5\text{MgO} \cdot 8\text{SiO}_2 \cdot \text{H}_2\text{O}$, which is now the recognized composition as contrasted to the widely published formula $\text{CaO} \cdot 3\text{MgO} \cdot 4\text{SiO}_2$. When X-ray studies of minerals were begun in the early 1920's, Schaller's findings were confirmed, and it was further learned that all amphiboles contained water of crystallization. Only in textbooks of mineralogy published since about 1940 will the definite statement be found: "All amphiboles contain hydroxyl." The water content of amphiboles is low—only 1 or 2 percent—whereas chrysotile contains about 13 percent water.

AMOSITE

There is some doubt that amosite is a distinct mineral species. Rabbitt (4) found by X-ray analysis of two amosite samples from South Africa that both were monoclinic in crystallization and therefore were not anthophyllites. The chemical composition of one indicated that it was probably actinolite, and the other was probably cummingtonite. Vermas (6) concludes that amosite is a fibrous form of the monoclinic amphibole grunerite $(\text{FeMg})_3\text{Si}_8\text{O}_{22}(\text{OH})_2$. However, it seems desirable to retain the name amosite in commercial usage where it serves a useful purpose.

Amosite may contain as high as 40 percent iron oxide, but, as it is monoclinic in crystallization it is not a true anthophyllite, although

³ Italicized numbers in parentheses refer to items in the bibliography at the end of this chapter.

it is commonly classed as a high-iron anthophyllite. Amosite, unlike the true anthophyllites, which are almost invariably weak and brittle, consists commonly of long, fairly strong fibers that have certain specialized uses. It is mined only in Africa.

ANTHOPHYLLITE

The composition of anthophyllite is now generally expressed by the formula $Mg_7(Si_4O_{11})_2(OH)_2$, sometimes written $7MgO \cdot 8SiO_2 \cdot H_2O$. The magnesium may be replaced in part by certain other elements, but complete replacement is not possible because the anthophyllites possess only limited isomorphism. Ferrous iron may replace magnesium up to 26.53 percent, but such an anthophyllite would still contain as much as 11.48 percent MgO . When the ferrous iron content exceeds 26.53 percent, the mineral ceases to be anthophyllite, as it becomes monoclinic in crystallization whereas all anthophyllites are orthorhombic.

The MgO content of anthophyllite is said to range from 5 to 50 percent. A series of 46 chemical analyses of anthophyllites assembled by Rabbitt (4) shows a maximum of 31.53 percent and a minimum of 11.48 percent. The one with the maximum MgO content contained 5.6 percent FeO . The CaO content of anthophyllites is very low; it averages about 0.5 percent and rarely exceeds 2 percent.

Aluminum is a more important constituent of anthophyllites than is commonly supposed. Of Rabbitt's 46 tabulated analyses, 14 show more than 10 percent Al_2O_3 , and 20 show more than 5 percent. Aluminum may replace magnesium or silicon.

TREMOLITE

In tremolite the calcium may be replaced in small part by sodium. The magnesium is replaceable by iron in considerable quantities and by aluminum to a lesser degree. Also, a small part of the silicon may be replaced by aluminum. Tremolite usually consists of gray to white silky fibers, which are for the most part weak and brittle, although fibers of considerable strength and flexibility are found at times. Both tremolite and anthophyllite are superior to chrysotile in resistance to chemical reaction.

CROCIDOLITE

Crocidolite or blue asbestos belongs to the hornblende group of amphiboles. Its simplest chemical formula is $3Na_2O \cdot 6FeO \cdot 2Fe_2O_3 \cdot 16SiO_2 \cdot H_2O$. Considerable variation in composition has been noted. Sodium may be replaced by potash, ferric and ferrous iron by magnesium or manganese, and ferrous iron by alumi-

num. Mineralogists now regard crocidolite as identical with riebeckite, being merely a fibrous form of that mineral. Crocidolite therefore bears the same relation to riebeckite that amosite bears to grunerite and that chrysotile bears to massive serpentine. Blue asbestos is produced chiefly in South Africa, but substantial quantities are now obtained in Western Australia, and a small output is obtained in Bolivia. Except for those in Bolivia and a recently discovered occurrence in New Quebec, Canada, no commercial deposits of blue asbestos are known in the Western Hemisphere. In Bolivian blue a large part of the iron is replaced by magnesium. The magnesium content of African blue asbestos is somewhat lower.

ERRATIC CHARACTER OF AMPHIBOLE FIBERS

As may be observed from the foregoing discussion, the replacement of one element by another in varying proportions is a prevalent characteristic of the several varieties of amphibole asbestos. This variation in composition results in corresponding changes in their physical properties. These properties may also be influenced by the presence of impurities. The somewhat erratic and unpredictable physical characteristics of the amphibole fibers have a profound influence on their use. An anthophyllite from one locality may give satisfactory service for some specific use, while one from another deposit, although appearing to be exactly the same, may be unsatisfactory. Thus, problems in amphibole asbestos procurement are much more difficult and complex than the procurement of mineral products like iron or copper, which, when pure, have constant properties, irrespective of the part of the world in which they may originate.

IMPORTANCE OF PHYSICAL PROPERTIES

The outstanding physical characteristic of asbestos is its fibrous structure. Other important fibers found in nature are those of animal origin, such as wool and silk, and those of vegetable origin, such as cotton and flax. Incombustibility is one of the striking differences between asbestos and the fibrous products of animal or vegetable origin. Of perhaps equal importance is the difference in structure. Each filament of cotton, wool, or silk is of measurable and fairly constant diameter and is indivisible into finer sizes. On the other hand, fibers of chrysotile asbestos can be divided and subdivided until a fineness is attained that is limited only by the delicacy of the machinery used and the skill of manipulation. The ulti-

mate fiber size is presumably the size of the ultimate molecule or crystal lattice of asbestos. In other words, fiberization is a cleavage process, and cleavage in minerals is defined as a tendency to split in a certain direction, that is, to separate along and between layers of molecules.

With respect to use, fiber size is important, and the size will depend upon the degree of fiberization attained in milling. Fibers obtained from different deposits vary in the ease with which they may be fiberized. Thus, two samples of chrysotile asbestos, given exactly the same mill treatment, may furnish products differing considerably in fiber diameter, because one of them separates or fiberizes more easily than the other. Such differences may have great practical importance because an asbestos that is difficult to fiberize may require such intense milling to reduce the fibers to desirable fineness that they may be broken into undesirable short lengths. Ease or difficulty of fiberization is therefore an important property of asbestos.

The use to which a chrysotile asbestos may be applied is governed largely by fiber length. The longest fibers command the highest prices and the shorter grades progressively lower prices. Apparently, therefore, primary attention must be given to milling processes that will separate the fibers from the parent rock and will fiberize them adequately with a minimum of fiber breakage.

The heat resistance of asbestos is important in many applications. Some users of asbestos confuse nonflammability with refractoriness. Nevertheless, many substances that will not burn will melt or decompose at relatively low temperatures. The fireproof property of asbestos is one of its chief assets; but, although unburnable, it will decompose and lose its essential physical properties at moderately high temperatures. Some students of the subject have conceived the idea that asbestos is a highly refractory substance by reading the statement made by Cirkel (1) that it can with-

stand temperatures of 2,000° to 3,000° F. easily, while some varieties can be subjected to a temperature of 5,000° F. with no apparent visible effects. With due respect to Dr. Cirkel, who wrote a splendid pioneer volume on a mineral of which little was known at that time, he was in error regarding the heat resistance of chrysotile.

Brandenberger and coworkers (3), who have made a comprehensive study of temperature effects on chrysotile at the Mineralogical Institute of the University of Zurich, state that the so-called adsorbed water of chrysotile is driven off at about 300° C. Between 550° and 600° C. all of the water of crystallization is driven off, and the mineral gradually alters to olivine. Accompanying this dehydration is a pronounced change in physical properties. At 400° C. there is a notable deterioration in fiber quality; and above 550° C., with more or less complete dehydration, chrysotile is completely decomposed. The amphibole varieties of asbestos will withstand somewhat higher temperatures than chrysotile. However, crocidolite, although having a low water content, is easily fused into a black magnetic mass.

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CHAPTER 14. SUBSTITUTES FOR ASBESTOS

INCENTIVES FOR SUBSTITUTE RESEARCH

Shortage is a strong incentive for seeking substitutes. The general worldwide shortage of asbestos that existed during World War II and the early postwar period led to wide research and experimentation on materials that might take its place. Germany's virtual isolation from sources of asbestos prompted testing in that country of such possible substitutes as glass wool, steel wool, iron wire, synthetic rubber, organic plastics, cellulose, and treated paper. Work on substitutes also was conducted with considerably intensity in the United States and several other countries.

Expanded production and a reduction in military requirements for asbestos by 1954 had brought supply and demand into approximate balance, and the progressive relief from shortages that characterized the years 1952 to 1954 led to a relaxation in efforts to find substitute products. Accordingly, there are few recent developments in this field. However, the major dependence of the United States upon foreign asbestos supplies, even though they are largely controlled by a traditionally friendly nearby nation, is a situation that demands constant awareness of the possibilities for substitution under emergency conditions. The merits of possible alternate products are therefore considered here.

SODA-LIME-SILICA GLASS FIBERS AND MINERAL WOOL

Glass and related fibers are manufactured in two basic forms—a short-fiber woollike material and a continuous filament. Rock wool, glass wool, and slag wool are used primarily as lightweight thermal insulation, such as house fill. Such applications, in general, are not substitutes for asbestos. Glass filaments made by more refined processes involving the use of platinum dies are of high quality and uniform size. Some of them are less than one-half micron in diameter and are adaptable to highly specialized uses, such as weaving into fabrics. Such filaments are used as substitutes for asbestos in some applications.

Glass fibers will not burn, but they will soften and coalesce when the temperature reaches a

certain point, which varies according to the composition of the glass. The heat and moisture resistance of the glass filaments is limited by the organic film applied to the individual fibers during manufacture to improve processing and reduce breakage during subsequent plying and weaving operations. Without such a coating, the fibers are relatively brittle and self-abrasive. For high-temperature applications most of the organic film is removed by heating for a short time at about 300° C. (572° F.). The fibers are then recoated with a material suitable for the operating temperature. When glass filaments are used without such coatings, their properties are impaired to some extent, but they will withstand temperatures up to 1,200° F., which is an advantage in certain applications.

Normally, glass resists weathering very well. Windowpanes generally show no weathering effects, even after many decades of use. However, the surface area per unit volume of very fine glass fibers is so great that exposure to water vapor results in relatively rapid deterioration. Fiberglas is therefore less resistant than asbestos to the effects of steam or moisture. Attempts have been made to use glass fibers in place of asbestos in asbestos-cement products, but such tests have given unsatisfactory results, chiefly because of a chemical reaction between the glass and cement, which decomposes the fibers and destroys their effective strength.

Glass fibers are efficient thermal insulators in various types of equipment, such as stoves and refrigerators, where conditions are not corrosive. The high tensile strength, the greater thermal stability compared with organic fibers, and the electrical resistance of glass fibers make them suitable for electrical insulation, such as sleeving for wire and tapes for the construction of some types of motors. Fiberglas is used in conjunction with, or as an optional alternate material for, asbestos in Navy shipboard cables. It is claimed, however, that the use of asbestos results in greater resiliency in finished cables than can be obtained with Fiberglas. Glass fibers are permitted in specifications for cable filler (material that fills in the spaces in a group of insulated cables), but they have not yet been developed in a form that gives entirely satisfactory cable performance. Because of its high electrical and heat resistance, very thin glass-

fiber paper may find advantageous use in condensers for electronic equipment; for example, its use may make possible a reduction in the size of the condensers.

A glass-asbestos cloth was designed during World War II to extend the supply of asbestos textile fibers. It has continued in use as a covering on thermal insulation applied to piping on naval vessels. It is woven with a plied yarn having one strand each of glass and asbestos yarn. Glass fabrics or combined glass-asbestos fabrics have some advantage over asbestos textile products because of lighter weight per square yard and greater strength, but they are generally inferior to asbestos fabrics in resistance to flexure, abrasion, and chemical action. Fabrics consisting of interwoven glass and asbestos yarns are now made in many weights and colors for use as theater curtains and for fire-proof draperies in schools, hospitals, libraries, hotels, and ships.

Coarse glass fibers compressed into bats are efficient lightweight air filters that are used extensively for cleaning large volumes of air. Asbestos is not widely used in this field.

The use of Fiberglas as a substitute for asbestos in friction equipment has, in general, given unsatisfactory results, chiefly because of the abrasive effects of glass on brakedrums. Also, the glass fabrics lack the high resiliency of those made of very finely divided asbestos filaments.

During World War II and the Korean conflict a large part of the production of Fiberglas was applied to military uses. Many manufacturers of electric insulating materials, such as manufacturers of asbestos cloth and tapes, laminates, varnished tubing, magnet-wire covering, and mica-insulating products, are listed as users of Fiberglas. Fiberglas was widely used during World War II for heat, sound, and electric insulation on aircraft. Over 90 percent of the output during World War II was used for military or essential civilian use.

Since it appears that Fiberglas can be substituted for asbestos in certain fields of application, its future availability is of first importance. A question has been raised as to the adequacy of Fiberglas production facilities. The manufacture of Fiberglas in ultrafine filaments was originally limited to a single plant operated by the Owens-Corning Fiberglas Corp. Such a situation tends to impose a serious limitation on the supply of an essential product in an emergency. With limited manufacturing facilities, the substitute product might be as difficult to obtain as the asbestos it is supposed to replace.

However, that situation no longer exists. The original company has enlarged its operations

greatly; it manufactures Fiberglas in seven widely separated factories. Furthermore, several other companies now manufacture the product under license. It is believed that facilities will be adequate to meet any reasonable demands that may develop in the near future.

A question has also been raised as to limitations on Fiberglas manufacture imposed by the need of platinum. At one stage in the process of Fiberglas manufacture the molten glass is drawn through perforations in a platinum-bottomed cell or bushing; apparently, no other substance can be substituted for the platinum so used. Because platinum is produced in limited quantities—a free-world production of about 800,000 troy ounces a year—and has wide scientific and industrial use, its availability for wider application in this industry deserves careful consideration. Platinum is a critical material during war periods. Three important circumstances tend to relieve to some extent the threat of a possible shortage:

1. There is very little loss of platinum during the process of Fiberglas manufacture. The holes through which the fibers are drawn will gradually enlarge, and the platinum bushing will accordingly have to be rebuilt, using the same platinum. Care is taken to recover any dust or fragments of platinum. The first installation is the important consideration, but subsequent replacement of losses is very small.

2. Research is being conducted constantly to find ways of reducing the quantity of platinum required in each bushing. Presumably, some saving is possible and will be accomplished.

3. Research is also being devoted to possible substitution of some less costly and more abundant substance for platinum. Limited progress has been made, and there is at least some promise of success.

Another raw material essential to Fiberglas manufacture that may be in short supply in times of emergency is cryolite, sodium-aluminum fluoride (Na_3AlF_6), which is mined only in Greenland. The supply, however, is augmented by artificial cryolite manufactured from fluorspar. If supplies of both these materials are limited, sodium silicofluoride may be substituted. It has been produced as a byproduct from phosphate rock.

HIGH-SILICA GLASS FIBERS

Glass fibers approximating vitreous silica in composition are superior to soda-lime-silica glass fibers in resistance to deterioration from the action of water vapor and to high temperatures, but their manufacture is a difficult problem. Fused silica is extremely viscous at its melting point ($1,728^\circ\text{C}$.), and its manufacture into thin filaments is very difficult. To over-

come this high viscosity, fluxes are added, the fibers are made, and the fluxes are then removed. Several methods are used, but they are similar in principle. First, filaments are formed from an easily workable composition, such as an alkali silicate. Second, the alkali or flux in the filament is removed by leaching or ionic substitution. The resulting fibers are relatively porous and high in silica. They will withstand with little deterioration temperatures exceeding 1,000° C. The minimum diameter of high-silica fibers on which data were available in 1952 was about 2 microns, and the average was much greater. On the other hand, natural asbestos fibers are only a fraction of a micron in diameter. Correspondingly, the silica fibers are much less flexible than natural chrysotile. Because of their high moisture resistance and ability to withstand high temperatures, the vitreous silica filaments undoubtedly can be substituted for asbestos in some applications, but it is doubtful if they can replace asbestos where flexibility and elasticity are prime considerations. Furthermore, the cost of manufacture is very high. High-silica-glass fibers are now made in much finer sizes than in 1952.

Dr. Rudolf Lentz claims to be the inventor of a process for making synthetic asbestos in Germany. His product, however, could not be called synthetic because its base was sodium silicate, and an analysis of the final product indicated that it consisted of over 97 percent SiO_2 . It was, in fact, a silica-glass fiber. Three companies were licensed to manufacture this product in 1943, but because of the military reverses suffered by Germany no progress was made (4).¹

OTHER SILICEOUS FIBERS

At least three companies are now making aluminum silicate fibers. They employ blowing processes, which do not require the use of platinum spinnerettes. Fusion may be accomplished with an electric arc. These fibers may be employed where exposed to temperatures of 2,000° F. or higher. They are costly to make and have special uses beyond the temperature ranges where asbestos products are employed.

Fibers of pure quartz are now made in micron sizes. They are also costly and are applied only at high temperatures.

ORGANIC SUBSTITUTES

German scientists attempted to manufacture yarn from short-fiber asbestos mixed with long organic fibers, such as cotton, cellulose, or synthetics, but the product obtained was very weak

(2). Cardboard with an organic plastic was used in Germany as a substitute for asbestos packing in flanges of steam and water pipes. This packing was satisfactory at pressures up to 5 atmospheres and temperatures up to 160° C. It is stated that substitutes for asbestos in high-pressure packings have not been successful and that all substitutes developed and used up to 1944 were inferior to asbestos (1).

A diaphragm of Perlon (synthetic fiber) paper coated with barite paste was tried by I. G. Farbenindustrie as a substitute for asbestos cloth as a diaphragm in a Stemens-Billiter cell in the manufacture of NaOH by electrolysis of NaCl solution. It failed within 30 minutes. However, a polyvinyl chloride diaphragm gave results equal to those obtained with asbestos cloth (3).

Although reports are somewhat conflicting, polyvinyl fibers appear to be inferior to asbestos in asbestos-cement products. Silicone products alone or in combination with glass fibers have been used successfully as wire covering in certain applications.

SUBSTITUTES FOR AMOSITE

As indicated elsewhere, an important use for amosite is in the manufacture of light, fluffy insulation for use on marine turbines and jet-planes. The fluffiness appears to be a function of fiber diameter, the finer fibers showing the higher degree of thermal efficiency per unit weight. Accordingly, it has been found that Fiberglas having fiber diameters of less than 1 micron has a thermal efficiency comparable with that of amosite, but Fiberglas of this quality costs 5 or 6 times as much as amosite. Calcium silicate and diatomaceous-silica insulation products are used as substitutes for amosite in some applications.

Chrysotile can be substituted for amosite in 85-percent magnesia products, with some increase in weight per cubic foot and with a somewhat lower thermal efficiency. A substantial substitution of chrysotile for amosite would, in some instances, increase the weight per unit volume beyond the limitations of military specifications.

SUBSTITUTES FOR CROCIDOLITE

Crocidolite was used widely for a time in making gas-mask filters. However, the Naval Research Laboratory found that glass fibers make superior gas filters. In gas-mask tests in a smoke-filled room, it was found that only 1 particle in 100,000 passed through the Fiberglas filter, and at the same time the mask caused no noticeable increase in normal breathing resistance. The filter paper can be made in any

¹Italicized numbers in parentheses refer to items in the bibliography at the end of this chapter.

ordinary paper mill (5). Because of the success attained with Fiberglas air filters, the use of Bolivian crocidolite is no longer regarded as essential in this application.

Because of its high resistance to chemical action, crocidolite has found wide use in making acidproof packings. One of the newer plastics is now replacing crocidolite to an increasing extent in this application, because it is stable up to 480° F., is resistant to acids and alkalis, and has low absorption.

The chief use of crocidolite in the United States is in the manufacture of asbestos-cement pipe. Its principal assets are its free filterability and high strength. No satisfactory substitutes are now available. Substitution of chrysotile for crocidolite in this application would, it is claimed, retard the drying time of the fabricated pipes so greatly that plant capacity

might be reduced as much as 50 percent. However, some of the harsh Canadian chrysotile fibers, such as those produced at the Munro mine, Ontario, can be substituted for blue asbestos to some extent.

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