ASBESTOS

A Symposium of Articles

by

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Research on Asbestos Fibres

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Introduction

VERY little fundamental research has been done on asbestos fibre to take maximum advantage of its properties and to determine in what commercial products it can best be utilized.

For the research chemist who is associated with asbestos development work, a thorough study of mineralogical information on asbestos deposits would furnish reliable information on the rock formations and the mineral impurities closely associated with the asbestos. Furthermore, he must have an intimate knowledge of the uses of the fibre in various products so that he can visualize the importance of the fibre and the role it plays in industry.

Some of the properties of asbestos fibres such as strength, composition, length, harshness or softness, and mineral associates are of considerable importance to the manufacturer because they are responsible for many production difficulties.

Fibre Strength

It has been known for some time that asbestos filaments have considerable tensile strength. These strengths have been referred to merely as *'weak'* to *'very strong'*. Not until recently have numerical values been applied to the strengths of asbestos fibres. But today we can take a thin fibre filament and mount it between two holders and apply a gradually increasing load or pull until the fibre breaks. By measuring the cross sectional area of the filament and the amount of load applied, we can calculate the tensile strength of the fibre in terms of pounds per square inch. This type of test is slow and rather difficult, but the fundamental data obtained furnish important basic information that can be applied to mechanical processing equipment and to certain asbestos products.

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During the processes of liberating the fibres from the wall-rock it is necessary to use some type of equipment that will crack the rock and release the fibre. The maximum strength of the fibre is preserved when this type of releasing is gentle and does not produce fractures at right angles to the fibre bundles.

It has been possible to submit crude bundles to processing equipment such as crushers, rolls, fiberizers, etc., and to test the tensile strengths of the fibres before and after processing in order to determine which type of equipment is best suited for opening fibre bundles without destroying the fibre strength. Even the speeds at which some pieces of equipment are operated have a definite effect upon the destruction of fibre strength and a change of several hundred r.p.m. may transform a strong fibre into a weak fibre.

When studying the fibre from a new deposit, it is important to know the strength of the fibre in its natural form, as 'crude', as well as after it has been processed. The basic information gained by this type of test is important when considering the installation of a new mill to process the fibre. If present milling practice is to be used, it may mean that certain pieces of equipment may require by-passing in order to preserve the fibre strength and not destroy the fibre length.

The strength of asbestos fibres is also important in certain commercial products, as for example textiles, papers, and asbestos-cement products. If the strength of the fibre is low, the loss in the textile plant will be high due to drops from the cards and willows. In papers, weak fibres will be ground down by the beater roll. Lifting of the roll may be required, or even reducing the beater cycle, in order to obtain a well formed paper where the fibres retain their maximum strength. In asbestos-cement products, the fibre strength is important. As the fibre strength is decreased by a processing method, so also is the modulus of rupture of an asbestos-cement board or sheet decreased.

Typical tensile strength values of chrysotile asbestos crudes range from 40,000 to 100,000 pounds per square inch. Sometimes these values are well over 100,000 provided the filaments have not been deformed by wall-rock movement during the period of crystallization.

Other fibres, such as amosite, will have values ranging from 15,000 to 90,000 pounds per square inch, while crocidolite will show strengths from 100,000 to 300,000 pounds per square inch. Some of these values are far greater than the tensile strength of the usual grades of reinforcing steel.

Composition of Asbestos Fibres

Commercial asbestos fibre, when carefully separated into various fractions, is found to be made up of a number of component parts: crudy fibres, in which the slender threads or filaments are not separated, but remain in bundles; dust, consisting of extremely fine particles, either fibrous or granular; fairly small size particles of serpentine rock or other minerals closely associated with the fibre deposit; and relatively pure fibres separated into thin threads or filaments. All of these fractions go to make up a commercial fibre and each component part plays a definite role when the fibre mass is used in industry. For example, the crudy bundles improve filtration in wet processes and contribute towards porosity, but they also impart to asbestos papers a rough texture which may be objectionable. Dust acts as a filler which decreases porosity, decreases filtration rates, and increases the density. Rock and other granular material may drop out as a loss during processing or, if it remains with the fibre, it will increase filtration rates, increase

porosity, and give a rough surface texture to papers or pressed products. If the granular material consists in part of magnetite particles, this is considered objectionable from the standpoint of the electrical industry. Therefore, each component of an asbestos mass plays a definite part and it is an extremely difficult task to separate these materials from the fibre mass commercially and to eliminate those that may be objectionable.

Knowing, then, that commercial grades of fibre contain opened fibres, crudy bundles, fines, and granular materials, it is possible to separate these by a special laboratory technique and express their values in percentages of the original fibre mass.

From our experience, it has been noted that certain grades of fibres require certain combinations of the fibre component parts, and that a change of 10 to 15 per cent in these fractions will make a large and noticeable difference in the manufactured product. Likewise, when we know the type of fibre and the percentages of its component parts needed for a product, we can develop this grade of fibre for this particular product.

Furthermore, when working with asbestos in plastics, the various component parts of a given grade of fibre are extremely important factors. In this case, we are involved in such physical measurements as absorption, wetability, fluidity, impact strength, power factor, bulking, and surface area. This means that the research chemist must know the effects of crudy bundles, fines, and granular materials upon the properties of absorption, wetability, fluidity, etc. After these facts have been established, he must understand the effects of various combinations of the fibre component parts (dust, crudy bundles, rock, etc.) upon these physical properties. With this fundamental information as a background, it is then necessary to make up molding powders, press them in molds, and study the properties of the molded material to see if the objective has been attained.

The results of all these studies place the producer of asbestos in a position to discuss problems understandingly with the plastics manufacturer and to help him with his problems, particularly in the selection of the proper fibre grade.

Fibre Length

The measurement of the true staple length of the fibres is probably the most difficult of the asbestos producer's jobs. Asbestos is unlike cotton, rayon, or other organic fibres that can be combed out and the lengths actually measured in inches or fractions of an inch.

The staple lengths of fibres in any given mass vary from those approximating 1/8 in. and longer to those of microscopic size. Methods that have been successfully applied to organic fibres have failed to give satisfactory results when applied to asbestos. Wet screening methods have given fairly good classifications providing the fibre surfaces are presented horizontally to the screen opening during the test. If the fibres pass lengthwise through the screen opening, the test loses most of its reliability.

A test that can measure the true fibre lengths and can be completed within a few minutes would most certainly be welcomed by the industry. Further effort should be directed by the research chemist to the solution of this problem.

Harshness and Softness of a Fibre

The terms *'harsh'* and *'soft'* are often used by the miner and manufacturer in connection with asbestos fibre.

In many cases, the harshness of a fibre is erroneously used to mean crudiness. This point should be clearly defined as the two terms are entirely different. The term *'crudiness'* means the presence of many hundreds of fibre filaments in bundles that are unopened and are wider than a thirty-second of an inch. The bundles also tend to appear stiff and will not bend through a 90° arc without fracturing. Of course, these crudy bundles could be soft, silky, or harsh, but, after they are properly opened, they have lost their crudiness as bundles or aggregates and appear as opened or willowed fibres that can be bent at right angles without breaking.

Harsh fibres, on the other hand, are usually weaker than soft fibres and, during a processing method whereby the thin filaments are separated and bent at right angles, they have a tendency to fracture easily, with resultant loss of fibre length. Some investigators have attributed the harshness of a fibre to the presence of mineral impurities which have crystallized close to the fibrils (1, 2, 3). Others believe it to be due to the water of crystallization or water of constitution of the asbestos (3). In any case, the degree of harshness of a fibre is an important factor in its use in industry.

If a harsh fibre is micro-pulverized and examined under a microscope, it is noticed that the fibres show an abrupt breakage and the pattern resembles a needle structure instead of the wavy pattern shown by a soft, silky asbestos fibre.

The degree of harshness of a given fibre may be estimated by a number of tests such as: (1) opening of the fibre in a standardized piece of equipment and measuring the length loss and increase of fines produced; (2) the tensile strength; and (3) its filtration properties before and after opening. The results of these tests may be expressed as the percent change and the numerical values used for comparison purposes.

It is interesting to note that a harsh fibre always retains a relatively fast filtration characteristic regardless of the type of processing. On the other hand, a so-called soft or silky fibre decreases in porosity at a rate proportional to the degree of opening of the fibre filaments.

It is the fast filtering characteristic of a harsh fibre that makes it attractive to the manufacturer, provided the fibre strength is not too poor. This type of fibre is an excellent material for 'freeing-up' a stock, giving porosity and aiding filtration. However, the manufacturer must be careful in handling harsh fibres or he may destroy the maximum fast filtering properties of the fibre by over processing.

Soft, silky fibres are normally difficult to handle by the manufacturer producing wet machine products. These fibres have a greater surface area than harsh fibres, and are also slower filtering. The degree of softness of a fibre can also be estimated by the same procedure employed for evaluating a harsh fibre and numerical values can be used for comparisons. Usually, it may be said that the softer and silkier the fibre, the greater the difficulty in handling it during the stages of manufacturing. Therefore, it is necessary for the manufacturer to have some knowledge of the workability of soft fibres before he attempts to use them, and it is usually the research man that can determine these properties and supply the necessary information.

Filtration

The filtration characteristic of any fibre mass is an important factor to the manufacturer using wet

methods for the production of asbestos products. For example, the rate of removal of water, either by suction or by pressure, when manufacturing asbestos papers, mill boards, shingles, asbestos-cement sheets, etc., will, to a certain extent, govern the production rates.

Therefore, in order to understand the problems facing the manufacturer, it has been necessary to develop a laboratory filtration test that can evaluate fibres as fibre masses, or as fibres in combinations with other ingredients that are used in commercial products.

The first step in this type of investigation was to determine the effects of all mineral impurities closely associated with commercial asbestos fibres. The next step was to study the filtration properties of asbestos fibres from all parts of the world and also, at the same time, determine the percentage of each mineral impurity.

This was followed by studying the effects of electrolytes, wetting agents, soft or harsh fibres, fibre particle size, weathered fibres, blends containing various types of fibre, crudy fibre bundles, and many others upon a standardized fibre in order to show the advantages or disadvantages as regarding the elimination of water from asbestos slurries. With this type of information available, it has been possible to express the degree of filtration change in percentage and then set up methods of correction so as to obtain the maximum improvement in filtration. Many production problems involving the elimination of water from fibre slurries have been investigated in the laboratory and the information has been successfully applied to the factory processes.

Value of X-Ray Studies

Today, X-ray diffraction studies are becoming one of the standard tools of the research chemist. They give the chemist a chance to obtain a preliminary answer to some of his problems within a few hours, whereas a chemical analysis may require weeks of analytical work.

Quite often, the chemical analysis of asbestos fibres shows the presence of small quantities of magnesium, silica, or water in excess of the normal amounts found in an average sample of asbestos. When these data are calculated in terms of minerals, they may indicate small amounts of talc, brucite, chlorite, etc., occluded in, or crystallized between, the fibrils. In such cases, a careful X-ray investigation shows the typical ring structure of the minerals and the data can then be recalculated showing the percentages of the mineral impurities present in the fibre.

X-ray studies, along with petrographic investigations, have furnished valuable clues to chemical reactions that may take place not only in asbestos fibres themselves, but in finished products.

Knowledge of Geology of Deposit as an Aid to the Manufacturer

If the manufacturer purchases fibre at random, the material he obtains may include asbestos from several different deposits, and the mineral formations of each locality will contribute some important factor to the fibre that may or may not be objectionable to his process.

For example, suppose a certain asbestos-cement manufacturer for a number of years purchased his fibre supply from one mine, where the rocks were very little faulted and hence there was very little fault fibre, and where such minerals as brucite, picrolite, and magnetite were present in only small amount. This manufacturer would have all of his processes well standardized on the fibre from this mine and everything operating in a satisfactory manner. Now suppose that he decided to change his source of fibre supply and the fibre came from a deposit in another locality where there was considerable faulting, and considerable amounts of fault fibre, brucite, picrolite, magnetite, and other minerals. What would happen?

First, if he did any re-processing of the fibre in his factory, such as willowing, he would notice a loss in fibre due to formation of dust or fines caused by the willowing action on the fault fibre, brucite, and minerals present.

Second, the fibre, having a total overall lower strength, would have a tendency to lose length during any processing stage.

Third, the surface area of the processed fibre would be increased and it would have a tendency to require more binding agent.

Fourth, the fibre, when wet, would be slimy and difficult to handle.

Fifth, the porosity of the fibre would decrease and the removal of water by normal filtration means, either by suction or by pressure, would be slowed down, thus resulting in a decreased output of the products.

Sixth, the strength of the final products would probably show a decided decrease in modulus of rupture.

If these changed conditions were suddenly thrust upon the manufacturer, without any forewarning, he would be in a difficult position. Consequently, today, the research chemist studies all of these problems long before the manufacturer needs to make the fibre change. He first consults the geological literature of the locality in which the fibre occurs and becomes familiar with the rock formations. With this information as a background, he obtains large representative samples of the fibre and studies its physical properties in the laboratory. This is followed by pilot-plant tests, where products are made under conditions similar to regular manufacturing procedures. When all of this work is completed he is ready to make a recommendation to the manufacturer as to the value of the fibre and as to whether it can be used successfully, and, if so, what changes in processing will be necessary.

It may be urged that these tests are time consuming and may not be worth the expense, but, if a manufacturer loses production in his factory for any length of time, his financial loss is considerably greater than the cost of the surveys and tests made by the research and development chemist.

Future of the Asbestos Industry

The asbestos industry appears to have reached a stage where considerable expansion of output of fibre is necessary. In making this statement it is, of course, assumed that there will be no displacement of asbestos by other materials in the products for which it has been used in the past and also that the many new developments now in progress will materialize commercially in the near future.

The demand for asbestos today far exceeds the supply, and it has been necessary for many producers of asbestos products to curtail production because of the shortage of fibre.

The situation has been relieved somewhat as a result of many refinements in extraction at the mills which have made it possible to increase recoveries and throw away less fibre in the tailing product.

Developments in the plastics industry in Canada and the United States during the past few years open up an estimated potential

market for short asbestos fibre that may reach 8,000 to 11,000 tons per year.

The asbestos-cement products industry in the United States and Canada, which includes flat sheets, corrugated sheets, pipe, shingles, etc., may, it is estimated, consume 200,000 tons of asbestos per year.

The asphalt tile industry, which uses short asbestos fibre, has shown considerable expansion during the past few years, and this consumption may be estimated at 120,000 tons of asbestos per year.

There is also an increasing production of asbestos papers, mill boards, brake linings, clutch facings, pipe coverings, roofings, black line, etc., that require asbestos fibres of various grades. The total amount of fibre used in these products in Canada and the United States might be estimated at 130,000 tons per year.

Therefore, it may be said that the potential volume of asbestos that could be consumed in Canada and the United States might reach a total of 450,000 to 500,000 tons per year for the next few years provided the fibre is available and the asbestos products manufacturers can continue, uninterrupted by labour conditions or shortage of materials, to expand the present factory equipment.

Conclusions

In concluding, the writer wishes to point out that, in our work on asbestos fibres in the Research Center, we have set up a procedure to be followed during our fundamental and development investigations. This plan of investigation includes the following types of approach:

(1) Obtain the complete history of the source of the fibre.
(2) Study its physical and chemical properties.
(3) Improve the physical or chemical properties of the fibre so that it will be better suited for its specific use.
(4) Study the processing technique and develop the best method in the pilot plant for handling the fibre and then recommend the procedure to be followed in the factory.
(5) After the preliminary investigations are completed, the processed fibres are submitted to other pilot-plant operations in the Research Center, where regular products are made on a semi-commercial scale.

If the problem involves very large tonnages of asbestos fibre, the work is transferred to the large-scale pilot plant at the mines at Asbestos, Que., where large size production milling equipment is used.

In this manner, we are able to follow the fibre from the earliest stages in the crude or mill rock throughout all its investigations in the laboratory and pilot plants, and during the time when the fibre is incorporated into the final product. This procedure gives the research man full responsibility for the research and development work until the factory accepts the material and takes over the production job.

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Filterability of Asbestos Fibres Used in Wet Processes

By M. S. BADOLLET

(*Annual General Meeting, Montreal, Que., April,* 1949)

(*Transactions, Volume LII,* 1949, pp. 260-264)

Introduction

THE manufacture of some asbestos products involves the use of asbestos in combination with water, cement, and granular fillers. This type of production is often called the wet or semi-wet process and requires the use of either pressure or vacuum to eliminate the excess water in the fibrous blend so that the product may develop the proper strength during the curing stage.

Asbestos-cement products available today are numerous and are a valuable contribution to the building industry. Their production in quantity depends upon the type of equipment employed, the speed at which it can be operated, and the factors involving the blending of asbestos, cement, water, and fillers.

Assuming that all mechanical troubles at a plant have been eliminated or are under control, it is still advisable to study the basic properties of the raw materials used in the asbestos-cement products.

The type of cement used is an important factor, but usually the manufacturer of the cement is willing to work with the asbestos development engineer and recommend the proper type to be used for the product.

The source of the water should not be overlooked as a general factor involved in the production cycle. Waters containing a high percentage of contamination such as silts, humus, or soluble salts may adversely affect the setting of the cement or cause a slowing down of the production rate in the factory.

Asbestos in combination with cement is an ideal material for building products. It is inorganic, will not deteriorate, and can be handled by mechanical equipment with a minimum reduction of fibre length.

The many physical properties peculiar to asbestos fibres (1) should be well understood by the manufacturer. They may be briefly enumerated as follows: fibre strength, fibre composition, sliminess, length, harshness, softness, and filterability or porosity. This last named property is important and it is the purpose of this paper to present some basic studies on filtration as applied to production problems.

Filtration Studies

The term filtration is used here to designate the removal of water from a slurry or wet matte of asbestos fibre by applying pressure or vacuum.

A simple laboratory procedure has been devised for accurately measuring the filterability of asbestos in water, or of asbestos in combination with water and cement. The apparatus (Figure 1) consists of a vertical bomb or cylindrical iron pipe threaded at each end so that it may be capped. The bottom cap is fitted with a screen and outlet so that the filtration proceeds on this disc of a definite area. The water or filtrate which passes through the filter matte is passed up vertically through a rotometer which accurately measures the rate of flow. Pressure is applied gradually by the use of a pressure regulator so that a constant rate of flow is maintained throughout the filter cycle. Slight agitation is maintained within the bomb by allowing the entering air to percolate

(1) See BALOLLET, M.S., *Research on Asbestos Fibres;* C.I.M., Trans., Vol. LI, 1948, pp. 131-134.

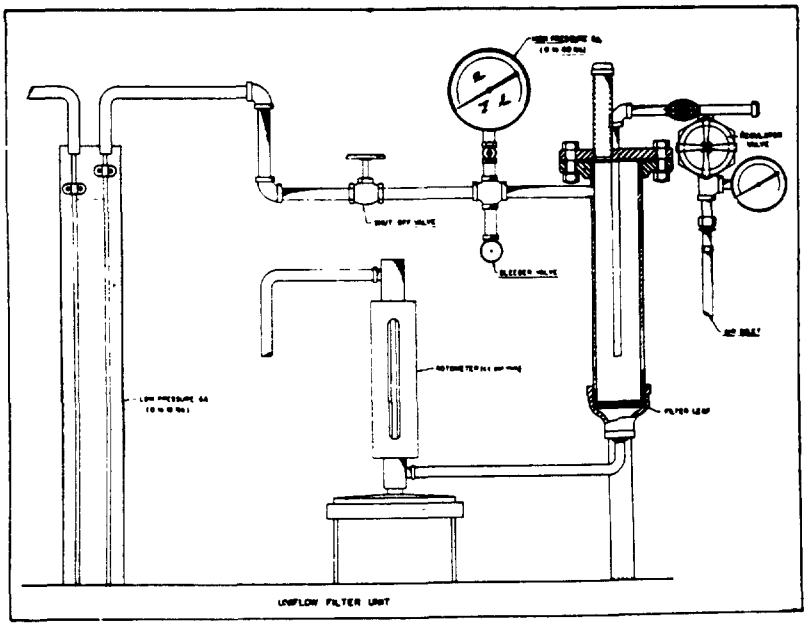

Figure 1.—Apparatus for measuring the filterability of asbestos.

*Research Centre, Johns-Manville Corporation, Manville, New Jersey.

upward from a point or several points above the filter disc. This prevents settling of the slurry and allows a gradual deposition of the fibre upon the filter disc.

The data obtained by such filter tests are plotted on co-ordinate paper and the areas under the curves are measured in square inches so that the values can be compared directly with each other.

Procedure is as follows: The top of the filter unit is removed and a small sample of the fibre under study, made up as a slurry in water, is poured into the bomb and the cap replaced. A low pressure is applied and the entire amount of fibre in the bomb is allowed to deposit on the filter disc or leaf to form a thin pre-coat. A larger sample of the fibre is now made up as a slurry and placed in the bomb for the actual test. By means of a pressure regulator, the float in the rotometer is maintained at a standard rate of flow (in terms of c.c. per minute). The pressure is continually applied so that the flow rate is kept constant. Pressure readings are recorded every 30 seconds and the pressure values are plotted against time in order to present the data graphically.

Effect of Asbestic Fines

A quantity of commercial asbestos fibre was first cleaned to remove all dust, rock, and asbestic fines. This clean fibre was then set aside for the filtration studies.

The asbestic fines or dusts used in these studies were obtained from an asbestos-mill dust house. A microscopic examination of the dust showed that the particles ranged in size from 0 to 40 microns and were of irregular shape with practically no fibrous structure.

Blends of these fines with the clean fibre were made up, containing, respectively, 10, 20, 30 and 40 per cent fines.

Filtration studies were made on each of these blends and also on the clean fibre. The results of the tests are given in Table I and are shown graphically in Figure 2.

The data, when plotted graphically (Figure 2), give typical filtration curves and from these we are able to measure the area under each curve and calculate the effect of the fines upon filtration.

It will be quite evident from inspection of Figure 2 that the presence of asbestic fines is objectionable since they adversely affect the filtration characteristics of an asbestos fibre. The manufacturer objects to the presence of asbestic fines because they slow down the wet process machines and also increase his overall fibre losses by passing through the equipment screens into the waste water.

It is known that commercial fibres contain various amounts of admixed asbestic fines and that, if these form a high percentage of the total fibre mass, they will cause serious manufacturing troubles such as slow filtering, poor saturation, and increased density, and, finally, will give a brittle product.

TABLE I.—EFFECT OF ASBESTIC FINES

AREA DESIGNATION (See Figure 2)	PERCENTAGE OF FINES IN SAMPLE	AREA UNDER CURVE AT 6 MIN.	PERCENT DECREASE IN POROSITY DUE TO PRESENCE OF FINES
E	0%	10.326 sq. in.	—
D	10%	12.148 sq. in.	17.64%
C + D	20%	15.989 sq. in.	54.84%
B + C + D	30%	22.655 sq. in.	119.40%
A + B + C + D	40%	27.373 sq. in.	165.10%

CALCULATION (example): $\frac{12.148 - 10.326 \times 100}{10.326} = 17.64\%$

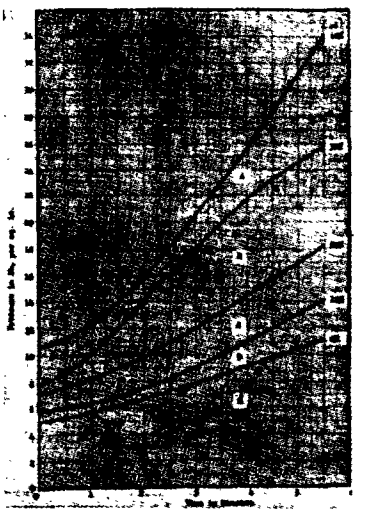

Figure 2.—Effect of fines on filterability of asbestos.

Effect of Temperature of Water

In many wet processes, the water temperature is an important factor and production rates can be increased by taking advantage of this fact.

A series of four tests were conducted at temperatures (F.) of 50°, 72.5°, 86° and 122°. In each case the same fibre was used, so that the only variable was the temperature of the water.

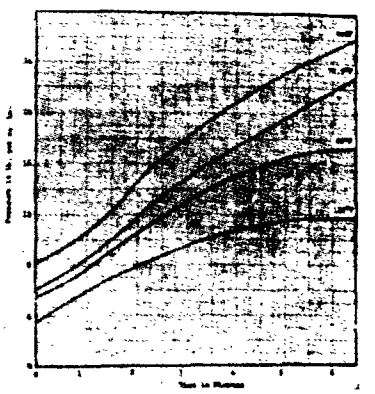

Figure 3.—Effect of water temperature on filterability of asbestos.

The results of the tests are presented in Table II and, graphically, in Figure 3.

TABLE II.—EFFECT OF WATER TEMPERATURE

TEMPERATURE °F.	AREA UNDER CURVE AT 6 MIN.	INCREASE IN FILTRATION RATE
59°	25.918 sq. in.	—
72.5°	21.629 sq. in.	16.6%
86°	18.481 sq. in.	28.9%
122°	13.295 sq. in.	48.7%

CALCULATION (example): $\frac{25.918 - 21.629 \times 100}{25.918} = 16.6\%$

These tests show that, by increasing the water temperature, it is possible to remove the water from an asbestos fibre slurry in a shorter time and thereby give the manufacturer an opportunity to increase his production rate. In some plants, warm water is used so as to gain this added advantage.

Effect of Serpentine Rock of Different Sizes

Serpentine rock relatively free from asbestos was ground in a ballmill and screened for size by sieving on a rotap apparatus. A constant weight of each screen fraction was then added to a constant weight of asbestos in order to determine which size is the most effective in improving filtration. The assumption was made that the rock particles were perfect spheres and that the average diameter of each particle was the average of the screen openings. Although it is realized that this involves a certain amount of error, the method does give a rough comparison of the specific surface area in terms of cm^2 per gram.

It was found that, of the several screen sizes of serpentine rock used in the tests, the most effective in improving the filtration characteristics of the asbestos fibre was the −20+35 mesh material. The larger sizes apparently do not give as good a porous structure to the fibre, and with the smaller sizes, also, the filtration rate is lower, due to decrease in the porosity of the fibre mass (see Table III and Figure 4).

Although the presence of some suitably sized serpentine rock is beneficial in improving the filterability of asbestos fibres, care must be taken not to use an excessive amount, which would adversely affect the physical structure of the asbestos-cement products. If the percentage of grit or serpentine rock exceeds that normally present in commercial grades of asbestos, then the asbestos-cement products will have lower strengths and increased densities.

Effect of Crudy Bundles or Pencils

Milled fibres as sold to customers frequently contain crudy bundles that are not properly fiberized. The presence of these bundles, if not further opened by re-processing, will have certain adverse effects upon filtration and upon the quality of the manufactured products.

TABLE III.—EFFECT OF SERPENTINE ROCK

SCREEN SIZE OF ROCK	CALC. SPECIFIC SURFACE AREA	AREA UNDER CURVE AT 6 MIN.	IMPROVEMENT IN FILTRATION
0	—	28.9 sq. in.	—
− 8 + 10 mesh	11.8 cm^2/gm.	14.8 sq. in.	48.8%
− 10 + 14 mesh	16.8 cm^2/gm.	11.8 sq. in.	59.2%
− 20 + 35 mesh	37.4 cm^2/gm.	9.0 sq. in.	68.8%
− 65 + 100 mesh	154.0 cm^2/gm.	16.1 sq. in.	44.3%
−150 + 200 mesh	294.0 cm^2/gm.	17.6 sq. in.	39.1%

CALCULATION (example): $\dfrac{28.9 - 14.8 \times 100}{28.9} = 48.8\%$

A quantity of crudy fibre was selected and fractions of various screen sizes were separated on a rotap apparatus so that a constant weight of these bundles could be added to a constant weight of fibre.

Figure 4.—Effect of rock particles on filterability of asbestos.

In this case it was necessary to make the assumption that the fibre bundles were perfect cylinders. The lengths and diameters of these bundles were measured under the microscope and then averaged for each screen fraction.

The crudy bundles with the smallest specific surface area had the greatest effect upon speeding up the filtration properties of an asbestos fibre (see Table IV and Figure 5). As the surface area of the bundles increased, the tendency was for filtration to be slowed down, thus indicating that, if all the bundles were completely opened, the filtration rate of the fibre would approach that of a normal fibre and would be classed as slow.

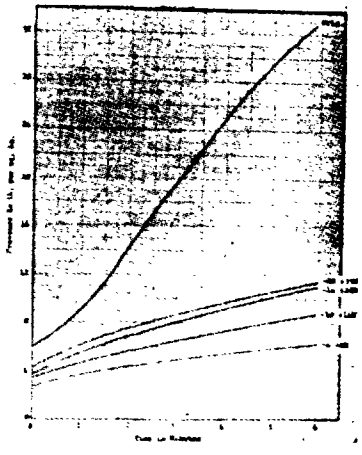

Figure 5.—Effect of crudy fibre bundles on filterability of asbestos.

Screening of the crudy bundles on the 10 mesh screen indicated that the grading for size was not accurate, as the specific surface area of these bundles should have been between 102 and 127 cm^2 per gram.

TABLE IV.—EFFECT OF CRUDY FIBRE BUNDLES

SCREEN SIZE	CALC. SPECIFIC SURFACE AREA	AREA UNDER CURVE AT 6 MIN.	IMPROVEMENT IN FILTRATION
Original	0	28.9 sq. in.	—
− 4+ 8 mesh	102.0 cm^2/gm.	7.1 sq. in.	75.5%
−10+14 mesh	168.0 cm^2/gm.	9.4 sq. in.	67.5%
−14+28 mesh	127.0 cm^2/gm.	11.6 sq. in.	59.8%
−28+35 mesh	164.0 cm^2/gm.	13.2 sq. in.	54.3%

CALCULATION (example): $\dfrac{28.9 - 7.1 \times 100}{28.9} = 75.5\%$

The other specific surface area calculations seem to agree with the general trend and indicate a decrease in the fibre bundle cross-section.

As shown graphically in Figure 5, the −4+8 mesh bundles increased the filtration rate more than did the −28+35 mesh bundles.

From the viewpoint of the manufacturer, the presence of the crudy fibre bundles would be considered satisfactory — particularly if he did any reprocessing — as he would have more effective fibre present in his product. It might even enable him to reduce the quantity of fibre used and make a superior product at a reduced fibre cost. However, the presence of crudy fibre bundles has a detrimental effect in some products because they impart a rough surface, and any subsequent sanding or polishing would result in the product having an uneven texture.

Fibres From Different Deposits

For these tests, samples of asbestos crudes from a number of sources were carefully processed so as to avoid contamination with particles of the wall-rock, and, after a preliminary opening by hand, were passed through a laboratory-type micro-pulverizer so as to obtain fibres of approximately the same size. The pulverized fibres were measured under the microscope and were then tested for filterability.

The cross-section measurements indicated that, for each prepared sample, the widths ranged from 1 to 5 microns and the lengths from 10 to 200 microns.

Figure 6 shows graphically the results of filtration tests. The slowest filtering fibre tested is the Arizona soft fibre (curve *A*). The prepared Canadian soft fibre (curve *C*) is faster filtering than the Arizona soft fibre. The Italian slip chrysotile (curve *D*) is faster filtering than the Canadian soft fibre.

The Cyprus chrysotile (curve *F*), which has a semi-harsh feel to the hand, would be considered fairly fast filtering in comparison with the other soft fibres. Curve *E* represents a typical Canadian semi-harsh fibre and it would be considered fast filtering. Curve *B* was obtained for a very harsh fibre from Arizona; this is extremely fast filtering.

The area measurements of each curve are given in Table V. In order to compare the curves we have taken the Canadian soft fibre as the standard. By this method we are able to express the filterability of each fibre as a percentage, with Canadian soft fibre taken as 100 per cent. Since the Arizona soft fibre was so slow filtering it was impossible to measure the area of its curve at the end of six minutes. As a consequence, the area measurements in these tests were all made at the end of four minutes instead of six minutes.

TABLE V.—CHRYSOTILE FROM DIFFERENT SOURCES
(Fibre width, 1-5 microns; fibre length, 10-200 microns)

IDENTIFICATION	CURVE (Figure 6)	AREA UNDER CURVE AT 4 MIN.	FILTERABILITY (Can. soft = 100%)
Arizona soft	A	13.80 sq. in.	37.6%
Canadian soft	C	8.50 sq. in.	100.0%
Italian slip	D	6.40 sq. in.	124.7%
Cyprus	F	3.30 sq. in	161.2%
Canadian semi-harsh	E	1.78 sq. in.	179.0%
Arizona harsh	B	0.24 sq. in.	197.2%

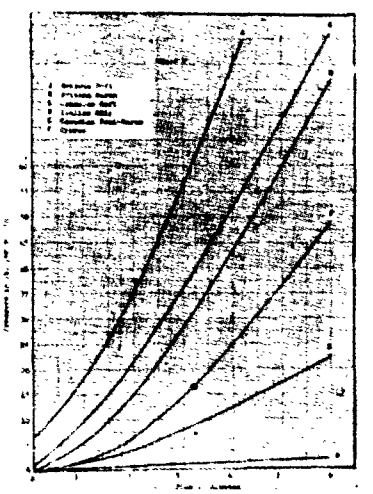

Figure 6.—Filtration characteristics of chrysotile fibre from various localities.

On this basis of comparison, the Arizona soft fibre (curve *A*) is 62.4 per cent slower filtering, and the Italian slip fibre (curve *D*) is 24.7 per cent faster filtering, than the Canadian soft fibre (curve *C*). For the Cyprus, Canadian semi-harsh, and Arizona harsh fibres, the filtration rate is faster than for the soft chrysotiles.

A physical examination of each of these fibres would show that the softer and silkier a fibre, the more difficult it is to filter. As the softness of texture decreases and the fibre assumes a certain degree of harshness, the fibre will filter faster.

Application of Technological Information to Manufacturing Processes

The importance of the filtration characteristics of asbestos fibres should not be overlooked by the manufacturer of asbestos products which are made by wet or semi-wet methods. In the manufacture of paper, millboard, shingles, pressed sheets, or pipe, the ease of the removal of the water will to a certain extent affect the production rate. If a fibre is difficult to dewater, then the manufacturer either changes his process mechanically, changes his grade of fibre, or uses some fibre blend that will allow him to maintain the production rate.

By adding a fast filtering fibre to a slow filtering fibre it is possible to step up production rates, but the manufacturer must be careful not to overdo this mixing for fear of losing strength in the product.

It is usually considered that fibres ranging from semi-harsh to harsh are fast filtering and likewise that the fibre strength decreases with its degree of harshness. Therefore the manufacturer must exercise care in selecting his fibre, or the ratio of soft to harsh fibre in his fibre blend must be well planned, in order to obtain the best fibre for his particular process.

At the present time, United States manufacturers of asbestos products who employ the wet or semi-wet process consume approximately 340,000 tons of asbestos per year. This includes approximately 11,000 tons of fibres from countries other than Canada and the United States. This immediately raises the question as to why these foreign fibres are used. Would they be used if Canada could supply the total tonnage required? The answer to this ques-

tion is not so much concerned with the availability of the fibre as with the particular physical properties of the foreign fibres that give the manufacturer the effects desired in his operations. These foreign fibres have the required free filtering properties and at the same time have strength. They also give the manufacturer sufficient latitude for blending, so that he can sweeten his slow filtering fibres with strong fibres that are fast filtering.

Conclusions

(1) The presence of asbestic fines or shorts decreases the filterability of a fibre mass in proportion to the quantity of fines or shorts present in the mixture.

(2) By increasing the water temperature it is possible to increase the filterability of a fibre mass and thus improve the operation of the process.

(3) The presence of serpentine rock will increase the filterability of a fibre mass provided the rock is not too small in particle size. In the tests made, −20+35 mesh material gave the maximum improvement in filtration; with smaller sizes, the filtration rate began to decrease, due to decreasing porosity of the mixture.

(4) Crudy fibre bundles will improve filtration. As the cross-section of the bundles is decreased, the filtration rate is slowed down. The presence of large quantities of crudy bundles may also affect the surface texture of the product, a factor which must be taken into consideration.

(5) Fibres from different deposits show considerable diversity in filtration characteristics. Soft, silky fibres are difficult to filter; semi-harsh to harsh fibres filter easily.

(6) By knowing the filtration characteristics of different fibres it is possible to select those that filter rapidly or to blend fibres to obtain the desired filtration results to fit the manufacturing process concerned.

Processing Asbestos Fibres: Effects Upon Physical Properties

*By M. S. BADOLLET**

(*Annual General Meeting, Toronto, Ont., April,* 1950)

(*Transactions, Volume LIII,* 1950)

Introduction

ASBESTOS as received by the manufacturer of asbestos products is in the form of either crudes or milled fibres processed to different degrees of texture. Frequently, the manufacturer finds that the fibres as he buys them are not adaptable to his plant processes, and, therefore, it is necessary for him either to contact the mine supplying the material and request a specific texture for the fibre or to reprocess the fibre in his own plant.

When the mine or mill manager is requested to change his milling equipment to produce a special grade of fibre with a specific texture, he would like to comply. However, if he began to make special fibre grades for each customer, he would be in the position of constantly rearranging his milling technique, adding more equipment, or building a new mill. In the end, his mill would be producing hundreds of different fibre grades of varying degrees of texture, which is a difficult accomplishment if he desires to maintain any quantity of production.

Viewpoint of the Miner

It is well known that asbestos fibres as produced at the Canadian mines fall into definite groups, such as crudes and milled fibre. Each of these groups has a number of sub-divisions, and many of the fibres have different textures such as crudy, semi-crudy, open, and well opened. No doubt these several degrees of texture have been established after many years of experience based upon the general demand of the customer. Therefore, the mill tries to maintain a set of standard fibre textures, with gaps between the different grades for future expansion if the demand is sufficient. In some instances, the customer demand for a particular fibre grade is great enough to warrant special milling techniques. In such a case, the mill places this specially prepared fibre in its regular production line. Each time it decides to produce a special fibre, several important points must be considered, such as: (1) Will this special fibre require new processing equipment or can existing equipment be used? (2) Will the over-all capacity of the mill be reduced? (3) Does this special fibre have specific physical properties that cannot be matched by present fibres offered to the public? and (4) Can the extra production cost be recovered?

Fibre milling is a technique that differs somewhat with each plant. All producers are continually making mechanical changes in order to improve their products while maintaining their production schedules. This problem is no easy one, and it requires full co-operation between the Sales staff and the Mill Department.

Viewpoint of the Customer

The customer has an established plant which produces a certain line of asbestos products and probably at one time he set up his plant with the minimum of equipment necessary for utilization of the regular grades of fibre as produced at the mines. After a number of years of competition and new developments, his products possibly did not meet the newer specifications, and the first question that came up for discussion was asbestos fibre. Was he using the proper fibre, or should he install equipment to re-process the fibre in order to change its characteristics? At this point, the Research and Development Engineer should step in and review the entire problem with the production department and decide whether the fibre must be changed to fit existing equipment, or whether the equipment should be modernized to handle the fibre. Since many manufacturers of asbestos products purchase their asbestos from more than one source — Canada, United States, Africa, Russia, and Australia — it is important for them to know how to handle the several fibres properly. This is particularly true when fibres of the same grade are purchased from two or more different sources and, consequently, may have entirely different physical characteristics.

To illustrate some of the problems facing the manufacturer of asbestos products, typical shipments of asbestos have been obtained from different sources and the effects of willowing upon the physical properties of these fibres have been investigated.

African Blue (Crocidolite)

This variety of asbestos would be difficult to use in its raw condition, as received in the United States, because of its crudy nature, quantities of unopened bundles of fibres, and the presence of pieces of rock of varying size. Therefore, the customer must either have some type of processing equipment to convert this fibre to the proper condition for use in his products or he must try to convince the miner in Africa to process his fibre to the customer specifications. Years of experience have shown that the easiest answer to this problem is for the customer to re-process the fibre himself, because he knows exactly what he wants.

African Blue fibre is strong but harsh, and by successive willowing action the fibre becomes bulky and loses length.

A normal Quebec-screen test, after one willowing action, shows that approximately 13 ounces of the total 16 ounces remain on the top screen. Successive willowing stages do not change this result sufficiently to show what is happening to the physical properties of this fibre.

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By a careful water eleutriation method, a definite indication can be obtained of reduction in fibre length after each willowing action. Figure 1 shows that, for five willowing actions, the +14 mesh fibre dropped from 52.6 per cent to 30.6 per cent, a length reduction of 40 per cent.

Coincident with decrease in fibre length, there is also an increase of fines (—200 mesh) from 30.4 per cent to 45.4 per cent, or an increase of 49 per cent. Therefore, to willow this fibre successfully, a minimum amount of willowing action should be used in order to avoid a loss in length of fibre and the formation of fines which would be lost in later stages of processing or product formulation.

In the production of asbestos products by wet methods, the density of the opened fibre as well as its ability to remain in suspension are important factors. The buoyancy of a fibre can be determined from a slurry of fibre in water, with a definite weight of fibre in a constant and definite volume of water. After thorough mixing, the slurry is allowed to settle, and the rate of settling is read in cubic centimeters for a given time. In most cases, the settling reaches equilibrium after one hour. The density can be determined by filling a standard measure with a capacity of, say, a cubic foot, and obtaining the weight of its contents. The results are then expressed as pounds per cubic foot.

Figure 2 shows that the buoyancy of the Blue fibre increases rapidly for the first willow pass, and that after the second pass the slope of the curve decreases. Conversely, the curve for the density values shows that the density decreases rapidly for the first pass and after the second pass changes only slightly.

An interpretation of the buoyancy and density curves indicates that this particular Blue fibre reached a high degree of opening at two passes through the willow and that further willowing, at added expense, would effect relatively little improvement in the quality of the fibre.

During the process of willowing a fibre there is another important change taking place in its surface area. This change, also, is indirectly reflected in the buoyancy and the density measurements.

Samples of the Blue fibre were measured for surface area by the air permeability method, using the Bowen apparatus and following the Lea and Nurse technique (1). A number of methods have been advocated for determining the surface area of solids and each has advantages and disadvantages. However, after considerable experimentation, it is thought that the method used in this investigation, while not giving absolute values, shows the general trend and indicates physical changes to the fibre after each processing action. Since it is known that willowing action on a fibre will open bundles into thinner cross-sections, reduce length, and create fines, there should result a cumulative measure of these effects by obtaining the surface area measurements.

Figure 3 shows the surface area measurements of the Blue fibre in its original state and after each willowing action. The results are expressed in square centimeters per gram of fibre, and the data, expressed graphically, yield a curve which shows that: (1) the surface area is increased after each willow action; and (2) this measurement shows a greater change per willow pass than the tests for buoyancy and density, because of the change in fibre length and the formation of fines.

The conclusions that can be drawn from these test data on opening African Blue are: (1) the fibre length decreases after each willowing pass, with resulting increase of fines; (2) the buoyancy and density values of the fibre show only small changes after two passes through the willow; (3) surface area measurements show that, after each willow pass, the area is increased; (4) a total of two passes through this particular willow would be the maximum treatment to produce a fibre for use in a plant; (5) one willow pass would be acceptable, since it produced a fairly open fibre with the minimum of length loss and creation of fines.

Rhodesian Fibre (Chrysotile)

This particular grade of fibre as received in the United States would also be difficult to use in most wet processes for the production of asbestos products, because of the presence of crudy fibre bundles.

The same procedure has been applied to this fibre as was used with the African Blue. The same equipment and rates of feed were adopted for all tests, so that the mechanical processing was constant in all cases.

This particular fibre was given a total of eight passes through the willow in order to determine the maximum opened condition of the fibre.

The Quebec-screen tests increased slowly to the maximum value of 12.6 ounces on the second screen at four passes, and then decreased to 11.7 ounces on this screen at the eighth pass.

The water eleutriation procedure for length indicated a decrease in fibre length (+14 mesh) after each pass, and a small increase in fines (—200 mesh). Figure 4 shows the two curves, which are entirely different from those for the African Blue fibre and which do not intersect at any point.

The slope of the curve for the +14 mesh fraction begins to level off after six passes while the curve for the —200 mesh fraction shows only a small increase in fines after six passes. In other words, the +14 mesh fibre decreased in length 61 per cent, but increased only 24 per cent in the objectionable —200 mesh fines.

The buoyancy of the fibre continues to increase rapidly after each pass. Figure 5 indicates that the slope of the buoyancy curve would begin to level off at some point after eight passes.

Density measurements show that the density of the Rhodesian fibre decreases rapidly for the first two passes and thereafter at a lesser rate, with indications that it would probably reach its minimum density after eight passes.

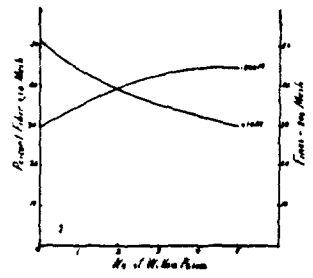
Surface area measurements made on this fibre show that it has less surface area than the African Blue after each pass through the willow. The curve (Figure 6) has a lesser slope than that for the Blue fibre, which would indicate that this fibre does not break down into shorter fibre lengths as rapidly as the latter. In other words, it resisted destructive action better than the African Blue under identical test conditions.

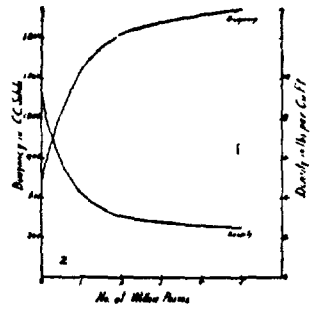
Canadian Chrysotile — Semi-Harsh

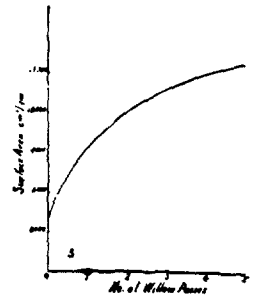
A quantity of Canadian semi-harsh fibre was obtained and subjected to numerous willowing actions to determine its resistance to fibre length destruction. This particular fibre contains considerable quantities of crudy fibre bundles that should be opened before it is usable in an asbestos product; therefore, it was subjected to a total of ten willow treatments.

The Quebec-screen test indicated

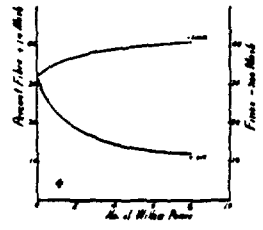
(1) For references, see end of paper.

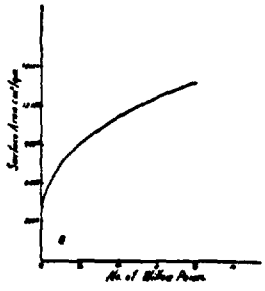




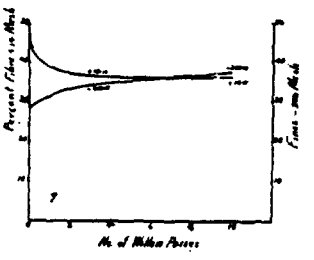


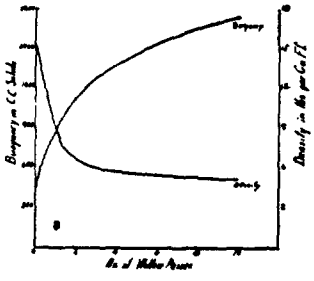
Figures 1, 2, and 3.—African Blue.

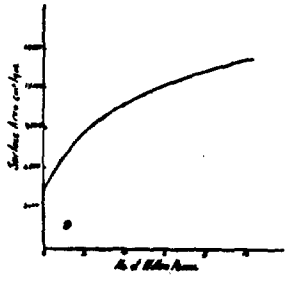




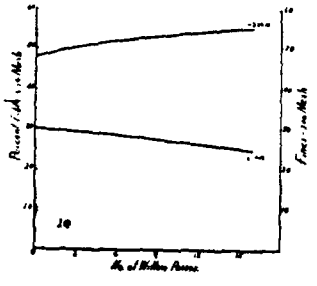
Figures 4, 5, and 6.—Rhodesian.

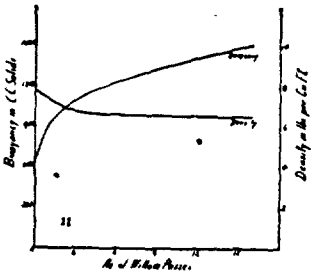


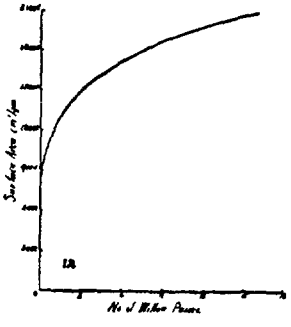




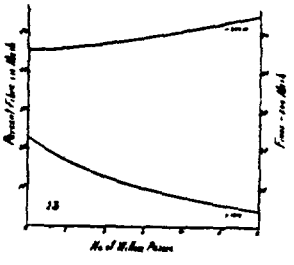
Figures 7, 8, and 9.—Canadian Semi-Harsh.

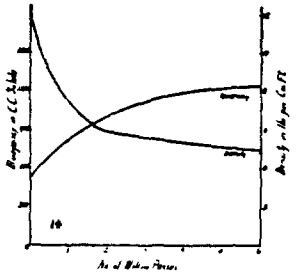


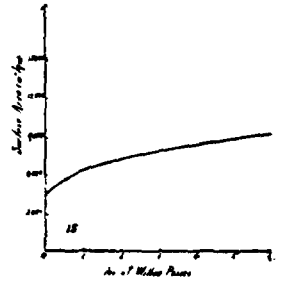




Figures 10, 11, and 12.—Canadian Soft.







Figures 13, 14, and 15.—Canadian Harsh.

a large increase on the second screen for the first pass, and only small increases for each succeeding pass up to six. From that point up to ten passes, the test indicated minor changes only.

The water eleutriation test indicated an 18½ per cent decrease in length for the +14 mesh fibre for the first two passes. Examination of the curve (Figure 7) reveals that the remaining willowing actions from two passes to ten had only minor effects upon the destruction of the fibre length. The fines (—200 mesh) show a 14 per cent increase for the first two passes and only a slight increase for the remaining treatments. From these data it can be concluded that this fibre resists destructive action and remains in good conditoin even after ten passes through the willow.

The buoyancy value of this fibre, as shown by Figure 8, increases rapidly for the first four passes, and then the slope of the curve begins to decrease.

The density values (Figure 8) show a large change for the first two passes and only minor changes for the remaining tests.

Surface area measurements are not increased as rapidly as in the case of either the Rhodesian or the Blue fibre. Figure 9 illustrates the increase in surface area and, as will be noted, the slope of the curve is less than for the two African fibres.

From the test data obtained on this Canadian fibre, it can be stated that willowing action is not detrimental to its physical properties and that it resists destructive action better than the African Blue or the Rhodesian fibre.

Canadian Soft Chrysotile Fibre

A typical Canadian soft, silky fibre was willowed a total of sixteen times in order to determine its resistance to the action of a willow.

The Quebec-screen test indicated a change on the second screen after the first pass. This same screen began to indicate a decrease after nine passes and, at sixteen passes, had decreased to a value slightly above that at the starting point.

The water eleutriation curves (Figure 10) show that this fibre, although it lost length and some pulverizing took place, did not disintegrate; therefore, it can be considered highly resistant to processing equipment. It would probably be satisfactory for use in its original state unless an increased fibre buoyancy was desirable for some specific usage.

The +14 mesh fibre decreased 20 per cent after sixteen passes, and the —200 mesh fines increased 14½ per cent for the same number of passes, a further proof that this fibre resisted the destructive action of the mechanical equipment.

The buoyancy of this fibre, as illustrated by Figure 11, shows a rapid increase for the first two to three willowings and only a gradual increase by subsequent treatments. However, the buoyancy values are all lower than those for the three fibres previously discussed, which shows that this fibre is relatively free from crudy fibre bundles and is fairly well opened.

The density values decrease for the first two to three passes and then practically level off, with only minor changes brought about by further processing.

A total of two willow passes would probably be sufficient to place this fibre in good open condition. From the curve obtained (Figure 10), it can be concluded that this number of willowing actions did little harm as regards destroying fibre length or pulverizing the fibre. The curve also indicates that the quantity of unopened bundles was small and that the fibre was fairly well opened at the asbestos mill prior to shipment to the customer. Therefore, this fibre can be used in its original condition, as received from the mine, without further processing on the part of the purchaser.

Surface measurements on the Canadian soft fibre are given in Figure 12. The fibre in its condition as received presents a greater surface than any of the other fibres discussed in this investigation. This would indicate that the combination of fibres of various lengths and fines created a large surface area.

The surface area of this fibre at any given pass is greater than that of any of the other fibres so far dealt with. Therefore, if a manufactured product requires a fibre of great surface area, this one should fit the specification. However, since this physical property is only one of many to be recognized, we must balance it against the other factors before reaching a final conclusion.

Canadian Chrysotile — Harsh Fibre

This harsh fibre of the chrysotile variety has some interesting characteristics from the viewpoint of its physical properties.

It was subjected to a total of six passes through a willow, and, in the Quebec-screen test, each pass indicated an increase on the second screen. The crudy fibre bundles opened easily and became fairly bulky, so that most of the fibre remained on the second screen.

Water eleutriation tests indicated a definite length loss in the +14 mesh fibre after each pass through the willow (see Figure 13). After six passes, this decrease in length amounted to 81 per cent and the quantity of fines (—200 mesh) showed an increase after each willow action. However, the amount of this increase is only 22 per cent, which would not be considered alarming. These data indicate that the long fibre will not resist flexing ation by willowing, and that shorter lengths were produced without pulverizing to dust. Therefore, any mechanical re-processing of this fibre after shipment to a customer should be extremely mild, or the fibre should be used without additional processing.

The buoyancy value of this fibre (see Figure 14), while showing an improvement after each pass, does not equal that of the other fibres discussed up to this point.

The density shows a rapid improvement for the first two willow passes and only minor changes after subsequent passes.

Therefore, for re-processing of this fibre, from the viewpoint of buoyancy or density, a minimum of two passes, or even one pass, would be considered sufficient. However, there is an important loss of length after one or two passes, and it might be advisable to avoid any further processing of this fibre.

Surface area measurements on this harsh fibre, shown graphically in Figure 15, indicate a smaller increase in area than for any of the other fibres tested in this investigation. In other words, this fibre maintains low surface area and low buoyancy, although it loses length, in processing. For certain products these properties are important and should not be overlooked; for other products, great care must be exercised in handling the fibre before and during its use.

The surface areas of all fibres tested are charted in Figure 16, which enables a direct comparison to be made between the several fibres for the same number of passes through the willow. The two extreme fibres are the soft, silky chrysotile of large surface area, and

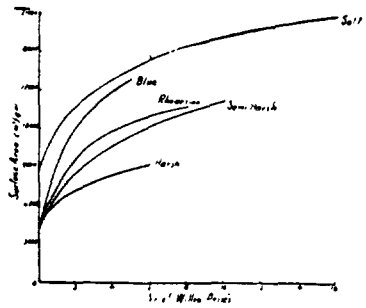


Figure 16.—Effect of willowing on surface area, various fibres.

the harsh chrysotile, having small surface area.

Effects of Willowing Upon Filterability of Fibre

When a fibre is opened by mechanical means, a fibre of greater surface area results. Figure 17 shows, for each of the fibres investigated, the effects of four willow passes upon its filterability.

The soft, silky chrysotile fibre rapidly becomes more difficult to de-water after each opening process, with the result that plant production is retarded.

The Rhodesian fibre remains fast filtering up to four passes through the willow, at which point it begins to show a trend toward more difficult filtration. However, after this number of willow passes, the fibre would still be considered satisfactory for any wet process.

Of all the fibres tested in this investigation, the filtration characteristics of the two identified as 'semi-harsh' and 'harsh' are least affected by the willowing process. Both would be considered ideal for sweetening poor filtering fibres, even if they had been highly opened by mechanical processes.

The filterability of African Blue fibre is only slightly affected by the willowing process, and at four passes it is still considered a fast filtering fibre.

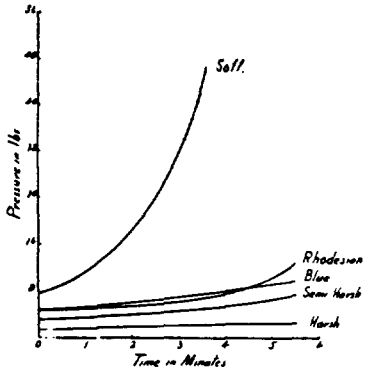


Figure 17.—Effect of willowing on filterability of various fibres.

Correlation of Test Data

In general, there is good correlation between buoyancy and surface area values at a given number of willow passes. When the surface area data and buoyancy values are expressed graphically, most of the points fall upon a straight line, indicating that either test can be used as a guide for determining the degree of opening of a given grade of fibre.

When the surface area measurements and the decrease in +14 mesh fibre expressed in percent are shown graphically for each willow pass for each kind of fibre, there appears to be a fairly good correlation, since most of these points also fall upon a straight line. This is an indication that the surface area of processed fibres is greatly influenced by the destructive action of willow hammers.

Application of Test Data

The manufacturers of some asbestos products require that asbestos fibres meet certain specifications as to rate of filtration, fibre strength, length, buoyancy, density, and surface area. In a previous paper on filtration, presented at the 1949 Annual General Meeting of this Institute (2), it was pointed out that, by opening a fibre, the rate of filtration is decreased. In all of the investigations discussed in the present paper, each fibre shows a trend to become more difficult to filter after each willowing action. Therefore, some decision must be made on the basis of the general over-all effect a willowing action has upon physical properties of the fibre.

Fibre strength (3) is important, and soft, silky fibres retain their strengths better than harsh fibres when processed by mechanical equipment.

If filtration is the most important factor governing the production rate of an asbestos product, then, given a fibre of satisfactory strength, a minimum amount of willowing should be used.

If a low density or a high buoyancy value is required and filtration is not important, then the fibre should be well opened to obtain its maximum fluffing condition.

If a fibre is required to have strength and high surface area with a minimum loss of fibre length and minimum formation of fines by a willowing action, then it is necessary to select a fibre or a blend of fibres that will meet these requirements.

The Research or Development Engineer should make a thorough study of the available fibres. Then, knowing the fibre specifications required for a given asbestos product, he should make definite recommendations to the manufacturer as to the kind of fibre and type of re-processing necessary to obtain the maximum value of the fibre for the specific utilization.

Conclusions

(1) Asbestos fibres as received by the manufacturer of asbestos products usually require some type of re-processing before they can be used to best advantage in a product.

(2) Any fibre re-processing method adopted by a manufacturer will produce changes in physical properties, such as a lowering of fibre strength, loss in length, formation of fines, different degrees of buoyancy, changes in density, increase in surface area, and a tendency to become more difficult to filter.

(3) The soft chrysotile fibres resist the destructive action of a willow fairly well, but have the greatest surface area and are the most difficult to filter at any given number of willow passes.

(4) African Blue fibre loses length, increases rapidly in surface area, becomes relatively buoyant after each willow pass, and filters rapidly.

(5) Rhodesian fibre loses length, increases in buoyancy, has less surface area than either the Canadian soft fibre or the African Blue fibre, and its filtration characteristics remain good even after four willow passes.

(6) The semi-harsh fibre resists the destructive action of the willow fairly well, but is less resistant to willowing action than the Canadian soft fibre, increases rapidly in buoyancy, is rapid filtering, and has less surface area than the Blue, Rhodesian, or Canadian soft fibre.

(7) The harsh fibre loses length rapidly, increases in buoyancy slowly, has the lowest surface area of all fibres studied in this investigation, and remains fast filtering after each willow stage.

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Asbestos, A Mineral of Unparalleled Properties

*By M. S. BADOLLET**

(*Annual General Meeting, Quebec City, Que., April*, 1951)

(*Transactions, Volume LIV*, 1951, pp. 151-160)

Introduction

THE DEMAND for general knowledge on asbestos fibres has increased considerably in recent years. A few publications have printed data showing some of the physical and chemical properties of asbestos, but in many cases this information is difficult to find and is seldom available when needed.

During the past ten years, Johns-Manville have received many inquiries on the physical and chemical properties of asbestos fibres. Fortunately, we had some of the information in our files, and we willingly supplied the data.

To help relieve this need, we have tried to present briefly in this paper some of the interesting and outstanding properties of asbestos. This information was obtained over a period of years by search of the literature and by experimental investigations.

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(1) For references see end of paper.

Properties of Asbestos Fibres

Table I (1, 2) presents, in convenient form for easy comparison, data on the principal properties of the several varieties of commercial 'asbestos' — actinolite, amosite, anthophyllite, chrysotile, crocidolite, and tremolite. Under each variety of fibre is a brief statement describing the properties in terms of structure, mineral association, origin, etc. Some of the more important data in Table I are expanded and presented in Table II (3).

Solubility of Asbestos

A report (4, 5) discussing the effects of acids and caustic on asbestos fibres was published in Germany in 1927. Re-published several times, it appears to be the only information available on the subject.

When, several years ago, it became necessary to obtain technical data, not available in the literature, on the solubility of commercial grades of asbestos, tests were arranged following the plan adopted by the author of the original article (4).

Samples were obtained of actinolite from Canada, amosite from Africa, anthophyllite from Georgia, chrysotile from Canada, crocidolite from Africa, and tremolite from California. These samples represented fibres obtainable in commercial quantities. They contained some mineral impurities and thus their degree of solubility was not identical with that of hand-picked, high-grade crudes from these localities.

The acids used in these tests were hydrochloric, acetic, phosphoric, and sulphuric. All were diluted to a 25 per cent acid solution, by weight.

Table II.—Physical Properties of Asbestos

	Chrysotile	Amosite	Anthophyllite	Crocidolite	Tremolite	Actinolite
Specific heat B.t.u./lb./°F.	0.266	0 193	0 210	0 201	0 212	0 217
Tensile strength, lb./sq. in.	80,000 100,000	16,000 90,000	4,000 & less	100,000 300,000	1,000 8,000	1,000 & less
Temp. at max. ignition loss, °F.	1,800	1,600 to 1,800	1,800	1,200	1,800	—
Filtration properties	Slow	Fast	Medium	Fast	Medium	Medium
Electric charge	Pos.	Neg.	Neg.	Neg.	Neg.	Neg.
Fusion point, °F.	2,770	2,550	2,675	2,180	2,400	2,540
Spinnability	Very good	Fair	Poor	Fair	Poor	Poor
Resistance to acids & alkalies	Poor	Good	Very good	Good	Good	Fair
Magnetite content	0-5.2	0	0	3.0-5.9	0	—
Mineral impurities present	Iron, chrome, nickel, lime	Iron	Iron	Iron	Lime	Lime, iron
Flexibility	High	Good	Poor	Good	Poor	Poor
Resistance to heat	Good. Brittle at high temp.	Good. Brittle at high temp.	Very good	Poor, fuses	Fair to good	—
Ionizable salts, micro-mhos (Relative elec. conductance)	1.82	1.34	0.58	0.84	—	—
Colour	Green, grey to white	Yellowish-brown	Yellowish-brown, Sometimes almost white	Blue	White	Greenish

PROPERTIES OF ASBESTOS FIBRES

	ACTINOLITE	ANOSITE (FERRO ANTHOPHYLLITE)	ANTHOPHYLLITE	CHRYSOTILE	CROCIDOLITE	TREMOLITE
STRUCTURE	RETICULATED LONG PRISMATIC CRYSTALS AND FIBRES	LAMELLAR, COARSE TO FINE FIBROUS AND ASBESTIFORM	LAMELLAR, FIBROUS ASBESTIFORM	IN VEINS OF SERPENTINE, ETC.	FIBROUS IN IRON-STONES	LONG, PRISMATIC AND FIBROUS AGGREGATES
MINERAL ASSOCIATION	IN LIMESTOME AND IN CRYSTALLINE SCHISTS	IN CRYSTALLINE SCHISTS ETC.	IN CRYSTALLINE SCHISTS AND GNEISSES	IN ALTERED PERIDOTITE ADJACENT TO SERPENTINE & LIMESTONE NEAR CONTACT WITH BASIC IGNEOUS ROCKS	IRON RICH SILICIOUS ARGILLITE IN QUARTZOSE SCHISTS	IN Mg LIMESTONES AS ALTERATION PROD. OF HIGHLY MAGNESIAN ROCKS, METAMORPHIC AND IGNEOUS ROCKS.
ORIGIN	RESULTS OF CONTACT METAMORPHISM	METAMORPHIC	METAMORPHIC, USUALLY FROM OLIVINE	ALTERATION & METAMORPHISM OF BASIC IGNEOUS ROCKS RICH IN MAGNESIAN SILICATES	REGIONAL METAMORPHISM	METAMORPHIC
VEINING	SLIP OR MASS FIBRE	CROSS FIBRE	SLIP, MASS FIBRE UNORIENTED AND INTERLACING	CROSS AND SLIP FIBRES	CROSS FIBRE	SLIP OR MASS FIRRE
ESSENTIAL COMPOSITION	Ca, Mg, Fe, SILICATE WATER UP TO 5%	SILICATE OF Fe AND Mg HIGHER IRON THAN ANTHOPHYLLITE	Mg SILICATE WITH IRON	HYDROUS SILICATES OF MAGNESIA	SILICATE OF Na AND Fe WITH SOME WATER	Ca & Mg SILICATE WITH SOME WATER
THEORETICAL FORMULA	$Ca(Mg.Fe)_3(SiO_3)_4 \times H_2O$	$(Fe.Mg)SiO_3$ 1-5% H_2O	$(Mg.Fe)_7Si_8O_{22}(OH)_2$	$3MgO.\ 2SiO_2 2H_2O$	$Na\ Fe\ (SiO_3)_2 FeSiO_3 \times H_2O$	$Ca_2Mg_5Si_8O_{22}(OH)_2$
CRYSTAL STRUCTURE	LONG & THIN COLUMNAR TO FIBROUS	PRISMATIC, LAMELLAR TO FIBROUS	PRISMATIC, LAMELLAR TO FIBROUS	FIBROUS AND ASBESTIFORM	FIBROUS	LONG & THIN COLUMNAR TO FIBROUS
CRYSTAL SYSTEM	MONOCLINIC	* ORTHORHOMBIC	ORTHORHOMBIC	MONOCLINIC (PSEUDO-ORTHORHOMBIC?)	MONOCLINIC	MONOCLINIC
COLOR	GREENISH	ASH GRAY, GREENISH, OR BROWN	GRAYISH WHITE, BROWN-GRAY OR GREEN	WHITE, GRAY, GREEN, YELLOWISH	LAVENDER, BLUE, GREENISH	GRAY-WHITE, GREENISH, YELLOWISH, BLUISH
LUSTRE	SILKY	VITREOUS, SOMEWHAT PEARLY	VITREOUS TO PEARLY	SILKY	SILKY TO DULL	SILKY
HARDNESS	6±	5.5-6.0	5.5-6.0	2.5-4.0	4	5.5
SPECIFIC GRAVITY	3.0-3.2	3.1-3.25	2.85-3.1	2.4-2.6	3.2-3.3	2.9-3.2
CLEAVAGE	110 PERFECT	110 PERFECT	110 PERFECT	010 PERFECT	110 PERFECT	110 PERFECT
OPTICAL PROPERTIES	BIAXIAL NEGATIVE EXTINCTION INCLINED	BIAXIAL & POSITIVE EXTINCTION PARALLEL	BIAXIAL POSITIVE EXTINCTION PARALLEL	BIAXIAL POSITIVE EXTINCTION PARALLEL	BIAXIAL ± EXTINCTION INCLINED	BIAXIAL NEGATIVE EXTINCTION INCLINED
REFRACTIVE INDEX	1.63± WEAKLY PLEOCHROIC	1.64±	1.61±	1.50 - 1.55	1.7 PLEOCHROIC	1.61±
FUSIBILITY	FUSIBLE AT 4	FUSIBLE AT 6, LOSES WATER AT MODERATE TEMPERATURES	INFUSIBLE OR DIFFICULTLY FUSIBLE	FUSIBLE AT 6	FUSIBLE AT 3	FUSIBLE AT 4
FLEXIBILITY	BRITTLE AND NONFLEXIBLE	GOOD, LESS THAN CRYSOTILE	VERY BRITTLE, NONFLEXIBLE	VERY FLEXISLE	FAIR TO GOOD	GENERALLY BRITTLE, SOMETIMES FLEXIBLE
LENGTH	SHORT TO LONG	2" TO 11" VARIES	SHORT	SHORT TO LONG	SHORT TO LONG	SHORT TO LONG
TEXTURE	HARSH	COARSE BUT SOMEWHAT PLIABLE	HARSH	SOFT TO HARSH, ALSO SILKY	SOFT TO HARSH	GENERALLY HARSH, SOMETIMES SOFT
TENSILE STRENGTH	VERY WEAK	FAIR, LESS THAN CHRYSOTILE	VERY WEAK	VERY GOOD	VERY GOOD, HIGHEST OF ALL VARIETIES	WEAK
ACID RESISTANCE	RELATIVELY INSOLUBLE IN HCl	FAIRLY RESISTANT TO ACIDS	FAIRLY RESISTANT TO ACIDS	SOLUBLE UP TO APPROXIMATELY 57%	FAIRLY RESISTANT TO ACIDS	FAIRLY RESISTANT TO ACIDS
SPINNABILITY	POOR	FAIR	POOR	BEST	FAIR	GENERALLY POOR. SOME ARE SPINNABLE

*Recent studies claim that the crystal structure is monoclinic.

For the caustic solubility tests, solid pellets of sodium hydroxide were dissolved in distilled water to obtain a 25 per cent solution, by weight.

Each fibre sample, consisting of 10 grams, was accurately weighed and placed in a flask containing 300 c.c. of the 25 per cent acid or caustic solution.

Two sets of tests were conducted, one at room temperature (26°C.) for indefinite periods, the other at boiling temperature in a reflux condenser for two hours. At the end of each test, the fibres were removed from the solutions, washed free from acids or caustic, dried, and weighed.

Table III shows the solubilities of these particular asbestos fibres in the four acids used and in caustic soda.

The action of boiling acids on asbestos fibres is severe, with chrysotile the most soluble. Acetic acid was not so effective as the mineral acids in dissolving chrysotile, and caustic had even less action on this mineral.

After chrysotile fibres had lost 55 per cent of their weight, examination showed the fibre structure to be almost all silica, brittle, and very fragile.

The high solubility values for actinolite are, it is believed, due to the presence of soluble minerals as impurities in the commercial product used by industry.

Anthophyllite seemed to resist acid action better than any other variety, with crocidolite second best, tremolite third, and amosite fourth.

All these solubilities would vary depending upon the source of the fibre and whether the samples represented pieces of 'crudes', or milled fibres as purchased on the market.

The action of acids and caustic at room temperature is slower than at boiling temperatures, but if the fibres are kept immersed in the solvent for a sufficient length of time, the solubilities finally reach the values obtained at boiling temperatures.

The tests at room temperature were conducted for periods of 24 hours, 192 hours, 360 hours, and 528 hours. After each time period, the fibres were removed, washed, and weighed, and the solubility calculated. The fibres were then replaced in fresh solutions of acid or caustic to begin the next cycle.

For convenience, only the solubility data for 528 hours are given in Table III since at this point most of the fibres apparently reached their maximum solubility, and this was approximately equal to the solubility after a two-hour treatment in boiling acids or caustic.

Such information is invaluable to a manufacturer desiring to produce an asbestos product which will be exposed to conditions similar to those in the tests. The most resistant fibre, if available in commercial quantities, naturally will be selected for the product.

TABLE III.— SOLUBILITY OF ASBESTOS

Per Cent Loss in Weight, Re-fluxing Two Hours
25% Acid or Caustic

	HCl	CH_3COOH	H_3PO_4	H_2SO_4	NaOH
Actinolite	20 31	12 28	20 19	20 38	9 25
Amosite	12 84	2 63	11 67	11 35	6 97
Anthophyllite	2 66	0 60	3 16	2 73	1 22
Chrysotile	55 69	23 42	55 18	55 75	0 99
Crocidolite	4 38	0 91	4 37	3 69	1 35
Tremolite	4 77	1 99	4 99	4 58	1 80

Per Cent Loss in Weight, Room Temperature 26°C. for 528 Hours
25% Acid or Caustic

	HCl	CH_3COOH	H_3PO_4	H_2SO_4	NaOH
Actinolite	22 55	12 14	20 10	20 60	9 43
Amosite	12 00	3 08	11 83	11 71	6 82
Anthophylite	2 13	1 04	3 29	2 90	1 77
Chrysotile	56 00	24 04	56 45	56 00	1 03
Crocidolite	3 14	1 02	3 91	3 48	1 20
Tremolite	4 22	1 41	4 89	4 74	1 65

EFFECT OF HEAT ON ASBESTOS

Since asbestos fibres frequently are exposed to elevated temperatures, it is necessary to determine which fibre most satisfactorily meets the demands.

With this in mind, the same fibres as used in the solubility tests were subjected to two hours' exposure at temperatures varying from 400°F. to 1,800°F., and the weight loss measured. The samples, after drying to eliminate surface moisture, were weighed, placed in a muffle

TABLE IV.— EFFECT OF TEMPERATURE ON LOSS IN WEIGHT OF ASBESTOS FIBRES

TEMP. °F.	TIME	LOSS IN WEIGHT				
		AMOSITE %	ANTHOPHYLLITE %	CHRYSOTILE %	CROCIDOLITE %	TREMOLITE %
400	2 hr.	0 23	0 05	0 30	0 08	0 04
600	"	0 57	0 24	0 85	0 25	0 08
700	"	0 80	0 30	1 78	0 49	0 13
800	"	0 98	0 38	2 17	0 73	0 22
900	"	1 07	0 41	2 83	0 83	0 26
1,000	"	1 16	0 44	3 99	0 86	0 29
1,100	"	1 36	0 52	10 38	1 00	0 37
1,200	"	1 39	0 54	12 75	1 04	0 37
1,400	"	1 43	0 54	13 43	1 03	0 47
1,500	"	——	0 64	——	——	0 56
1,600	"	1 52	1 12	13 62	0 93*	0 67
1,700	"	—	1 73	—	—	1 40
1,800	"	1 53	2 39	13 77	0 77*	2 18

*Iron changing in weight due to oxidation.

where temperature was maintained automatically, removed after a two-hour exposure, cooled to room temperature in a desiccator, and reweighed. The percentages of loss in weight are presented in Table IV.

Generally speaking, the amphibole fibres such as anthophyllite and tremolite resisted the heat fairly well at temperatures below 700°F. The chrysotile fibre, on the other hand, began to show a suddenly increased weight loss at 700°F., and a rapid increase above 1,000°F.

At higher temperatures, all fibres began to change in physical characteristics, but the amphiboles did not disintegrate so rapidly as the chrysotile fibres. The crocidolite fibre at 1,600°F. and higher showed a definite oxidation of iron and became brittle.

Chemical analysis of chrysotile fibres showed that the ignition loss values varied with the mineral impurity present. Therefore, it was decided to determine the nature of these impurities and their effect on ignition loss values.

A series of chrysotile asbestos fibres from Arizona, Australia, Rhodesia, Russia, and Canada were selected. These fibres were individually tested by placing a sample in an ultimate analysis train, with heating units electrically controlled.

The air taken into the combustion chamber was dried by passing it through sulphuric acid and absorbing the water and carbon dioxide with magnesium perchlorate, $Mg(ClO_4)_2$, and ascarite.

The temperature of the combustion unit was accurately determined by a chromelalumel thermocouple connected on one end to a potentiometer, and on the other to the side of the asbestos sample in the combustion tube.

Any gases, such as water and carbon dioxide, driven off the asbestos sample were weighed after being recovered in a second absorbing train containing $Mg(ClO_4)_2$ and ascarite in two different *U* tubes.

Prior to the test, the combustion train was purged for half an hour at 220°F. with dry air. Then the temperature was raised by 1,000°F. and the absorbed gases weighed. Later, the test was repeated by raising the temperature to 1,800°F. and weighing the absorbed gases.

The data shown in Table V give the percentages of water and carbon dioxide driven off each fibre at the two temperatures.

The Arizona fibre had a high ignition loss at 1,800°F. This loss consisted of 12.89 per cent water and 1.91 per cent carbon dioxide. At 1,000°F., 0.54 per cent carbon dioxide was expelled from the sample. Calculated as $MgCO_3$, this indicates the presence of 1.03 per cent $MgCO_3$. As the temperature was raised to 1,800°F., additional quantities of carbon dioxide were driven off, which, assumed as having been combined with CaO, would represent 3.11 per cent $CaCO_3$, indicating that the Arizona fibre tested contained a high percentage of calcium carbonate.

These calculations of CO_2 as representing $MgCO_3$ and $CaCO_3$, respectively, are based upon the dissociation temperatures of these compounds. Magnesium carbonate dissociates at temperatures below 1,000°F., and calcium carbonate at a temperature of approximately 1,630°F.; a temperature of 1,800°F. for one hour, therefore, should be sufficient to drive off all the CO_2.

The Australian fibre contained 12.48 per cent H_2O and 0.96 per cent CO_2; loss in weight on ignition was 13.33 per cent. Recalculation of the carbon dioxide as carbonates indicated that this fibre contained 1.26 per cent $MgCO_3$ and 0.68 per cent $CaCO_3$ as impurities.

The Canadian fibre identified as *"A"* shows a water content of 14.28 per cent, which is higher than the theoretical amount of water in the asbestos molecule. X-ray diffraction patterns of this fibre show the presence of brucite, $Mg(OH)_2$, which would break down and produce water during the heating period, accounting for the high water content of the fibre. The magnesium carbonate is calculated at 1.62 per cent and calcium carbonate at 0.27 per cent.

The Rhodesian fibre contained a much higher percentage of magnesium carbonate than any of the other fibres tested — 4.85 per cent. The calculated amount of calcium carbonate is 0.79 per cent.

The Canadian fibre identified as *"B"* resembles the *"A"* sample in having a water content higher than that of pure serpentine, and here again the X-ray diffraction pattern showed the presence of admixed brucite. The magnesium carbonate content was calculated to be 0.86 per cent, and calcium carbonate, 0.07 per cent.

The Russian fibre is a harsh chrysotile having a low water content (11.74 per cent at 1,800°F.). The presence of 1.47 per cent mag-

TABLE V.— COMBUSTION ANALYSIS OF CHRYSOTILE ASBESTOS

SOURCE OF FIBRE	TEMPERATURE °F.	PER CENT H_2O	PER CENT CO_2	TOTAL PER CENT H_2O+CO_2	PER CENT IGNITION LOSS OF FIBRE	CARBON DIOXIDE CALCULATED IN TERMS OF PERCENTAGE OF	
						$MgCO_3$	$CaCO_3$
Arizona	1,000	3.37	0.54	3.91	3.87	1.03	
"	1,800	12.89	1.91	14.80	14.80	1.03	3 11
Australian	1,000	1.50	0 66	2.16	2.06	1.26	
"	1,800	12.48	0.96	13.44	13.33	1 26	0.68
Canadian (A)	1,000	5.47	0.85	6.32	6.23	1.62	
"	1,800	14.28	0.97	15.25	15.17	1.62	0.27
Rhodesian	1,000	1.82	2.54	4.36	4.28	4.85	
"	1,800	12.00	2.89	14.89	14.84	4.85	0.79
Canadian (B)	1,000	3.75	0.45	4.20	4.14	0.86	
"	1,800	13.31	0.48	13.79	13.75	0.86	0.07
Russian	1,000	1.98	0.77	2.75	2.64	1.47	
"	1,800	11.74	1 06	12.80	12.72	1.47	0.66
Canadian (C)	1,000	2.25	0.47	2 72	2.66	0 90	
"	1,800	11 93	0.51	12 44	12 40	0.90	0.09

nesium carbonate and 0.66 per cent calcium carbonate was indicated.

Canadian fibre identified as *"C"* is a semi-harsh fibre with a low water content (11.93 per cent). The total amount of CO_2 driven off is small and is calculated as representing 0.90 per cent $MgCO_3$ and 0.09 per cent $CaCO_3$.

From these data it can be seen how readily ordinary ignition-loss figures can be misunderstood if the presence of mineral impurity is not taken into account. For example, most ignition-loss tests on chrysotile asbestos are made to determine molecular water content. If the fibre contains impurities such as brucite, magnesium carbonate, or calcium carbonate, an error is introduced into the calculations and the fibre is shown to have an ignition loss greater than the theoretical quantity of molecular water. This could be a serious error in determining the asbestos content of an asbestos textile, from which the organic fibre is burned purposely and a correction factor is applied for the molecular water content of the asbestos.

Effect of Heat on Tensile Strength

A piece of Canadian crude was set aside and a number of small fibre bundles, approximating 20 to 30 microns in cross-section, were selected and heat-treated at different temperatures in an automatic controlled muffle.

The original fibre bundles had a tensile strength of 131,000 lb./sq. in.

Four sets of fibre bundles were heated for 3-minute periods at temperatures of 600°F., 800°F., 1,000°F., and 1,200°F. The effects on the tensile strengths of the fibres are shown in Table VI.

At temperatures higher than 1,200°F., the fibre bundles were too brittle to handle and were considered rather weak.

The same fibre, when heated for one hour at the temperature stated, had a tensile strength as follows: 400°F., 129,000 lb./sq. in.; 600°F., 100,000 lb./sq. in.; 1,200°F., less than 2,000 lb./sq. in.

These data show that temperatures and times of exposure affect the tensile strength of chrysotile fibres, especially at 1,000°F. and higher, where the strength begins to decrease rapidly.

Tensile Strengths of Various Materials

Reference has been made on several occasions to the fact that asbestos fibres are strong. As an interesting comparison, data have been selected showing the approximate tensile strengths of such materials as iron, steel, cotton, rock wool, glass, and several varieties of asbestos.

Table VI.— Effect of Heat on Tensile Strength of Canadian Chrysotile Crude

	Tensile Strength (lb./sq. in.)	Per Cent of Original Tensile Strength
Original crude—No heat	131,000	—
Heated 3 min. at 600°F.	120,000	91.6
" " " " 800°F.	96,000	73.3
" " " " 1,000°F.	78,000	59.5
" " " " 1,200°F.	42,000	32.0

Table VII. — Comparison of Tensile Strengths of Various Materials

Type of Material	Tensile Strength (Lb./Sq. In.)
Ingot iron	45,000
Wrought iron	48,000
Carbon steel	155,000
Ni-Cr steel	243,000
Piano steel wire	300,000
Cotton fibre	73,000 to 89,000
Rock wool	60,000
Glass fibre	100,000 to 200,000
Chrysotile asbestos	80,000 to 100,000
Crocidolite asbestos	100,000 to 300,000
Amosite asbestos	16,000 to 90,000
Tremolite asbestos	1,000 to 8,000

The values given in Table VII are approximate and are cited solely for the purpose of illustrating the comparative strengths of some materials used in industry. It will be noted that chrysotile and crocidolite asbestos fibres are exceptionally strong and are comparable in that respect to glass and to some grades of steel.

The tensile strength values for the asbestos fibres are based upon breaking loads applied to fibre bundles measuring approximately 20 microns in cross-section.

Comparison of Surface Area of Fibres

It is a recognized fact that asbestos fibres appear as bundles consisting of many thousands of individual fibrils not visible to the eye. This would indicate that asbestos should have a great surface area when fully opened.

Table VIII.—Comparison of the Surface Area of Various Fibres

Type of Fibre	Surface Area by N_2 Adsorption (Sq. Cm./Gram)
Nylon	3,100
Acetate rayon	3,800
Cotton	7,200
Silk	7,600
Wool	9,600
Viscose rayon	9,800
Asbestos (Chrysotile)	130,000 to 220,000

The data in Table VIII show the surface areas of nylon, rayon, cotton, silk, wool, and chrysotile asbestos. The values for asbestos are so large in comparison with the other fibres tested that it seems hardly possible that they could have such great surface area.

The large surface area value of asbestos is a very important factor. It gives wide coverage and at the same time furnishes strength to asbestos products.

Comparsion of Fibre Diameters

The approximate diameter of fibres of various types has been measured and recalculated in terms of the number of fibres or fibrils required to equal one linear inch. The results are interesting and they show that a very large number of asbestos fibrils is required to make a linear inch. Table IX gives approximate data for fibres of hair, ramie, wool, cotton, rayon, nylon, glass, rock wool, and asbestos. The extremely small cross-section of asbestos fibres as compared with others will be noted.

TABLE IX.— COMPARISON OF APPROXIMATE FIBRE DIAMETERS

TYPE OF FIBRE	FIBRE DIAMETER IN INCHES	FIBRILS IN ONE LINEAR INCH
Human hair	0 00158	630
Ramie	0.000985	1,015
Wool	0.0008 to 0 0011	900 to 1,250
Cotton	0.0004	2,500
Rayons	0.0003	3,300
Nylon	0.0003	3,300
Glass	0.00026	3,840
Rock wool	0.000142 to 0.000284	3,520 to 7,040
Asbestos (Chrysotile)	0 000000706 to 0.00000118	850,000 to 1,400,000

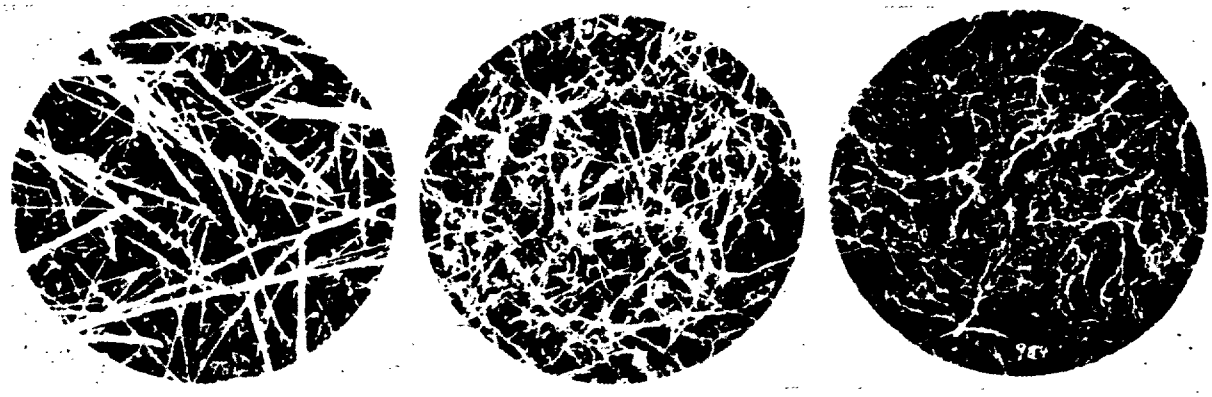
method of investigation is of considerable interest.

On a number of occasions we have had the opportunity of examining asbestos fibre under the electron microscope through the courtesy and co-operation of Dr. James Hillier*. The several varieties of fibres studied and discussed in this paper were submitted to the RCA Laboratory to be photographed at two different magnifications to show the structure of the fibrils.

Chrysotile

The soft Arizona chrysotile at a 4,000 magnification shows fibre bundles which appear wavy with frayed ends (see Figure 2)‡.

The same fibre at a magnification of 35,000 shows bundles in which



Harsh type — Semi-harsh type — Soft type

Figure 1.—Photomicrographs of chrysotile asbestos. x 100.

PHOTOMICROGRAPHS OF CHRYSOTILE

Three samples of chrysotile were selected, representing three different degrees of texture. Each of these three fibres, mounted on a cover glass, was placed under a microscope and photographed at 100 magnifications. They are shown in Figure 1.

The ***harsh*** chrysotile fibre at this magnification resembles the structure of splinters and has a needle-like structure. The fibres are springy, bulky, fast-filtering, and usually not so high in tensile strength as soft, silky fibres. This type of fibre will break quickly under flexing action.

The ***semi-harsh*** fibre appears partially as a harsh, and partially as a soft, fibre. The fibres have lost most of the needle-like structure and appear as thick, wavy bundles. It is difficult to show in a picture that they are different from soft fibres. Chemically, they are the same as the latter, but the measurements show quite different physical properties. Such physical tests as filtration, willowing, surface area, bulk, and strength will bring out the true properties of this fibre and show how it differs from the soft, silky chrysotile.

The *soft* fibres appear as thin threads which are very soft, not bulky, slow-filtering, and extremely strong. As noted above, they have the same chemical composition as the semi-harsh fibres, but quite different physical characters.

The soft, silky chrysotile fibres make up the bulk of asbestos used in industry. They are available in large quantity and usually are cheaper than the semi-harsh or harsh fibres.

ELECTRON MICROGRAPHS OF ASBESTOS

The electron microscope is a valuable tool for examining materials which are difficult to see by ordinary microscopic means. Since asbestos exists in thin cross-sections, this the fibres appear as hollow tubes (Figure 3). This feature was first reported by Dr. Hillier in April, 1949 (6), using a magnification of 94,000, and it has since been reported by Bates, Sand, and Mink (7), of Pennsylvania State College. Our measurement of the thin fibrils indicated a cross-section in the range of 214 and 284 A† units, while Dr. Hillier reported fibril diameters of 180 A units. This would account for the fact that soft chrysotile fibres have large surface areas and show a preference to open lengthwise if properly fiberized.

Amosite

The amosite from South Africa, at a magnification of 4.000, shows

*RCA Laboratories, Princeton, N.J.

‡In this and all succeeding Figures showing electron micrographs, the magnification has been reduced from that stated in the text. The caption below each Figure gives the magnification as thus reduced.

†Angstrom.

Figure 2.—Electro micrograph, chrysotile asbestos. x 1,733.

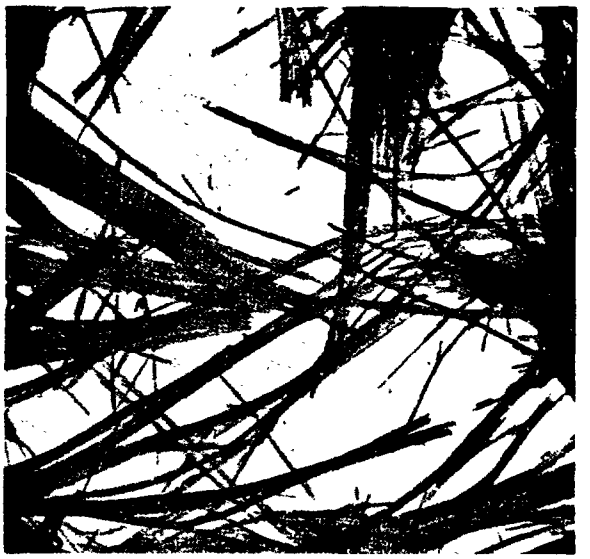


Figure 3.—Electron micrograph, chrysotile asbestos. x 15,200.

straight bundles criss-crossing the field (Figure 4).

The same fibre at 35,000 magnification shows rather thick bundles that still remain straight and indicate a plane of cleavage that is clean-cut and abrupt (Figure 5). Whenever a small fibril is split from a small bundle, its cross-section appears to be approximately 300 A units. However, only a few small bundles appear in this picture, while chrysotile fibre, on the other hand, apparently breaks down lengthwise easily and shows numerous small fibrils within the range of 300 A units and less.

The fact that amosite fibre tends to remain as large, thick bundles may well account for its freeness in filtration, small surface area, and bulky appearance.

Anthophyllite

At a 4,000 magnification, anthophyllite fibres appear as a mixture of thick and thin bundles which show clean, even breaks at the ends (Figure 6).

At a 35,000 magnification, some fibrils appear thin and flexible while others are stubby, thick bundles (Figure 7). The cross-section of the thin flexible fibrils is equal to, and possibly smaller than, that of chrysotile fibrils, placing them at approximately 200 A units. It is to be noted that no hollow-tube structure appears within these thin fibrils.

This particular sample of anthophyllite is soft, not strong, and breaks easily during processing.

The mineral impurities in the fibre are visible as plates in the electron micrographs.

This fibre is found in Georgia as a mass fibre, and considerable non-fibrous material is associated with the recovered fibre.

Crocidolite

The crocidilite used in this investigation was the typical blue fibre from South Africa.

Figure 4.—Electron micrograph, amosite asbestos. x 1,733.

Figure 5.—Electron micrograph, amosite asbestos. x 15,200.

Figure 6.—Electron micrograph, anthophyllite asbestos. x 1,733.

Figure 7.—Electron micrograph, anthophyllite asbestos. x 15,200.

At a 4,000 magnification, the fibre appears as straight, stiff, brittle bundles, and in most cases the ends show clean breaks (Figure 8).

At a 35,000 magnification, the bundles appear fairly thick, but there is evidence that slender fibrils of approximately 300 A units exist (Figure 9), though they are few and far apart. The brittle nature of the fibre probably prevents individual fibrils from splitting off lengthwise, and consequently all that is seen is the large bundles.

Bolivian Blue

Bolivian blue asbestos is a type of crocidolite fibre which differs somewhat from normal African crocidolite in chemical composition. It is a soft, silky fibre, not very strong and easily pulverized.

At a 4,000 magnification the fibre bundles are clean, tightly bound, and show evidence of brittleness (Figure 10).

At a 35,000 magnification, the bundles still appear clean and tightly held together (Figure 11). An examination of the few bundles in the field indicates that, if the bundles are properly opened, they will show fibrils of approximately 300 A units.

Tremolite

The tremolite under investigation is from California and is considered of good quality.

At a 4,000 magnification, the cross-section of the bundles varies from thick to thin (Figure 12). The bundles do not appear to be held tightly together and they show a tendency to fray out.

Examination of the bundles at 35,000 magnification shows evidence of individual fibrils existing at approximately 300 A units (Figure 13).

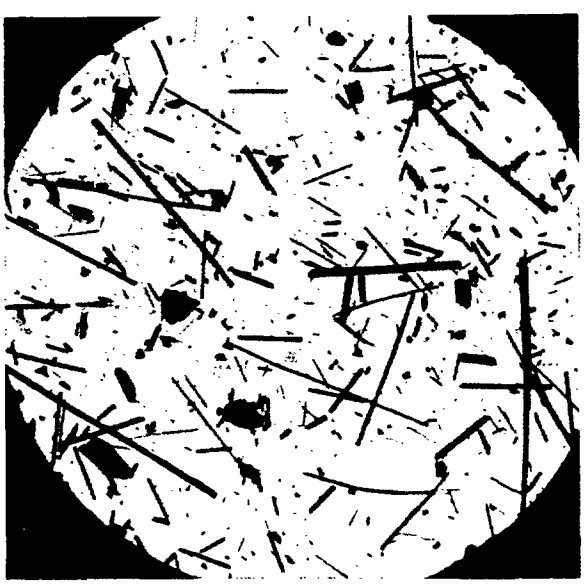


Figure 8.—Electron micrograph, crocidolite asbestos. x 1,733.

Figure 9.—Electron micrograph, crocidolite asbestos. x 15,200.

Figure 10.—Electron micrograph, Bolivian blue asbestos. x 1,733.

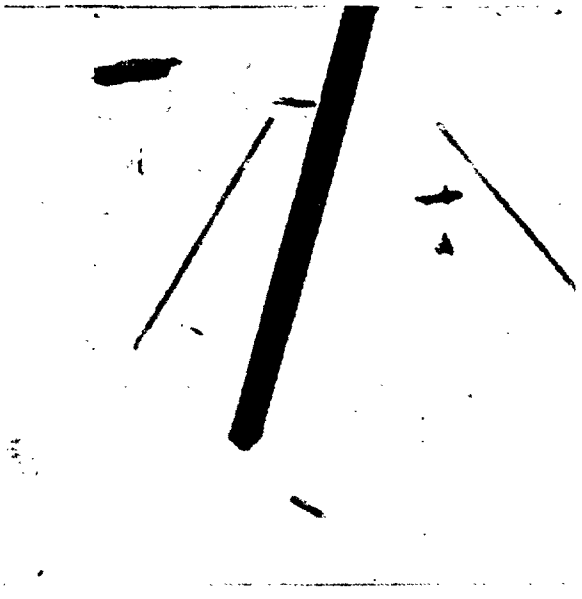


Figure 11.—Electron micrograph, Bolivian blue asbestos. x 15,200.

Actinolite

The sample of actinolite was obtained from Canada. Previous tests showed high solubility, indicating the presence of impurities.

The electron micrograph at 4,000 magnification verifies this fact as it shows only a few fibre bundles, with a high percentage of plate-like minerals present (Figure 14).

Sampling this grade of actinolite for electron microscope studies is a considerable problem and many examinations would be required to obtain a satisfactory field. However, it was recognized that this sample was a milled commercial product and the pictures do show the true nature of the material.

At a 35,000 magnification, only one large, thick bundle appears in the picture. There is a suggestion of breaks along the end, but there is no indication as to the size of the individual fibril (Figure 15).

CONCLUSION

The various properties of the six varieties of asbestos investigated are given in convenient table form to serve as a quick reference.

Solubility data of the six varieties of asbestos show that chrysotile asbestos is readily attacked by acids and that the amphibole fibres are fairly acid-resistant.

The effect of heat on the different varieties of asbestos varies. Chrysotile shows small ignition losses at temperatures below 700°F. and a rapid increase in loss at 1,000°F. and above. The amphiboles show small ignition losses since they contain only small percentages of water of crystallization.

Ignition losses also indicate the presence of water and carbon dioxide. Some chrysotile fibres show the presence of brucite, magnesium

Figures. 12.—Electron micrograph, tremolite asbestos. x 1,733.

Figure 13.—Elecrton micrograph, tremolite asbestos. x 15,200.

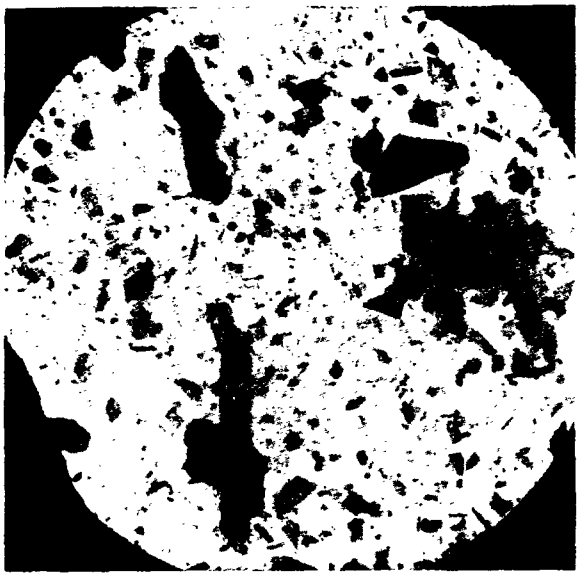


Figure 14.—Electron micrograph, actinolite asbestos. x 1,733.

Figure 15.—Electron micrograph, actinolite asbestos. x 15,200.

carbonate, and calcium carbonate; therefore, great care should be taken in interpreting ignition-loss data.

High temperatures and lengths of exposure decrease the tensile strength of chrysotile fibres. At temperatures above 1,000°F., the strength decreases rapidly.

Charts are presented to show that asbestos fibres have great tensile strength and large surface areas.

Photomicrographs at 100 magnification show that the soft, silky, chrysotile fibre is wavy, whereas the harsh fibre has a straight or needle-like structure.

The electron micrographs of the six varieties of asbestos at 4,000 and 35,000 magnifications show the fibre bundles, individual fibrils, and their approximate cross-sections, and may help to explain some of the physical properties of asbestos fibres used in commercial products.

Acknowledgments

The author wishes to thank Dr. James Hillier and the RCA Laboratory for their help in producing the electron micrographs of the six varieties of asbestos described in this paper.

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Asbestos Floats

*By M. S. BADOLLET**

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Introduction

ASBESTOS FLOATS may be defined briefly as blends of airborne particles of fibrous asbestos and dusts produced during the milling stages and collected by Cottrell precipitators, dust sheds, or baghouses.

The various grades of asbestos floats on the market contain fibrous asbestos particles ranging in length from microscopic to approximately ¼-inch. The fines or dusts present in the floats are from 40 microns to 2 microns or less in cross-section.

Airborne asbestos particles are of diverse length because they are collected at numerous places in the mill. There are: (1) dusts removed from dry rock storage bins, (2) dusts removed from rock and fiber screens, (3) particles from the tops of collectors, and (4) fines removed by suction from the processing equipment.

Sometimes the airborne particles are kept segregated, so that there is a partial separation by gravity. This is accomplished by a series of dust chambers enclosed in a long, rectangular building. The longest and heaviest particles fall nearest to the air flow entrance, the smallest at a point farthest away and nearest the exit. Sometimes the air from the dust chamber building is passed through a series of baghouses or electric precipitators to collect the extremely fine particles which normally escape to the atmosphere.

In other instances, the airborne particles by-pass the dust chambers and are passed through rows of bag collectors.

Regardless of the method of collecting the particles, the milling department must select proper fiber sizes for blending, producing uniform floats to meet the requirements of the trade.

Sometimes one grade of float can be used successfully in many commercial products; in other cases, great care must be taken to produce a float for use in a specific product.

The present total production of all grades of Canadian floats approximates 40,000 tons per year and it is possible that this quantity may be greatly increased by the proposed expansion programmes now going into effect in Canada.

Since floats are valued at $40 per ton at the Canadian mines, a tonnage of 40,000 has a potential sales value of $1,600,000. This division of the asbestos industry is a good business, and it is well worth the concentrated effort of research and development engineers to find new uses, and so expand the market, for all available floats.

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Physical Properties of Floats

According to the Quebec Screen classification, there are two general classes of floats, known as *7RF* and *7TF*.

Samples of various commercial floats were obtained on the market and a series of tests were devised to determine the differences in their physical properties. Some of these tests were similar to those made by many manufacturers who use floats in their products. The results of some of these tests are given in Table I. They do not, however, include the official Quebec Screen test. Manufacturers using floats usually set up their own specifications, based upon requirements for their particular products.

Loose Density

The loose density of floats can be measured by slowly sifting the powder into a can or container of definite dimensions so that the weight per cubic foot can be calculated.

Although in some products the loose density of the floats is not particularly important, in others it is critical, so each float must be considered as an individual case.

In the present investigation eleven *7RF* floats were tested and their loose densities were found to range

TABLE I

Identification	Loose Density lb./cu. ft.	Material +100 M %	Fines −200 M %	Grit +48 M %	Whiskers +48 M %	Grit −48 M +80 M %	Whiskers −48 M +80 M %	Oil Adsorption c.c./g. fiber
(1) 7RF....	19	3	96	0 04	1.90	0 02	0 64	0 66
(2) 7RF....	20	4	93	0 14	2.50	0 14	0 66	0 74
(3) 7RF....	21	4	93	0.24	2 26	0 12	1 18	0 75
(4) 7RF....	22	4	93	0 16	1.30	0.20	0 94	0 68
(5) 7RF....	22	3	95	0 12	0.80	0 10	0 46	0 65
(6) 7RF....	24	5	90	Tr	1.16	0.04	0.96	0 68
(7) 7RF....	24	5	89	0.06	1.28	0.10	1.12	0 71
(8) 7RF....	20	6	91	0 12	4.12	0.56	1.10	0.66
(9) 7RF....	25	7	84	0 24	0 70	0.46	1.30	0.65
(10) 7RF....	23	7	88	0.46	2.38	0.54	0.92	0.65
(11) 7RF....	14	1	96	0.04	0.50	0.02	0 84	1.05
(12) 7TF....	23	2	96	Tr	0.30	Tr	0.50	0.75
(13) 7TF....	23	2	95	0.06	0.60	0.06	0.70	0.65
(14) 7TF....	26	3	91	0.00	0.10	Tr	0 16	0 68

from 14 to 25 pounds per cu. ft. The heaviest is No. 9 and the lightest No. 11. Nos. 1 to 5, inclusive, and No. 8, all with loose densities between 19 and 22 pounds per cubic foot, may be considered as falling within the same range, as also may Nos. 6, 7, 9, and 10, which are slightly heavier (23 to 25). Float No. 11 is in a class by itself and is light in weight as well as bulky (loose density 14). If density were the only physical property that had to be considered, this record would enable the manufacturer to select the proper one for his purpose.

The three *TF* floats included in the Table differ from the *RF* floats in degree of particle fineness. Nos. 12 and 13 have identical loose density (25) while No. 14 is heavier (26).

Classification by Wet Washing

Fibre and Grit +100 *Mesh*

A classification of the particles can be obtained by a wet-washing method which determines the amounts of fibre and grit plus-100-mesh and of fines minus-200-mesh. This information is particularly useful if the floats are to be used in molding, extrusion, or spraying.

The *RF* float No. 11 contains only 1 per cent of material larger than 100 mesh. In the other *RF* floats, the content ranges from 3 to 7 per cent, indicating the presence of material that is sometimes referred to as 'whiskers'. In the plastics industry, particles plus 100 mesh may be helpful in producing impact strength in the product.

The three *TF* floats contain almost identical amounts of plus-100-mesh material. In two of them the percentage is lower than in the first ten *RF floats*.

Fines —200 *Mesh*

The fines minus-200-mesh in the *RF* floats range from 84 to 96 per cent, and in the *TF* floats from 91 to 96 per cent.

The material between plus 100 mesh (fiber and grit) and minus 200 mesh (fines) would be collected on the 200 mesh screen. Its amount can be obtained by adding the plus 100 mesh and minus 200 mesh values shown in the Table and subtracting the sum from 100.

This test, although useful, does not distinguish between, or give the relative amounts of, 'whiskers' (asbestos fibers) and particles of grit that might be present in the floats.

Grit +48 *Mesh*

In many cases, the grit particles in the floats are of very diverse size. Usually, they are small pieces of serpentine rock and magnetite, or small bundles of asbestos fiber. Complete classification, therefore, requires a further breakdown to determine the quantities of these objectionable particles present in the floats.

This test is made by water elutriation and by careful separation of the grit from 'whiskers' or fiber bundles.

The amount of grit plus-48-mesh in the eleven *RF* floats ranges from a 'trace' to 0.46 per cent. The percentage is lowest in samples Nos. 1, 6, and 11 and highest in No. 10. Although these quantities of grit seem small, they could cause considerable trouble in a manufacturing process by plugging extrusion apparatus or scoring the walls of expensive molds.

The three *TF* floats are almost free from grit plus-48-mesh.

'Whiskers' +48 *Mesh*

'Whiskers' are short asbestos fibers that may be valuable or objectionable, depending upon the use for which the product is required.

The quantity of whiskers in the eleven *RF* floats ranges from 0.50 per cent (in No. 11) to 4.12 per cent (in No. 8). In the *TF* floats, the range is from 0.10 per cent (No. 14) to 0.60 per cent (No. 13).

Grit —48 *Mesh* +80 *Mesh*

In some special products, the presence of grit smaller than 48 mesh, and even smaller than plus 80 mesh, is considered objectionable. Therefore, a further separation is made to determine the quantities of this grit that may be present in these floats.

As shown in Table I, the range for the eleven *RF* floats tested is from 0.02 per cent (Nos. 1 and 11) to 0.56 per cent (No. 8).

Two of the *TF* floats are free from this size of grit and the third (No. 13) contains only 0.06 per cent.

'Whiskers' —48 *Mesh* +80 *Mesh*

The presence of whiskers in the sizes of minus 48 mesh and plus 80 mesh is also objectionable because they affect the surface of certain products.

The eleven *RF* floats tested contain whiskers of this size ranging from 0.46 per cent (No. 5) to 1.30 per cent (No. 9). Corresponding figures for the *TF* floats are a low of 0.16 per cent (No. 14) and a high of 0.70 per cent (No. 13).

In the manufacture of plastics, the presence of whiskers results in non-uniform pourability of the molding powders. This necessitates a re-screening operation so that uniformly coated powders will properly fill the molds. In many cases, the whiskers and crudy fiber bundles are not thoroughly covered by the organic plastic material and this increases the water absorption properties of the plastic material, which may result in the formation of blisters.

Oil-Adsorptive Capacity

The capacity of a float to adsorb oil is important because it gives an indication of ability to hold an organic liquid when manufacturing a plastic or caulking compound.

This test, made by manufacturers, consists of titrating a given weight of float with oil until its adsorptive capacity is reached. In practice, the adsorptive capacity is considered to have been reached when oil can be released from a ball of the thoroughly mixed float and oil by applying a small amount of pressure against it. The results of this test are expressed in terms of cubic centimeters of oil per gram of float.

For the eleven *RF* floats tested, the oil adsorptive capacity ranges from 0.65 to 1.05 cubic centimeters per gram. The value for No. 11 (1.05 c.c./gm.) is much higher than that for any of the others, which all fall between 0.65 and 0.68 c.c./gm. except Nos. 2, 3, and 7 (0.71 to 0.75 c.c./gm.).

Two of the *TF* floats, Nos. 13 and 14, have closely similar adsorptive capacity, 0.65 and 0.68 c.c./gm., respectively. No. 12 gave a higher value (0.75 c.c./gm).

Miscellaneous Physical Tests

Numerous other tests, of importance to the manufacturer of certain asbestos products, are made on floats. Data for these are given in Table II and are summarized in the following paragraphs.

Surface Area

Study of the surface area of each float was made to obtain data on its covering power as a filler. In this test, the surface area is measured by the air permeability method by means of the Bowen apparatus, fol-

TABLE II

Identification	Surface Area	Density lb./cu. ft.		Compressibility* % Thickness at 200 Compress.		Springback, % Thickness at Max. Compress.		Suff. Cond. of Pressed Specimen	Ionizable Salts, Micromhos/cm/10 volts	Dry Bulk, Vol. of 100 g. cc.	Water-Soluble		Magnetic Rating
											Solids %	Chlorine as Cl %	
	cm²/gm.	1,000 p.s.i.	3,000 p.s.i.	2,000 p.s.i.	3,000 p.s.i.	2,000 p.s.i.	2,000 p.s.i.						
(1) 7RF	14,800	89.9	94.7	29	32	2.5	2.8	Sm'l whiskers & bundles	219	350	0.16	0.017	4.7
(2) 7RF	11,300	93.6	97.0	28	32	3.1	3.7	"	218	335	0.17	0.024	6.3
(3) 7RF	13,000	93.5	99.2	28	32	3.2	3.3	"	222	340	0.18	0.029	6.1
(4) 7RF	11,800	95.5	99.1	29	32	3.3	3.4	Grit & few whis. & bund.	206	305	0.16	0.025	6.0
(5) 7RF	13,000	95.0	98.2	28	31	2.6	3.4	Sm'l amt. of grit & whis.	212	300	0.17	0.022	5.7
(6) 7RF	14,000	100.0	105.4	28	32	3.8	4.0	Coed, smooth	379	320	0.36	0.15	4.1
(7) 7RF	13,900	100.8	105.2	28	32	3.4	4.0	"	293	295	0.38	0.16	5.1
(8) 7RF	12,500	102.7	107.7	28	32	3.6	4.2	Grit mostly	421	260	0.26	0.15	5.1
(9) 7RF	7,500	99.6	105.8	27	31	3.4	3.9	"	190	255	0.12	0.0049	5.9
(10) 7RF	8,600	101.2	105.8	28	31	3.0	3.4	"	243	285	0.14	0.0038	9.6
(11) 7RF	20,800	93.6	99.2	35	39	5.8	6.7	Good surface	260	475	0.15	0.0015	3.4
(12) 7TF	15,400	95.0	100.0	27	31	3.3	3.7	Good surface	221	295	0.15	0.022	5.0
(13) 7TF	11,300	94.8	99.4	27	30	3.5	3.3	Large grit	176	260	0.14	0.034	4.0
(14) 7TF	15,600	96.0	99.5	27	29	3.3	3.3	Good surface	396	275	0.36	.16	3.9

*Measurements start at 200 p.s.i. as zero point.

lowing the Lea and Nurse technique (1).

The eleven *RF* floats tested show a wide range in surface area, from 7,500 cm²/gm. (No. 9) to 20,800 cm²/gm. (No. 11). In other words, float No. 9 has the lowest, and float No. 11 has the greatest, covering power as a filler. In plastics, the surface area of the float governs the amount of filler that can be used successfully prior to pressing in a given mold.

Two of the three *TF* floats (Nos. 12 and 14) have the same surface area, approximately 15,500 cm²/gm. For No. 13 the value is 11,300 cm²/gm. The high value of 15,500 for Nos. 12 and 14 indicates the presence in these floats of a large percentage of fines.

Density at 2,000 and 3,000 p.s.i.

Ten-gram samples of each float were subjected to pressures of (1) 2,000 p.s.i. and (2) 3,000 p.s.i. and their densities calculated in pounds per cubic foot. These pressures were selected because they correspond to the range of pressures used in the plastic-molding industry, and the data obtained are helpful in selecting the proper asbestos filler for molding powders.

At 2,000 p.s.i., the densities range from 89.9 lb./cu. ft. (No. 1) to 102.7 lb./cu. ft. (No. 8). Several of the samples have substantially identical density, but for the group as a whole the differences in density are such as would influence the selection of the filler to be used for certain products.

At 3,000 p.s.i., the densities range from 94.7 lb./cu. ft. (No. 1) to 107.7 lb./cu. ft. (No. 8). The increase in density for the additional 1,000 p.s.i. pressure ranges from 3.2 to 6.2 lb./cu. ft.

Compressibility of Floats at 2,000 and 3,000 p.s.i.

In this test, a 10-gram sample of the float is compressed at 200 p.s.i. and its thickness measured. It is then compressed at (1) 2,000 p.s.i. and (2) 3,000 p.s.i. and its thickness again measured. The reduction in thickness, expressed as a percentage, gives a measure of the compressibility for each float. Thirteen of the fourteen floats tested show about the same percentage of compressibility (27 to 29). For No. 11, the value (35) is appreciably higher.

This is an important property and must be taken into consideration when pressing a molding powder to a definite size after the molding cavity has been properly filled. Uniform compressibility is important as a bulky fiber will also exhibit poor dimensions after pressing.

Springback After Release of Pressures

The amount of 'springback' of a molding powder is another important property considered by plastics manufacturers. If the springback is too great, it will be difficult to obtain the proper dimensions for a molded product. Too much emphasis cannot be placed upon this property.

All fourteen floats were tested for springback at pressures of both 2,000 and 3,000 p.s.i. As will be noted from the data in Table II, the springback factor is uniformly low for all of them except No. 11 which, also, is the sample with the highest percentage of compressibility.

To use float No. 11, with a springback of 5.8 and 6.7 per cent, allowance must be made for its compressibility or the plastics manufacturer cannot control the dimensions of his product.

Surface Condition of Pressed Blocks

The surface characteristics of pressed blocks of the floats are noted in Table II. The surfaces usually show long 'whiskers', short stubby fiber bundles, and grit, which generally are considered poor properties from the viewpoints of appearance and water adsorption.

A smooth surface is desirable, provided the molded product meets all other specifications of the manufacturer. Five of the floats give good smooth surfaces and probably will be satisfactory for use in molding powders, provided other properties are acceptable.

Ionization Salts

For the manufacture of some special types of molding powders, it is essential that the asbestos fibre have low electrical conductivity. In this case, some plastics companies make a test on water-soluble material leached from floats. Apparently, all floats contain a certain quantity of water-soluble material. Its conductivity is determined, and the result of the test is expressed in terms of micromhos per centimeter per 10 volts. For the eleven *RF* floats tested, this factor ranges from 190 (No. 9) to 421 (No. 8). For the *TF* floats, Nos. 12, 13, and 14, the values are, respectively, 221, 176, and 396.

It is not known at present which values are objectionable, but it appears that a conductance of 300 micromhos or higher per centimeter

(1) For references, see end of paper.

per 10 volts may cause trouble, with the molded plastic product having a low dielectric strength.

Dry Bulk

The bulking values of floats are sometimes considered important factors in plastics as well as in dry-wall joint fillers.

By some manufacturers, the bulking value is expressed as the volume, in cubic centimeters, of a given weight, say 100 grams, of the float. Some fillers should have high dry-bulk value while others should not; this depends entirely upon the intended application.

The eleven *RF* floats have dry-bulk values ranging from a low of 255 (No. 9) to a high of 475 (No. 11). For the three *TF* floats, Nos. 12, 13, and 14, the values are, respectively, 295, 290, and 275—differences that may lie within experimental error.

Water-Soluble Material

All floats were analyzed for water-soluble materials by allowing a sample of each to stand in distilled water for 63 hours and filtering off the clear water. Aliquots of the filtrates were dried and weighed to determine total solids, and these were then analyzed for chlorides.

The amount of water-soluble material in the eleven *RF* floats ranges from 0.12 per cent (No. 9) to 0.38 per cent (No. 7). In the *TF* floats the range is about the same, with a maximum of 0.36 per cent for No. 14.

No good correlation exists between the ionizable salt values and the quantity of water-soluble material.

The percentage of chlorine in the residues also was determined. For the eleven *RF* floats it ranges from 0.0015 to 0.16 per cent, and for the three *TF* floats from 0.0034 to 0.16 per cent.

Magnetic Rating

Since many floats are used as fillers in products employed by the electrical industry, it may be important to learn something about their magnetic ratings. The test, an adaptation of the Mapes (2) test, measures the amount of magnetite present.

Ratings of the eleven RF floats range from 3.4 (No. 11) to 9.6 (No. 10). The other nine *RF* floats have ratings between 4.1 to 5.9 with an average of 5.4. The three *TF* floats range from 3.9 to 5.0, averaging 4.3.

The maximum magnetic rating value for a successful float is not known precisely, but it is believed that the manufacturer would prefer the lowest rating available. It is known that the smallest trace of magnetite can be easily detected in a magnetic field and it may result in the rejection of the plastic material.

Use of Asbestos Floats

Asbestos floats have a definite use in such industrial products as automobile body coatings, adhesives, caulking compounds, dry-wall joint filler, lubricating greases, asphalt and cold-water paints, plastics, molding powders, welding rods, insecticides, radiator scaling compound, acoustical plasters, cements, and many others.

Asbestos floats offer to manufacturers the advantages of being a low-cost inorganic filler, which will improve impact strength and provide good workability, good binding qualities, heat resistance, fair acid and alkali resistance, large surface area, and availability in commercial quantities.

A recommendation for the best grade of asbestos floats for a particular product should be made carefully, since each product has its own requirements and specifications.

Automobile Body Undercoating

A float for automobile body coating to be applied by spray gun may require the absence of 'whiskers' and large particles of grit. If the coating is to be applied by brush, however, the presence of whiskers and grit would not be objectionable. Therefore, the selection of a float for this job depends upon the method of application and such other factors as bulk and fluidity when incorporated in a binder.

Adhesives

The use of floats in adhesives depends upon the type and application of the adhesive product. The proper recommendation can be made only after knowing the desired properties of the adhesive and the method of application. The amount of floats in adhesives (3) varies between 9 and 40 per cent of the mix, depending upon the product.

Caulking Compounds

Caulking compounds may be sensitive to changes in grade of floats. For example, a gun grade of caulking compound may require a float relatively free from whiskers and grit, while, for a caulking compound applied by knife, a float containing whiskers and some grit could be used. In general, the use of floats in caulking compounds (3) may range from 4 to 15 per cent by weight of compound.

Wall Joints

The manufacturer of dry-wall joint filler is very careful in his selection of floats. His specifications for asbestos fiber are rigid and he insists upon good bulking value, freedom from grit, good coverage, and no whiskers. Very few natural floats on the market today fulfill these requirements and, therefore, a special float must be made for this job. The amount of floats (3) required for this use may vary between 5 and 20 per cent of the dry mix ready for the market.

Lubricating Greases

Various types of floats have been used in some grades of lubricating greases, but in most greases grit is objectionable. Whiskers may be permitted unless the customer's specification indicates otherwise. The amount of float used in greases varies between 10 and 25 per cent of the product (3).

Paints

Paints, with either asphalt or cold-water base, may require a grit-free and whisker-free float if smooth surface is demanded. Otherwise, some grit and whiskers are allowable. Paints may contain from 5 to 11 per cent of floats.

Plastics and Molding Powders

Floats, with specifications varying from customer to customer, are used extensively for plastics and molding powders.

The general opinion of the plastics manufacturer is that fibrous float structure increases impact strength, allows a wide range for adjusting quantity of floats as filler, furnishes good binder retention and workability, imparts hardness and toughness to the moldings, increases heat and fire resistance, reduces natural shrinkage of resins and binders, reduces warpage and deformation, makes cold-molding possible by controlling the flow under pressure in the molds, allows blending of mineral and organic fillers, imparts good finish, improves the

electrical properties, and reduces the cost of moldings.

Molded plastics are carefully checked for specific gravity, flexural strength, tensile strength, compressive strength, impact strength, water absorption, dielectric strength, power factor, shrinkage, heat resistance, visual observations of molding qualities, and ejection from the mold. It is important, therefore, that the plastics manufacturer select asbestos floats with care so that molding powder and molded product have the desired properties. The asbestos floats used as a filler in these materials generally form from 60 to 80 per cent of the mix (3).

Welding Rods

The welding rod manufacturer desires a float which will produce good coating as a filler, and which lacks whiskers and grit that might clog extrusion equipment. Floats also should be free from any sulphide mineral, or at least should contain less than the 0.01 per cent of sulphur that would produce obnoxious gas during welding. The amount of floats used for coating rods varies between 8 and 10 per cent*.

Insecticides

Floats sometimes are used as filler for insecticides to be dusted or sprayed onto flowers, weeds, and other plants. In this case, the float should be a fine dust so that it will impart large coverage. Floats for this purpose must compete with such other powders as talc and diatomaceous earth. The amount of float in a ready-to-use insecticide is approximately 4 to 5 per cent.

*British Patent 535,355; Canadian Patent 365,792.

Radiator Sealing Compound

Various combinations of materials, including fine asbestos, are used in sealing compounds for automobile radiators. The asbestos forms from 1 to about 6 per cent by weight of the solids content of the mixture†.

Acoustical Plasters

Based upon the weight of the dry compound, some acoustical plasters contain from 6 to 15 per cent of asbestos floats. In this application, the floats function as a filler to provide bulk and fire resistance. Whiskers and grit are not objectionable unless a spray gun is used.

Cements

Cements and adhesives are considered similar by some authorities, and the amount of floats needed for adhesives would apply also to cements. Depending upon the type of cement and the application, the asbestos floats content ranges from 9 to 40 per cent (3). In many cases, whiskers and grit are permitted.

Conclusions

(1) Fourteen asbestos floats produced in Canada have been examined in tests similar to those made by customers in their own laboratories.

(2) Many of these floats have almost identical characteristics; however, one float, No. 11, differs considerably from all the others and has many unique properties.

(3) The type of float required for a particular product depends upon the use for which the product is manufactured, and each manufacturer has his own specifications and methods for testing the float.

(4) Float characteristics such as grit, whiskers, compressibility, springback, and magnetite rating are usually carefully checked by the plastics manufacturer, since these qualities affect his products.

(5) Bulk, surface area, and density values of floats are considered important factors in such products as wall joint fillers, caulking compounds, some pressed products, and acoustical plasters.

(6) The amount of ionizable salts, water-soluble solids, and chlorides in the floats is a matter of importance and frequently is checked by plastics manufacturers interested in improving the electrical properties of their products.

†U. S. Patents 2,391,737, 2,315,321.

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Asbestos Fibers: Production and Usage

*By M. S. BADOLLET**

(*Annual General Meeting, Edmonton, April,* 1953)
(*Transactions, Volume LVI,* 1953, pp. 237-239)

DURING the past five years, production of asbestos fibers has increased in all countries that list asbestos as one of their mineral resources. Despite the many small mines that have been opened in Canada, United States, Mexico, South America, Italy, South Africa, Australia, Yugoslavia, and Rhodesia, the supply still does not meet the demand. It is estimated that total 1952 world production of asbestos fibers of all varieties approximated 1,600,000 tons, with Canada suplying 966,382 tons (1), or 60 per cent of all fiber mined.

Asbestos fiber brokers continually are offering odd-lot samples of chrysotile, amosite, crocidolite, tremolite, and anthophyllite fibers to manufacturers, quoting fantastic prices for tonnages varying from just a few to 50 or more in a month. In many cases, the samples are not properly graded and contain quantities of rock impurities and finely ground dust.

When vendors submit samples of asbestos fibers, the manufacturer should consider them in terms of price, quality, quantity, and as possible substitutes for fibers currently used in his products.

Grading of these odd-lot fibers in most cases has been poorly done, with resultant non-uniform fiber lengths. In some instances, a number of miscellaneous lots of fibers have been blended for sale. This blending produces a fiber that is difficult for the manufacturer to accept as a substitute for the well-standardized Canadian fibers.

All fibers offered to the purchasing departments of most manufacturers usually are forwarded to their research units, where they are carefully examined for length, grade, and quantities of rock, dust, and such foreign materials as wood and wire. Comparisons are made with standard Canadian grades, or, if the fiber is of some other variety, comparison is made with shipments of that grade received during the past five years. If the sample is only a small quantity, such as a few grams, it is placed between two glass plates and reflected against a white wall, where the lengths may be measured and the impurities counted. When large samples are available they are given special tests to evaluate the fibers for use in regular products. These special tests include air separation and screening in a pilot plant to determine impurities ranging from large +4 mesh fragments of rock to −35 mesh granular material. Then the clean fibers as well as the original fibers are combined separately with the necessary ingredients to produce a commercial product. Physical tests on the product furnish further factors for evaluating the fiber.

Should a sample of fiber pass laboratory tests, it is customary to request three to ten tons for a plant test before final approval is given. When the large shipment of fiber arrives it is thoroughly sampled and re-tested, and the data compared with those of the original sample. If both sets of data are comparable and the plant tests are satisfactory, fiber specifications are drawn up for future purchases of this grade and variety of asbestos.

In some cases, the quality of the fiber is so poor that anyone accustomed to fiber examinations will realize that it is worthless before tests are made.

The three varieties of asbestos used in large quantities industrially are chrysotile, amosite, and crocidolite. Although actinolite occasionally appears on the market, no published records show how much is used, and we may consider it of minor importance.

Chrysotile

Chrysotile asbestos is the most popular variety for industrial purposes and probably accounts for 90 per cent of all asbestos fibers used in industrial products.

The quantity of chrysotile imported by United States industry in 1952 was approximately 734,500 tons (2), 668,800 tons of which came from Canada. When available, some Rhodesian and Arizona chrysotile fibers are used in textiles, special papers, and asbestos-cement products. Last year the textile industry in the United States imported 26,445 tons (2) of chrysotile fibers, including No. 1 and No. 2 crudes and Group 3 fibers. This amount includes 24,631 tons of spinning fiber from Canada, and 1,824 tons of C.&G. No. 1 and No. 2 from Rhodesia. These fibers usually are re-processed by the consumer and then carded and formed into blankets, rovings, threads, cords, ropes, and yarns of various classifications depending on demand. Asbestos cloths, tapes, wicks, and braided tubing all are made to meet particular specifications.

Fibers prepared in the textile plant (3) are used in such products as awnings, brake linings, blankets, conveyors, curtains, clothing, gloves, bag filters, draperies, coverings for electrical and power plant equipment, flexible metal tubings, packings, chemical filters, thermal insulating materials, friction materials, clutch facings, gaskets, electric blankets, ironing board covers, joint fillers, turbine jackets and blankets, and plastics.

The shortage of spinning fiber has resulted in off-grade so-called

*Research Center, Johns-Manville Corporation, Manville, New Jersey, U.S.A.

(1) Preliminary estimate by Industry and Merchandising Division, Dominion Bureau of Statistics, Ottawa.

(2) BOWLES, Oliver, U.S. Dept. of Interior, Washington, D.C., private communication.

(3) *A Primer on Asbestos Textiles,* prepared by the Asbestos Textile Institute, 1946.

'textile' fibers being offered to customers. Most of these fibers come from sources other than Canada and often are poorly graded. They sometimes are brittle and contain high percentages of non-fibrous materials.

On several occasions, small samples of textile fibers from foreign countries have been submitted and found to be satisfactory in length, strength, and in quantity of such impurities as magnetite, limestone, rock, and dust. An order of a ton of the fiber, however, proved entirely different and resulted in large card drops because of brittleness and non-uniformity of fiber length. Brokers submitting samples of textile fibers should get a guarantee from the miners that shipments of fibers will be equal to samples submitted to prospective customers.

For papers and millboards, most manufacturers use fibers of Groups 3 to 6, depending upon the kind of products being made. The longer fibers are used in special papers or diaphrams requiring sufficient length to give reinforcement. The types of paper products manufactured by a paper mill are numerous and may be mentioned briefly as electrolytic cell or diaphram, wick, pipe covering, millboards, roofing papers, laminated roll board, roofing felts, pipe line felts, welding paper, and similar materials.

Fibers for asbestos-cement products vary from Groups 4 to 7, inclusive, depending upon the methods of manufacture. This group of products includes shingles, pipes, jackets, flat sheets, corrugated sheets, wall boards, and electrical panels.

Asbestos asphalt roof coatings usually contain fibers of Groups 6 and 7, and floats, depending upon the particular coating being manufactured. The use of floats was discussed in *Asbestos Floats* (4) presented at the Ottawa General Meeting of the Institute in January, 1952. In this presentation, many of the physical properties and uses of floats were discussed.

The popularity of floor tiles made from organic resins and asbestos fibres has resulted in exceedingly large sales. Group 7 fibers used in floor tiles by all leading United States manufacturers amounted to approximately 170,000 tons in 1952.

Asbestos-cements contain fibers of Groups 6 and 7, as well as floats, the fiber used being governed by the cement. The quantity of fibers used in these products in the United States in 1952 was approximately 30,000 tons.

Amosite

United States industry imported 18,319 tons of amosite fibers (5) from South Africa last year. This was approximately 30 per cent of the total African production.

Samples of amosites are being offered by many vendors and brokers. In some cases, the same samples appear under different identification numbers. These envelope samples actually are too small for evaluation and many times appear to be of good quality, although larger samples of the same fiber contain high percentages of rock and are rejected. In many cases, the fiber length is so short that it falls into the filler classification. When properly processed, this variety of asbestos is bulky and light in density, and frequently is suitable for insulations.

Amosite imported into the United States gradually is becoming shorter in length and dirtier, and contains considerable rock. It is necessary, therefore, for the consumer to reprocess the fiber to remove the non-fibrous material which should have been removed in Africa. This additional processing cost plus loss of the non-fibrous material has raised the cost of this fiber to a point where substitutes will be given consideration.

It is not known what kind of control tests are maintained on the production of amosite fibers in Africa, but it is suggested that, whatever they are, they should be reviewed in terms of consumer needs.

Amosite is not as strong as chrysotile or crocidolite, nor does it have the good flexing properties of these fibers for use in textiles. Occasional samples of amosite, however, possess sufficiently high strength and good flexing properties to be used in textiles, if they were available in quantity. Products requiring light weight and not needing high strength can be greatly improved by the use of this variety of asbestos. Amosite fibers, with or without other varieties of fibers, will exhibit low densities, fairly good strengths, and good insulation properties, and, when properly processed, can be formed into magnesia blocks and pipe coverings of low density and good insulating properties.

Amosite, combined with other fibers and fillers, is used to produce lightweight asbestos-cement wallboards that are attractive, easy to install, and possess good insulation properties. A most recent installation of this construction is found in the fireproof walls of the new American ship, *United States*.

Crocidolite

Crocidolite asbestos is found in commercial quantities in South Africa and also in Austria. Smaller mines in other countries do not produce much fiber of this variety. Africa produced 44,734 tons of crocidolite last year. United States industry imported about 7,100 tons, including 274 tons of Australian Blue fiber (6).

That the quality of crocidolite fiber has decreased during the past five years is evidenced by a decrease in length and an increase in rock and extreme fines in the form of finely ground ironstone. Many vendors and brokers are offering samples of crocidolite as odd lots. Some fibers are so short that they fall into the filler class. If the quality of this variety of fiber continues to decrease, it will be natural for customers to investigate substitutes.

Because of its physical properties, crocidolite lends itself to some special applications that are not practical for chrysotile. For example, this type of fiber has very high tensile strength, has good acid-resisting properties, will give good porosity when formed into a filler mat, and will filter out small particles of dusts, smokes, and suspended particles in gases.

Crocidolite can be converted into textiles with some difficulty but it does not lend itself to carding and weaving as easily as does chrysotile.

Probably its greatest application is in asbestos-cement products where its properties of strength and increased porosity improve manufacturing processes and boost production rates. Crocidolite is extremely effective in acid-resisting gaskets and the so-called service

(4) Badollet, M.S., C.I.M., Trans., Voy. LV, 1952, pp. 185-189.

(5) Bowles, Oliver, U.S. Dept. of Interior, Washington, D.C., private communication.

(6) Bowles, Oliver, U.S. Dept. of Interior, Washington, D.C., private communication.

sheets. Filter mats or filter pads made of crocidolite, or of crocidolite in combination with chrysotile or with such organic fibers as cotton wool, or cellulose, have appeared on the market. These filter pads are found in gas masks, industrial masks, and more recently as the small plug in the top of some cigarettes. Applications for crocidolite are broadening.

Anthophyllite

Anthophyllite asbestos is found in several parts of the world in deposits of varying size. Its colour varies from white to brown and some of its physical properties discourage its use in commercial products. No estimate has been published of the quantity of anthophyllite fiber used by United States industry in 1952, but the amount is very small.

Because the strength and flexing properties of this fiber are poor, it would not be considered a good reinforcing fiber for asbestos-cement products. In most samples of anthophyllite submitted to industry, the fibers are short and would be equivalent to Groups 6 and 7 and floats. On rare occasions, however, the fibres have lengths equal to Group 3 and are bulky.

Anthophyllite of good length can be processed to produce a bulky mass with fairly good insulating properties. There is a tendency, however, for the fibres to disintegrate into short fibres during most processing methods. Special mechanical processing equipment, therefore, should be used in milling anthophyllite.

Most manufacturers consider this type of asbestos as a filler to be used in products where strength is not an important objective. As a filler it might be considered as a partial replacement for the stronger chrysotile fiber, but only at a sacrifice of some product strength.

In asbestos-cement products, this fiber will decrease strength and increase bulk. For some time, anthophyllite has been used for welding-rod coatings, and has been considered successful as a cheap filler. In plastics, a good grade of anthophyllite is bulky and does not give the impact strength exhibited by chrysotile. It also is difficult to coat completely and 'bundles' appear on the surface of the molded product.

Recently, this fiber has been tried as a filler in floor tile in competition with chrysotile. Here, colour and fiber strength are important factors. In tiles of light colours, the brown anthophyllite requires more white pigments to offset the dark colour. White anthophyllite does not present this problem. As for strength, anthophyllite lacks the resistance of chrysotile to the processing action of the mixers and rolls and probably would be reduced in length. Finally, decrease in floor tile strength will depend upon the quantity of anthophyllite in the mix.

There is no doubt that the use of this fiber as a filler will be investigated in many products. Its success will depend considerably on freedom from impurities, fiber quality, uniformity of fiber length, and the conditions of the fibers as sold to the consumer. Quality control to insure standard production will be a critical factor.

Tremolite

Tremolite asbestos is found in many parts of the world in varying degrees of purity. Some deposits exhibit fibers of good strength and flexibility while others yield a product that is rather weak and reduces to powder during processing. Some deposits of tremolite have long, strong fibers that may be converted into textiles and are satisfactory for use in asbestos-cement products, while fibers from other deposits can be used only as a cheap filler.

Many samples of tremolite being submitted by vendors and miners possess fair to poor quality, indicating contaminaiton. The demand for this variety of fiber is small and only a few customers are interested. The quantity of tremolite consumed by industry is not known, but it can be assumed to be small.

Often tremolite is purchased and re-purified by an acid treatment and sold for special uses in the filtration of chemicals, pharmaceuticals, blood plasma, and in Gooch crucibles in analytical chemistry laboratories. These specialty items bring high prices.

Actinolite

Actinolite asbestos occurs in serpentine areas in various parts of the world and sometimes is closely associated with tremolite. The quantity of actinolite used by industry is not known, but it may be presumed to be small.

Because of unattractive physical properties, including brittleness and low strength, it is difficult to use actinolite interchangeably with other asbestos fibers. Very little use is made of actinolite except as a cheap filler, and even for this purpose the quantity incorporated in a product must be closely controlled.

Conclusions

The demands for all varieties of asbestos fibers have increased greatly during the past five years and in most cases shortages still exist.

The quality of Canadian chrysotile fibers has been kept at a high level, but the quality of fibers from other countries has, in general, declined. This is particularly true of amosites and crocidolites from Africa.

Producers of amosite, crocidolite, and anthophyllite fibers should review their specifications for controlling fiber quality. This should be accomplished by consulting with the manufacturer to obtain his viewpoint on fiber requirements.

Manufacture of asbestos products in the United States, Canada, and other countries has expanded greatly during the past few years, and this expansion, in turn, has increased exploration and mining activities for asbestos deposits all over the world.

Heat Treatment of Chrysotile Asbestos Fibers

By M. S. BADOLLET and W. C. STREIB**

(*Annual General Meeting, Toronto,* 1955)

(*Transactions, Volume LVIII,* 1955, pp. 33-37)

ABSTRACT

A commercial method has been developed for controlling the texture of chrysotile asbestos fibers so that they may possess properties comparable with natural semi-harsh fibers for use in wet processes.

The physical properties of the soft, silky and slimy fibers are partially altered by a flash-heating process which removes a portion of the molecular water.

The heat-treated fibers show an improvement in filterability, an increase in bulk, absorption, and surface area, and better electrical properties, such as volume resistivity.

* * *

Introduction

CHRYSOTILE ASBESTOS fibers are found in nature having varying degrees of texture, referred to as soft, semi-harsh, and harsh. Fibers of each type of texture have inherent characteristics which directly affect their usefulness to industry. Visual differences are apparent under a microscope where it is seen that the soft-textured fibers have a silky, serpentine or wavy appearance, whereas the harsh-textured fibers are coarser and spicular†. Semi-harsh fibers, of course, have properties intermediate between these extremes.

Fankuchen and Schneider (1) have shown by the use of low-angle X-ray scattering that the diameter of the harsh type of chrysotile fiber is somewhat greater than that of the soft variety. Surface area measurements on various chrysotiles of different textures tend to confirm their findings. By nitrogen adsorption methods, it was found that the surface areas of soft types of chrysotile asbestos are approximately $23M^2/g$ whereas for the harsh types they are as low as $11M^2/g$.

The reason for these differences in fiber texture has been a matter of conjecture for some time, and the literature (2) contains several suggested explanations, such as the $MgO : SiO_2$ ratio, lime content, presence of calcite, pressure of formation, weathering, transition between asbestos and talc, and molecular water content of the fiber. After examining fibers of widely differing textures, it was found that the best correlation seems to exist between the water of constitution and the degree of harshness. The paramount differences between harsh- and soft-textured fibers, however, are in their respective strengths and filtration characteristics. Furthermore, it is the wide difference in these properties which directly influences their industrial usages. For example, a soft, silky fiber usually has high tensile strength and is extremely flexible. However, it is also usually slimy and difficult to de-water when used commercially to produce products involving wet methods. On the other hand, harsh and semi-harsh fibers de-water rapidly, but are generally low in tensile strength, and, in many cases, brittle to the point that the flexing characteristics are vastly inferior to those of the soft chrysotiles.

Obviously, it would be desirable to produce a fiber incorporating the strength properties of the soft-textured fibers with the rapid filtering properties of the harsher types. The commercial or industrial importance of such a fiber would be an increase in the production rate of wet-machine products and possibly the utilization of lower grades of poorer filtering fibers where high product strength might not be of the utmost importance. Since the water content of chrysotile appears to be correlated with its texture, it was decided to examine heat-treatment as a means of modifying the texture of the soft fibers and improving their physical properties.

Effect of Heat on Texture of Fiber

Samples of chrysotile crudes, carefully cleaned of wall-rock and fiberized, were prepared and classed as soft, silky, and slimy when wet by water. Careful heating of these samples in the laboratory under controlled conditions at various temperatures and for various durations of exposure definitely indicated that a soft fiber can be converted to one exhibiting the characteristics of a harsh or semi-harsh fiber.

Dehydration studies of chrysotile asbestos have been made by numerous investigators (3) and the effects of temperature are well known. However, the purpose in the present application was to dehydrate the chrysotile molecule only partially and to bring the water content in the range normally encountered in the harsh-textured fibers.

The "loss on ignition" shown in analyses of semi-harsh to harsh chrysotile fibers usually ranges from less than 12 per cent to 13 per cent, depending upon the degree of harshness. The theoretical percentage of molecular water or water of constitution in pure asbestos is approximately 13 per cent. This is represented by the hydroxyl radical in the molecular structure as expressed by the formula $Mg_6(OH)_4Si_4O_{10}$, where the heat first breaks down the components to $3Mg_2SiO_4$, SiO_2, and $4H_2O$. Therefore, any reduction in the number of hydroxyl radicals present, as would be effected by heat, will decrease the total amount of water of constitution, and this affects the physical properties of the fiber.

For the applications under consideration, the water of constitution was to be reduced about 30 per cent, or, in other words, the fiber sample was to be heated until its loss in weight amounted to about 4 per cent. In most of the tests, however, this loss actually ranged from 0.3 per cent to 3 per cent. Excessive heating has a deleterious effect upon

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†Photomicrographs showing these differences were published in C.I.M. *Transactions*, Vol. LIV, 1951, p. 156.

(1) For references see end of paper.

fiber strength (4), and if carried too far severely reduces the usefulness of the fiber as a reinforcing filler. Hence, a carefully controlled heat-treatment process is required to attain the desired product.

Laboratory tests were conducted also on Canadian *Group* 6 fibers from regular production in which they, too, were exposed to heat treatment at various temperatures for varying time intervals. Again, the fibers produced possessed texture characteristics similar to those of semi-harsh and harsh fibers. In the fibers from regular production, there are impurities such as brucite, carbonates, and others. Heating will result in ignition losses higher than the theoretical 13 per cent of water of constitution of pure asbestos.

Physical Properties of Heat-Treated 6*D* Fiber

Table I lists some of the physical properties of the 6*D* fibers before and after the heat treatment. The data show that as the heat-treatment temperatures and times are increased, filtration is improved, water of constitution is reduced, magnetite is decreased, and the strength of an asbestos-cement block containing the heat-treated fiber is decreased.

Figure 1, in which percentage increase in filterability is plotted against temperature, shows the effect of the heating at time intervals of fifteen minutes and three minutes.

Figure 2, showing the percentage increase in fiber filterability at different heating-time intervals at temperatures of 700°F. and 1,200°F., demonstrates that heating at a high temperature for a short period will yield a fiber having the same degree of filterability as that obtained by heating at a lower temperature for a longer period.

Table I.—Physical Properties of 6D Fibers Before and After Heat Treatment

Temperature °F.	Time Min.	Increase in Filterability %	Residual H_2O in Sample %	Residual Magnetite %	Asbestos-Cement Panels	
					Modulus of Rupture, p.s.i.	Residual Strength %
—	—	—	100.0	100.0	3,310	100.0
600	15	7.0	98.4	90.2	—	—
600	30	25.0	98.7	86.9	—	—
900	7	25.0	97.1	90.2	3,280	98.2
900	15	79.0	95.3	82.0	2,490	74.5
1,200	1	25.0	99.4	—	—	—
1,200	2	67.0	94.9	85.3	—	—
1,200	3	71.0	95.3	78.7	2,760	82.6

Another interesting comparison is that of the percentage of residual water with the percentage of increase in filterability. As shown in Figure 3, there is a definite correlation, and the amount of water in the molecule governs the degree of filterability of the fiber.

The effect of heat upon the magnetite present in chrysotile from regular production is to convert, partially, the F_3O_4 to Fe_2O_3, which is non-magnetic. In Table I, the reduction in the amount of magnetite remaining in the fiber after heating at 600°, 900°, and 1,200°F. shows that the magnetic character of the chrysotile is considerably reduced by heat treatment.

Table I also shows the effect of heat treatment upon asbestos-cement panels made of a Canadian 6*D* fiber. In the Table, the strengths of these panels are expressed as modulus of rupture in pounds per square inch. Panels made with fibers heated at the temperature of 900°F. for 15 minutes still retained 74.5 per cent of their normal strength. Panels made with fibers heated at 1,200° F. for 3 minutes still retained 82.6 per cent of their normal strength.

Another advantage of heat-treatment of chrysotile is its effect upon the volume resistivity of the fiber. Table II illustrates the vast increase in the resistivity of a heat-treated Canadian 6*D* fiber which is used in the manufacture of asbestos paper.

These data show that, as the molecular water was reduced, the volume resistivity expressed as megohm inches was greatly increased. Figure 4 illustrates this graphically by a plot of the percentage of residual water against the logarithm of the volume resistivity. The area between these curves represents the decrease in electrical resistivity due to the adsorption of surface moisture upon the fiber surface. However, even when the fibers were tested at 71°F. and 44 per cent relative humidity, the improvement in electrical properties was highly significant. A log-log plot of residual water and resistivity has much the same contour as that in Figure 4. The combined effect of improved filterability and electrical

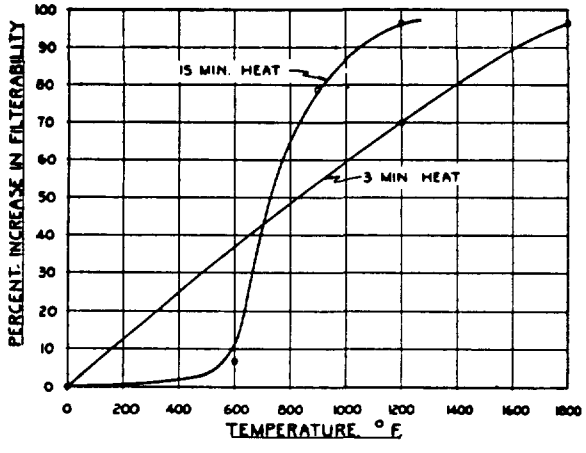

Figure 1.—Percent increase in filterability *vs.* temperature (°F.)

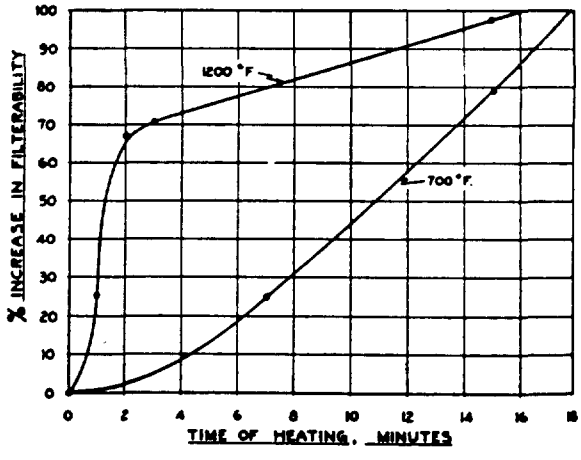

Figure 2.—Percent increase in filterability *vs.* time of heating (min.)

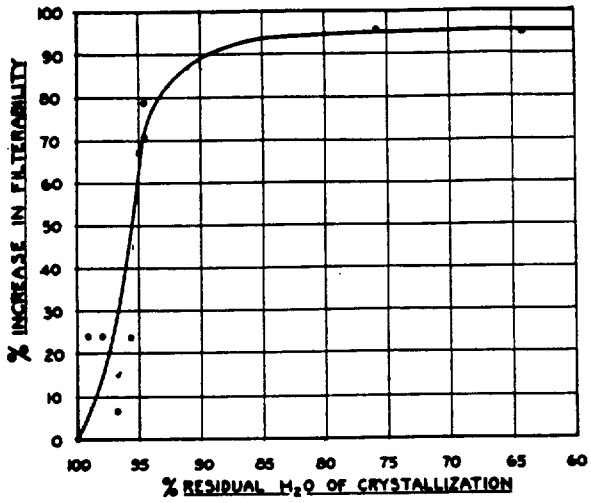

Figure 3.—Percent residual H_2O *vs.* percent increase in filterability.

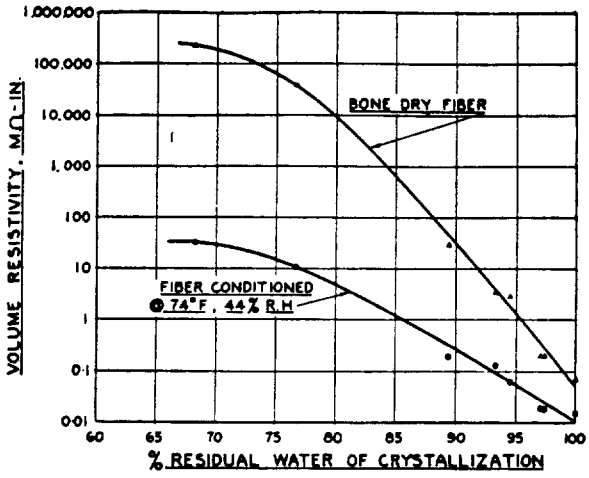

Figure 4.—Effect of heat treatment upon volume resistivity of 6D chrysotile asbestos.

properties is of direct interest and importance in the manufacture of electrical papers.

X-ray diffraction studies were made on a Canadian chrysotile fiber heated for one hour at temperatures of 400°, 500°, 600°, 700°, 800°, and 900°F. They showed that the structure remained typical of chrysotile. At 1,000°F. for one hour, the surface was amorphous, but, after carefully scraping off the surface, examination of the interior revealed the X-ray diffraction patterns were mostly those of chrysotile. At 1,400°F. for one hour, the entire mass had the structure of olivine. This study indicated that chrysotile, after losing small amounts of its molecular water, still retains much of its general structure. Anderson and Clark (5) heated chrysotile to constant weight at 900°C. and showed that the resulting fiber structure was not so definite as in natural fiber.

TABLE II.—EFFECT OF HEAT TREATMENT ON RESISTIVITY OF FIBER

Residual Water %	Residual Water, Log	Volume Resistivity 74°F., 44RH		Volume Resistivity Bone Dry	
		Megohm inches	Log resistivity	Megohm inches	Log resistivity
100	2.000	0.016	−1.796	0.08	−1.097
97.3	1.988	0.023	−1.638	0.29	−0.538
97.0	1.987	0.026	−1.585	0.29	−0.538
94.5	1.975	0.075	−1.1249	4.10	+0.613
93.3	1.970	0.110	−0.9586	4.80	0.681
76.7	1.885	13.30	+1.1239	52,000	4.716
89.4	1.951	0.25	−0.6021	41.0	1.613
68.2	1.834	45.30	1.656	300,000	5.477

Application of Heat

Various types of heating units were investigated, such as a muffle, infrared, dielectric, different types of commercial furnaces, and flash calcining. The main problem was to obtain a uniformly heated asbestos particle throughout any given mass, whether suspended in a gas atmosphere or as a thin or thick layer on a conveyor belt. Another problem was to devise a temperature control system that could be regulated manually or made automatic. A final problem was cooling of the treated fiber before it was bagged.

Several years were required to investigate all of the possible methods of applying heat to produce heat-treated fiber. Finally, the flash-calcining system was selected as the most appropriate.

Heat-Treatment Pilot Plant

A flash-calcining unit was purchased from the Nichols Engineering and Research Corporation, and a pilot plant with a processing capacity of two tons of fiber per hour was erected at Asbestos, Que.

A diagram of the unit is presented in Figure 5, which shows the path of asbestos particles and gases throughout the system. Thermocouples were installed at strategic points, and the temperatures were recorded on charts for a permanent record. After some experience, it was decided which thermocouple provided the most critical control, and from them on, the desired temperatures were regulated by this particular thermocouple reading.

The furnace, which was oil-fired, left no deposit of soot or other impurity in the fiber product since complete combustion took place in the chamber outside of the calcining tower. A gas-fired furnace would be ideal because the combustion chamber could be reduced in size or entirely eliminated.

The pilot plant building was a three-story structure located on a railway siding near the asbestos mill at Asbestos. In the basement was placed the mechanical driving mechanism for operating the air locks and a fan. The first floor contained the combustion chamber, pyrometer recorders, oil burner, and fiber-feeding conveyor. The second floor contained the bagging spouts where the fiber was sampled, bagged, sewed, and chuted to the boxcar for shipment.

The flash calciner unit was 26 ft. high by 8½ ft. in diameter, and was lined with fire brick. The bottom of the calciner was conical to enable the heated fiber to drop automatically into an air lock and be removed from the heating unit as rapidly as it collected.

The natural fiber was fed to a fan unit that gently willowed the fiber, freed it of lumps, and suspended it in an air stream so that it would fall by gravity down through the hot gas-heating zone. Peepholes

along the side of the calciner permitted a clear view of the fiber falling down through the hot gases.

A complete check was made of the mechanical operation of the furnace, and gas analyses as well as air balances were conducted on the entire system. The time of fiber exposure to the heat was approximately 5 seconds.

Any impurities, such as wood or organic materials, were consumed by the hot gases and disappeared completely before reaching the bagging spouts. Therefore, no complaints were ever made on the presence of wood in the fiber product.

In 1947, the calciner was operated at a capacity of two tons per hour, and it required 3 to 5 Imperial gallons of oil per ton of fiber, depending upon the temperature of operation. The total operating cost, taking into account losses and operational expenses, varied from $5 to $10 per ton. Three men could run the pilot plant after adjustment of temperature. One man fed the conveyor, one man bagged, and one man sewed the bags. The entire unit was closely supervised by additional men, who gathered data on the operation.

During the years of 1947 and 1948, the pilot plant was run on all grades of fibers varying from Group 3 to Group 7 inclusive, and the resultant fibers were investigated in the Company's plants and converted into products. Based upon their filtration properties, the fibers produced by heat-treatment belong in the texture class of semi-harsh to harsh, depending upon the temperature of the treatment. These fibers showed improvements in filterability and absorption, which can be translated into increased production in wet processes, and in better saturation of asbestos felts. The major fields in which heat-treated fibers can be utilized are asbestos-cement products, millboards and asbestos papers, and felts.

'Floats' produced as a by-product of the heat-treating system were promising; they were bulky and had excellent electrical properties. The magnetite content of the floats decreased as the temperature was increased; however, the total iron by chemical analysis remained approximately unchanged. The surface area by gas-absorption techniques showed a definite increase with temperature increase. Bulk, water absorption, and oil absorption also increased as the temperature was increased. All these factors are favourable in heat-treated floats to be marketed as fillers for such products as plastics.

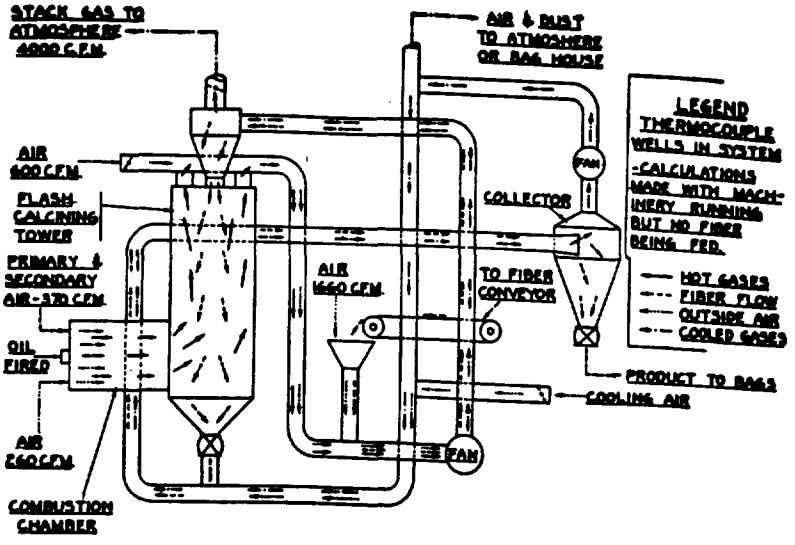

Figure 5.—Diagrammatic sketch of pilot plant.

The method of producing partially dehydrated chrysotile fibers is covered by U.S. Patent 2,616,801 and Canadian Patent 504,310 (6) and applications have been filed in other countries.

Packing fiber in jute or paper bags by mechanical or hydraulic packers is now becoming popular in the asbestos industry. Normal chrysotile fibers which are soft or silky are unaffected by this type of packing. Heat-treated fibers, when compressed to a pressure of 500 p.s.i., showed only slight changes in physical properties. There was no decrease in length but there was a slight increase in density and a small decrease in absorption and filterability. These small changes in physical properties were considered unimportant, and, therefore, pressure-packing of heat-treated fiber is satisfactory.

In the heat treatment process, the colour of the fibre changes from greenish-grey to cream or light brown, depending upon the temperature of the treatment.

The bulky nature of the heat-treated fibers is very apparent in such tests as the Quebec screen, Rotap, density, and absorption.

Although heat-treated fibers showed no evidence of fusion, microscopic examination did reveal that fiber bundles exhibited fraying effects that increased fiber surface area and coverage.

Advantages of Heat-Treated Fibers

Since heat-treated fibres are somewhat similar to natural semi-harsh to harsh fibers, they can compete with these commercial fibers in industrial usage.

Deposits of semi-harsh to harsh chrysotile fibers exist in various parts of the world but very seldom does any one deposit contain a complete range of different fiber grades. Generally, there is little variation in the degree of harshness of the fiber in any one particular orebody.

Industrial Use of Heat-Treated Chrysotile Asbestos Fibers

The process of heat-treating asbestos fibers allows the producer to make products of any degree of harshness he desires for any particular usage. Operators of mines in which the ore contains a slimy chrysotile fiber which is difficult to dewater may now have a means of converting their raw material into a product with the filtering characteristics that are requisite in wet processes. Furthermore, the texture of the product can be controlled, and at the same time its physical properties can be improved at a nominal cost per ton.

The manufacturer who uses heat-treated fiber will obtain increased production rates on wet-machine operations, improved saturation capacity of his paper felts, and better electrical properties. Also, these treated fibers will enable him to use lower grades that are difficult to dewater.

Conclusions

(1) A heat-treatment process has been developed for converting soft, silky, slimy chrysotile asbestos fiber

into fibers possessing properties competitive with those of natural semi-harsh to harsh fibers. The process, a flash-heating system, was operated as a pilot plant at the rate of 2 tons per hour for several years.

(2) The process allows the mine and mill operator to control his product and to produce any desired texture for fibers grading from Group 3 to Group 7 and 'floats,' at nominal additional cost.

(3) By heat treatment, the physical properties of the fibers have been partially altered by the removal of small quantities of molecular water and a partial conversion of magnetic iron oxide (magnetite) to the non-magnetic oxide, Fe_2O_3.

(4) The improvements in filterability, increased bulk, increased absorption, increased surface area, and better electrical properties. such as volume resistivity, are all a direct function of the temperature and time of heating.

(5) The tensile strength of heat-treated fibers, as well as the strengths of asbestos-cement panels containing them, will decrease as the temperature and time of treatment is increased. However, this disadvantage is minor and the products are equal to those obtained by using natural semi-harsh to harsh fibers.

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The Role of Asbestos in Plastics

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(*Annual General Meeting, Quebec City, April,* 1956)

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Introduction

DURING the past twenty years the use of asbestos fiber in molding compounds has increased considerably, and hence the plastics field has served as an outlet for large quantities of asbestos fibers from Canada. It is estimated that approximately 14,000 tons of asbestos fibers varying from Group 4 to floats are used by the plastics industry.

The utility of fillers in molding compositions has long been known. Their original purpose was to help make molding practical and to reduce the product cost. In the early days, these fillers consisted of sawdust, cotton waste, powdered asbestos, silica, diatomaceous earth, sand, clay, powdered glass, cork, marble dust, slate flour, or other materials. Each filler had certain good characteristics as well as certain objectionable ones.

In this presentation it is proposed to discuss only asbestos as a filler in molding plastics.

Types of Plastics

In general, molding plastics can be divided into the following classes: (1) cold-molded, (2) thermoplastics, and (3) thermosetting.

Cold-Molded Plastics

Asbestos fillers have the following advantages in the cold-molding field:

(1) Lower molding cost

(2) Make cold-molding possible by controlling the flow of material under pressure while it is in the cold mold

(3) Improve mechanical properties

(4) Increase hardness

(5) Decrease molded shrinkage

(6) Increase heat and fire resistance

(7) Allow ejection of the cold moldings from the mold, and improve handling and movement of the uncured moldings without danger of deformation or warpage

Unfilled moldings would be impractical in the cold-molding field of bitumens and phenolics. Because the filler must produce sufficient handling strength, asbestos, with its fibrous character, is desirable. Binders normally used are asphalts, pitches, gilsonite, polymerizable oils, resins, and similar compounds.

Cold-molded products of the bituminous type are sometimes loaded with as much as 85 per cent of asbestos. Such a product possesses good heat resistance and fairly good electrical insulating properties, and is low in cost. Its strength is not equal to that of hot-molded products; however, it is sufficient for the type of moldings made with cold-molding powders.

Cold-Molded Phenolics

Viscous solutions of a suitable phenolic resin are used as binders in cold-molded phenolics. The advantages of this higher-priced type of cold-molding compound are: better surface finish, lighter colours, more dimensional uniformity, and better mechanical and electrical properties.

Manufacturing Method

Cold-molded compounds are in general made by loading the fillers into a heated internal mixer, after which the binders and other ingredients are added in liquid form or in solution. This mass becomes somewhat tacky and, after discharge, it is allowed to 'season'. Later on it is screened to separate lumps, whiskers, and other extraneous material to provide a fairly uniform granular compound for molding.

The grades of asbestos used in the cold-molding field are normally described as floats and shorts. The quality and physical characteristics of the asbestos are important and should be controlled. The most important and troublesome variables within this field are:

(1) Texture and quality of fiber should be as constant as possible so that the molder can set up his working formula and not be forced to make repeated changes.

(2) Bulking property of fiber should be kept constant. For example, if the fiber is increased in bulking properties, more binder is required and this increases product cost. On the other hand, if the fiber is too heavy or less bulky, the molding material becomes tacky because it does not absorb the proper quantity of binder. This condition also causes screening and molding difficulties, sticking to the molds, increased baking time, and softer moldings. Often, the mechanical strength of the product is lowered.

(3) Excess moisture in the asbestos also can cause trouble, such as sticking and blistering. Normally, asbestos as received by the molder contains from one to two per cent of moisture. Under some storage conditions in customers' plants, the fiber may pick up additional moisture; this is why some plant operators pre-dry their fiber as a protection against any moisture increase due to storage conditions.

(4) Non-uniform fibers should be at an absolute minimum. They may be described as those that have 'whiskers' or long fibrils in excess of the average fiber length for that particular grade. These 'whiskers' twist and tangle and interfere with the efficiency of the screening process. They also cause sticking to the molds, produce surface blisters, and in most cases affect the finish and the appearance of molded products.

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After the molding powders are properly sized by screening, they are ready to be placed in the mold. At this point, the bulk factor is extremely important because preforming and final molding are one and the same operation. Moreover, positive molds are used, and most molded parts are each fitted with from one to several metal inserts. The molds are loaded by means of a small hand rake or mechanical rake. Good pourability and proper bulk of the molding compounds are indispensable at this step for good and efficient cold-molding. If the molding compound charge is insufficient, then the molded part is off-size; and if the charge is excessive, the product is heavy and in some extreme cases may even damage the mold.

The cold-molding operator has his own responsibilities. He must develop a well-balanced compound in which the ratio of binder to filler is adjusted in relation to the bulk value of the filler. If he does this, sticking and off-size products, as well as other troubles, will be minimized or eliminated.

In most cases, the compounds are dusted with a powdered lubricant before they are loaded into the mold, to prevent any sticking tendency. If the formulation is made correctly, the cold-molded compound will flow properly and produce good material. The main factors the operator must constantly watch are: (1) bulk of the asbestos filler; (2) ratio of binder or filler; (3) proper size of particles of the molding compound; and (4) molding pressure as well as baking temperatures and cycles.

In general, it may be stated that cold-molded products are not suitable for power factor applications of any importance; but they are used extensively as heater plug parts and as housings for the shielding of electrical units. High loading of asbestos as a filler imparts the heat and flame resistance required.

Thermoplastics

In the thermoplastics field the fillers generally used are zinc oxide, titanium oxide, blanc fixe (barium sulphate), talc, diatomaceous earth, and asbestos.

The common names of the most familiar thermoplastics are: cellulose nitrate, cellulose acetate, cellulose acetate butyrate, ethyl cellulose, vinyls, polystyrenes, vinylidene chlorides, and esters of acrylic acid.

The disadvantages of fillers in thermoplastics may be summarized as follows:

(1) Mineral fillers increase the specific gravity and molding weight of both thermoplastics and thermosetting molding compounds.

(2) Fillers preclude production of transparent or translucent plastics (molded, cast, or fabricated). Translucency can be obtained only to a limited extent when the refractive index of the plastic and the filler are approximately the same; in these cases, however, the moldings lack quality.

(3) Fillers decrease water and moisture resistance.

(4) Fillers also reduce electrical and mechanical properties. The exceptions are resistance to arcing and compressive strength.

(5) Fillers in most cases damage the delicate molding and fabricating equipment.

(6) Fillers frequently introduce new and sometimes complicated problems in the difficult art of colouring, mottling, and configuration of thermoplastics.

(7) Fillers in thermoplastics impose the need for special types of processing, molds, and methods of molding.

(8) Fillers increase the quantity of waste and re-work.

(9) Fillers make injection and extrusion molding methods troublesome and wasteful. Consequently, work along these lines is chiefly experimental at present.

Asbestos improves the heat resistance and compressive strength of the thermoplastic moldings. It also reduces the cost and the tendency to cold-flow, with resultant deformation and warpage. Although hardness is improved, the increase is only moderate. Resistance to flammability and arcing is also improved by asbestos; however, this is true of all mineral fillers.

Incorporation of fillers in thermoplastics is usually handled by one of three different methods, briefly described as follows:

(1) Preliminary mixing of the plastic binder in powdered or flake form with the plasticizers, fillers, and other ingredients in ball mills or in internal mixers.

(2) Blending of the ingredients, including binders, plasticizers, and fillers, with or without solvents, in heated kneaders. Hot-rolling is followed by calendering, stamping, or by molding.

(3) Incorporation of the fillers and plasticizers on the hot rolls after the plastic binder has been consolidated into a plastic sheet. This procedure is used for blanking and/or fabricating and/or molding.

To obtain a good product requires considerable good judgment on the part of the operator. This is influenced by: (1) method of incorporation; (2) time of mixing; (3) temperature of mix; (4) percentage of filler; (5) type of filler; (6) mixing technique; and (7) type and condition of the plastic binder.

Because of the conditions under which hot-rolling is practical in the thermoplastics industry, and because the binders are plasticized, the operation is a safe and efficient one for the operator. Binders remain fusible indefinitely, and this permits perfect blending by pulling the filled compound in fairly thin sheets over and over as required. Filler loadings are usually on the low side.

In most cases, a well-formulated compound can be processed and molded without sticking to hot steel; however, in some special cases lubricants are used to minimize possible difficulty.

Most of the thermoplastics used for regular molding can be produced in a large variety of molding flows, because the plastic base and the plasticizer content, or their ratios, can be changed within wide limits.

In thermoplastics, the molder must give close attention to: (1) nature, grade and flow of the base; (2) nature of the plasticizer, whether it is a solid or liquid; (3) percentage of plasticizer; (4) nature and percentage of fiber; (5) preheating; (6) molding temperature; and (7) molding pressure.

Special techniques have been developed by the trade for the drilling and machining of each particular type of thermoplastic, filled or unfilled.

Asbestos, especially light-coloured fibers, can be used in moderate percentages in the manufacture of thermoplastic molding or calendering materials based on ethyl cellulose, vinylchloride acetate, and vinylchloride (polyethylene has been tried experimentally). The asbestos filler improves the hardness, heat resistance, burning rate, compressive strength, and arcing resistance of the product but it affects

adversely such characteristics as specific gravity, translucency, appearance, depth of colour, other colour possibilities, flexibility, shock and flexural strength, water resistance, and electrical properties.

In the thermoplastics field, the use of fillers is very limited. Vinyl chloride acetate and vinylchloride-base floor tiles, however, constitute a very important and growing field. Work is also being done on floor coverings.

Asbestos is used in some types of shellac-base compounds also, but not to the extent it was in the past.

One manufacturer in the United States has been producing injection moldings in very large quantities with a compound made with mineral fillers, asphalts of high purity, pitches, plasticizers, and hardening or strengthening agents such as asbestos or other fibers of short or medium length. We understand that the cost of these moldings ranges from $20 to $200 per ton.

Thermosetting Plastics

The thermosetting field of plastics is large, and use of fillers has many advantages. Filled moldings are cheaper, and the fillers control the flow of the molding compound. In addition, they improve the mechanical strength and dimensional uniformity, they make the moldings more dependable and durable, and they decrease the shrinkage and warping tendencies of moldings after their ejection from the hot mold. Filters shorten the curing time and increase hardness; they improve heat, fire, and arcing resistance.

Some of the disadvantages in the use of commercial fillers in these plastics are: increase in specific gravity and molded weight; decrease in water and moisture resistance; lowering of electrical properties; increase in wear and tear on equipment and molds. Moreover, asbestos introduces grit, rock, and magnetite. These impurities increase deterioration of equipment; they make drilling and machining operations difficult.

In the production of thermosetting plastics it is generally accepted that, if the compound has a tendency to stick to the hot-mixing rolls, it will also stick to the molds and cause rejections, expensive delays, and cleaning jobs. Moreover, the mirror polish of the cavities may be damaged, and internal lubrication of the molding compounds is indispensable.

If the compound flows poorly, production is decreased. Also, moldings are mechanically weak, untrue, and defective dimensionally, and electrical and other properties are erratic.

On the other hand, if the compound flows immoderately and too rapidly, it causes excessive case hardening, excessive and wasteful flash, lack of dimensional accuracy, decreased mechanical and electrical strength, and upsetting of pins, removable parts, inserts, and the like. It also interferes with the efficiency of the ejecting devices.

Chrysatile asbestos as a filler has a number of advantages, some of which are common with other fillers. Advantages of chrysotile are: (1) it is mineral in nature; (2) it is available in large quantities; (3) it is low or moderate in cost; (4) it is fibrous in structure; (5) it is possible to adjust percentages used in relation to fiber length; (6) it is easy to process and mold in compounded form; (7) it retains the binders; (8) it is inert to reactions involving rolling, molding, and curing of the compounds; (9) it permits the manufacturer to use high percentages of filler, *e.g.*, 65 to 70 per cent; (10) it allows the molder to vary the percentage and fiber length to achieve desired mechanical strengths; (11) it imparts toughness; (12) it provides better surface finish than soft wood flours, barytes, or mica; (13) it retards the burning rate; (14) it supplies heat and fire resistance; (15) it increases hardness; (16) it reduces the natural shrinkage of the resins and plastic binders; (17) it allows blending with mineral and organic fillers; and (18) it increases the moisture resistance of moldings partly filled with cellulose fillers.

Compared with other mineral fillers, chrysotile has the following advantages: (1) it is fibrous and available in lengths desired; (2) it has excellent binder retention; (3) it is easy to process and mold; (4) it may be loaded at higher levels than other mineral fillers; and (5) it produces the hardest and toughest moldings at loadings impossible with other fillers.

Asbestos - filled thermosetting moldings excel all others in heat resistance, up to temperatures of 450°F., because asbestos loadings can be made at higher percentages than is possible with other mineral fillers. The impact strength can be varied within wide limits by varying the quantity and length of asbestos.

Chrysotile asbestos has some disadvantages however. Chief of these are:

(1) *Combined Water*

Combined water is present as a part of the chrysotile structure. If temperatures of molded products reach 450°F. or higher and some of the combined water in the asbestos is liberated, the molding will blister and crack. This difficulty is particularly significant when heater plugs and other electrical and heating appliances are involved.

(2) *Fiber Length*

Fiber lengths of asbestos used in plastics vary, depending upon the grade. The molder must understand the type of fiber and something about its properties, especially the specific gravity, bulk, molded weight, mechanical and electrical properties, water and moisture resistance. In addition, he must understand mixing techniques, colouring, surface finish, molded shrinkage, and percentage of fiber available in the asbestos grade used.

(3) *Dust or Fines*

The so-called 'dust' or 'fines' in asbestos may be granular, fibrous, or talcy. Variations in the ratio of dust to fiber, and its degree of fineness, will affect all those properties mentioned under the heading of fiber length. For example, surface quality of the molding will improve as the percentage of dust increases; however, all other conditions being equal, the surface quality of the molding will be lowered as the fibrous structure of the dust, or as the particle size of the dust, increases. In other words, a fine granular dust will impart the best surface finish.

(4) *Talcy Dust*

Talcy dust adheres to the surfaces of the fibers, producing what is called the 'talcose' effect. It retards, and in extreme cases prevents, adhesion of the resin binder to the asbestos filler and adhesion of the blending charge to the hotter of the mixing rolls. This often results in increased rolling time, sticking, fouling, irregularities, poor detail, inferior surface finish, and increased rejections or waste.

(5) *Rock*

The so-called 'rock fraction' in asbestos, which is mostly ground serpentine, is usually present in dif-

fering percentages. This fraction has a tendency to segregate when the ingredients forming the molding compound are given the preliminary dry- and cold-mixing. Accumulation of rock on the bottom of the mixer or ball mill unbalances the disposition of the ingredients. Presence of this rock in a molding compound will tend to scratch the delicate mirror polish of the mold, which is costly to repolish.

(6) *Pencils of Fiber*

'Pencils' are defined as fiber bundles not well opened, and thin in cross-section. These pencils cause the charge to stick to the hot rolls and molds as a result of the pencils being crushed between the friction rolls or under the molding pressure. When this happens, the newly exposed fiber surfaces remain partly coated and do not ride with the charge on the rolls or within the mold. When the pencils remain uncrushed they are enclosed by the binder, and, when opened by the grinding operation, they appear as poorly bound units, or as uncoated fibers or specks that show on the exposed surface of the moldings and throughout their mass. These pencils may also be blamed to a certain extent for blistering of material within the mold or in service.

(7) *Lumps of Fiber*

If the fiber is lumpy before the molding powder is made it will cause about the same trouble as pencils. Lumps must be removed to ensure good disposition. The fiber product as produced from the mine should be void of lumps; if not, it should be screened or lightly fluffed before use.

(8) *Whiskers*

Small percentages of long fibers in an extremely short fiber product are called 'whiskers'. Although these whiskers may be only a fraction of an inch longer than the main makeup of the fiber grade, they cause sticking and affect surface quality and appearance.

(9) *Grit*

Grit is usually smaller in particle size than the rock discussed earlier; it is harmful, however, and can damage the molds.

(10) *Magnetite*

Magnetite, an iron oxide having magnetic properties, is usually present in most grades of chrysotile asbestos. Its removal is difficult. The effect of magnetite on electrical properties has been the subject of much discussion, particularly when it is coated by a resin. Its black colour is objectionable in moldings of light colour or shade. Electrical properties of the molding may or may not be affected by the presence of magnetite.

(11) *Alkalinity*

Chrysotile asbestos has a high alkalinity because of the nature of the molecular grouping of its elements, which, in the presence of water, combine to form a small percentage of $Mg(OH)_2$. The *pH* is usually around 9.3 to 9.7. In many molding powders this alkalinity is not objectionable; in others, such as urea formaldehyde, alkalinity is troublesome. However, asbestos is not used to fill resins of this type.

(12) *Capacity for Moisture Absorption*

Asbestos, unfortunately, has a high capacity for absorbing moisture. This effect can be counteracted, however, by oven-drying before the molding powders are made.

(13) *Surface Finish Imparted by Asbestos*

Floats of good grade impart good finish as well as the desired toughness and mechanical strength. As the result of considerable experimentation, floats of excellent quality are now available.

(14) *Phenolic Molding Compounds*

Phenolic resins include the condensation products resulting from the controlled reaction of phenol with formaldehyde or with furfuraldehyde. The ratio of the reactants can be varied. The variations as well as the type of condensing agents, modifiers and/or additives used determine the characteristics of the resultant resin. One- and two-step resins and variations are made; they are used within the field discussed, the type selected being based on the properties desired in the end product. Phenolic molding compounds are made by blending short-fibered asbestos and/or floats and subjecting the mixed ingredients (including fiber) to some type of mechanical or heat treatment while the mass is in motion. Chief among these treatments are: (1) preliminary dry-mixing in ball mills or in internal mixers followed by hot-blending in friction rolls, and finally grinding of the mass to powders of the desired fineness; (2) preliminary dry-mixing in ball mills or in internal mixers followed by hot-friction blending in Banbury mixers, and grinding to powders of the desired fineness. By this method of treatment, fiber length is sometimes reduced, and consequently the toughness and mechanical strengths of the moldings are decreased. However, good blends are made and the curing cycles are reduced.

The purpose of the hot-rolling or hot-blending in Banburys is two-fold, (1) to ensure thorough blending of the resin, fillers, dyes, and lubricants, and (2) to facilitate the advance of the resin in order to decrease molding time. Moreover, reduction in the amount of condensation produced in the mold favours production of perfect, blisterless moldings and tends to reduce molding flash. Thermoset flash is practically useless. On the other hand, the thermoplastics type can be reworked and mixed with virgin compound, with or without the addition of plasticizers to compensate for volatilization in molding.

Preforming.—Phenolic molding compounds are usually preformed in suitable equipment. Preforms produced with the original powders are made in various forms and sizes or pellets, or in shapes approximating the final molding. This method accelerates production, assures uniformity of the molding charge, and reduces waste and flash to a minimum.

Preheating.—Molding preforms are usually preheated in special ovens to bring them to the proper degree of plasticity. Preheating reduces molding time.

When long or very long asbestos fibers are used in phenolic molding compounds they are mixed with the finely powdered resins and other ingredients in internal mixers, or by spraying liquid resins, or in solutions. The resultant mixture, although not very uniform, is used for molding. Mechanical mixing does not affect fiber length, but it does create a problem of loading the mold because of the high-bulk factor. Toughness and mechanical strengths are improved, but flow within the mold is retarded. Consequently the molding cycles are longer, more internal lubricant is usually needed, surface quality is poor, and the molded mass is not so uniform as that resulting from short asbestos grades.

The furan resins include the products resulting from the reaction of furfuryl alcohol and furfural;

ASBESTOS-FILLED PLASTIC MOLDING COMPOSITIONS (1)

THERMOSETTING TYPES

	Phenolics		Furans	Melamine Formaldehyde	Cold Molded	
	Molded	Cast	Molded	Molded	Organic	Inorganic
Specific gravity	1.52–2.00	1.70	1.75	1.70–2.00	1.87–2.15	1.60–2.2
Specific volume, cu. in. /lb.	18.2–13.8	16.3	15.80	16.3–13.8	14.8–12.9	17.3–12.7
Mold shrinkage, in. per in	0.0005–0.006	—	—	0.005–0.007	0.010–0.017	0.000–0.010
Tensile strength, p.s.i.	4,000–6,500	3,000–6,000	3,000–4,500	5,500–7,000	1,400–3,000	2,200
Compressive strength, p.s.i.	15,000–35,000	10,500–12,500	10,000–13,000	30,000	6,000–15,000	18,000
Flexural strength	7,000–15,000	5,000–8,000	6,000–9,000	9,000–11,000	3,700–10,000	2,000–7,500
Impact strength, ft. lb. /in on notch-1zod test	0.27–3.5	—	—	0.28–0.40	0.40	0.40
Hardness, Rockwell	M95–M115	R110	R110	M110	M80–M90	M75–M95
Thermal conductivity, 10^{-4} cal /sec /sq. cm per 1°C /cm	8–16	8.4	—	13–17	—	—
Resistance to heat (continuous), °F.	350–400	300	265–330	250–400	500	900–1300
Heat distortion temp., °F.	290–350	—	—	265	>400	>400
Dielectric strength, ⅛ in. thickness, short time, volts per mil	100–350	—	—	350–400	85–115	45
Dielectric strength, ⅛ in. thickness; step by step.— volts per mil	75–325	—	—	320	50–75	50–80
Dielectric constant, 10^6 cycles	5–7	—	—	6.1–6.7	6.0	—
Dissipation (power) factor, 10^6 cycles	0.10–0.50	—	—	0.041–0.050	0.07	—
Arc resistance, seconds	Traces	—	—	120–140	75–200	100–500
Water absorption, 24 hr., ⅛ in. thick, %	0.10–0.50	—	0.01–0.2	0.08–0.14	5.5–2.0	0.5–15
Burning rate	*Nil*	Almost *nil*	Slow	*Nil*	*Nil*	*Nil*
Effect of weak acids	None to slight	Same as molded	Same as phenolics	None to slight	Slight	Slight
Effect of strong acids	Decomp. by oxidizing acids; others sl. /none	"		Decomposes	Decomposes	Decomposes
Effect of weak alkalies	Depends on alkalinity; sl. or marked	"	None	Very light att'k	None	None
Effect of strong alkalies	None on bleed-proof materials	"	None to slight	Slight attack	Decomposes	None
Effect to organic solvents	Poor	"	Completely resistant	None on bleed-proof olours	Attacked by some	None
Machining qualities	Fair to good	"	Fair to good	Fair	Poor to fair	Poor
Molded qualities	In mold	In mold	Good	Good	Fair to good	Fair to good
Cure			In mold or oven	In mold	In oven	In oven

(1) Data taken from *Modern Plastics Encyclopedia*, 1955 edition.

furfuryl alcohol with formaldehyde; furfuryl alcohol and ketones, and finally the product resulting from the polymerization of furfuryl alcohol.

Resins made by reacting phenol and furfural also belong to the furan group, but their properties place them with the phenolics.

(15) *Melamine-Formaldehyde Molding Compounds*

Calcium cyanamide, a fertilizer prepared by heating calcium carbide with nitrogen under pressure, is the starting point in the synthetic preparation of melamine. This water-soluble material reacts with formaldehyde adjusted to a *pH* of 7.2 to 9.0 by means of caustic soda. The primary advantages of melamine formaldehyde resins compared with cheaper urea formaldehyde types are increased stability to heat and hot water, and greater resistance to alkalies and fruit juices. Moreover, the melamine formaldehyde resins permit use of alkaline fillers, such as asbestos. Such fillers cannot be used with the urea resins because they would inhibit setting.

Molding powders are prepared by mixing the liquid resin with the desired percentage of filler. Double-arm open mixers provided with ducts to remove the formaldehyde fumes are used. The damp mass is dumped onto a screener provided with a device to break up the damp resin-filler mixture. From this screener, the compound is conveyed to the oven drier. The galvanized iron shell of the driers must be acidproof. The continuous conveying belt should be chromium plated. The compound, spread in thin layers, is dried under very closely controlled temperature and humidity conditions. During the drying cycle the water content drops from 50 to 1 per cent and chemical condensation of the resin proceeds.

Cutting and grinding are the next steps. Grinding is done in ball mills where pigments, lubricants, and catalysts are added. The catalysts develop acidity when the compounds are heated to molding temperatures. These curing agents reduce the curing time and make the molding operation faster and more economical. The compound taken from the ball mills is ground to a fine powder to provide a more uniform molding powder.

If a molding compound of higher density is desired, the material is heated from 120° to 220°F. in Banbury mixers. The partial fusion thus obtained reduces the volume of the molding compound.

Powders must be kept in cold storage under controlled conditions.

(16) *Color of Thermosetting Moldings*

For most phenolic molding compounds used for industrial and many other applications, the colour is not important. Colours other than black and brown are available today, however, and the filler has to be selected accordingly.

(17) *Textures*

Asbestos of the chrysotile variety, whether in the form of shorts or floats, should be of soft texture. Semi-harsh and harsh chrysotile fibers have a tendency to pulverize during the processing cycles and are more difficult to coat with resins than are the soft chrysotile fibers. Likewise, the molder will have less trouble in formulation if he knows that the physical properties of his fibers are not altered during his processing.

In the paper, *Heat Treatment of Chrysotile Asbestos Fibers* (1), it was stated that this kind of fiber in the form of floats is very good for use in plastics because of its improved physical properties.

Considerable research is being done in the fields of polyester and epoxy resins with asbestos in various forms. These fields may be very important in the not-too-distant future.

(18) *Physical Properties of Fiber-Containing Moldings.*

The accompanying Table, taken from the *Modern Plastics Encyclo-*

(1) BADOLLET, M. S., and STREIB, W. C., *Heat Treatment of Chrysotile Fibers;* C.I.M., Trans., Vol. LVIII, 1955 pp. 33-37.

pedia for 1955, shows the various properties of the asbestos-filled molded compositions of the thermosetting type.

Conclusions

The role of asbestos in plastics has been reviewed from the viewpoint of its usage in the cold-molding, thermoplastic and thermosetting fields. The advantages and disadvantages of chrysotile asbestos in these fields have been discussed, as well as general methods of compounding the fillers with the resins.

The use of asbestos in plastics is important to both the plastics manufacturer and the asbestos industry, and it will continue so for a long time.

Today, in the competitive market, it is necessary for the asbestos fiber salesman to understand the usage of asbestos in plastics and to be able to help the manufacturer wherever possible. His contacts furnish the leads for future development by the mines of the proper grades of asbestos for the plastics industry. The closest possible co-operation between the mines and the plastics manufacturer is essential to assure the success of the product by keeping variations in quality within the narrowest limits.

Identification of Minerals Associated with Asbestos by X-Ray Diffraction Patterns

By M. S. BADOLLET and J. P. McGOURTY†*

(*Annual General Meeting, Vancouver, April,* 1958)

(*Transactions, Volume LXI,* 1958, pp. 169-174)

Introduction

IT HAS LONG been customary for chemists to analyze samples of asbestos and their associated rocks by routine chemical procedures. Results of these investigations are usually reported in the conventional way, *i.e.*, the percentages of the various constituents existing in the sample under investigation. Often an examination of the data shows that re-grouping of the chemical analyses and re-calculation of the data in terms of minerals will shed more light on the true composition of the sample.

The late Dr. H. C. Cooke in his G.S.C. Memoir 211 (1) presented an exhaustive study of analyses of asbestos and rocks taken from the Thetford, Disraeli, and eastern half of Warwick map-areas in the Province of Quebec. Also he discussed the composition of asbestos and other fibers of the Thetford district in a paper he presented to the Royal Society of Canada in 1935 (2). Both papers include a series of analyses of fibers from the chemical point of view. The analyses are accompanied by a recast of the data in terms of minerals in which Dr. Cooke sought to deduce the mineral composition of each sample. This presentation of data was well done. It has been stimulating to the X-ray specialist who is interested in carrying the investigation further to confirm the predictions of the chemist, mineralogist, and geologist, and to make definite identification of the minerals which the chemical analyses indicate to be present.

Dr. Cooke was very co-operative in furnishing us with samples of material identical to those he used in his studies. We accepted his chemical analyses and his re-cast minerals data and have applied the X-ray technique for checking and identifying the minerals actually present in the samples. The dual purpose of this investigation was, first, to explore the limits of the X-ray diffraction method for identifying the minerals; and second, to develop a simplified technique for applying this information in sample identification. Such a technique would be of great value to company geologists in searching for new asbestos deposits, as well as in the examination of drill cores.

X-Ray Technique Employed

The X-ray pictures were taken by the Norelco X-ray diffraction unit with a Debye-Scherrer camera for a four-hour exposure, using copper radiation with a nickel filter. All samples were carefully powdered in an agate mortar before they were examined in the unit.

The X-ray pictures accompanying this paper carry the following identifications:

	A Line
S—Serpentine	2.49
C—Chrysotile	2.44
A—Antigorite	2.53
B—Brucite	2.35
F—Iron oxide	1.61
G—Grammatite (tremolite)	8.4
E—Epidote	2.9
Q—Quartz	3.34

When doubt existed in identifications, it was necessary to adopt spectrographic and petrographic techniques.

Discussion of Data

*Sample 1**

Sample 1 represented a "normal red-weathering serpentine from a chromite pit in the northwest corner of lot 19 N.W., Range X, Coleraine township". The chemical analysis (Table I) revealed that it contained SiO_2, MgO, and H_2O, with small amounts of other metals. Re-casting into minerals by Dr. Cooke indicated that the sample was mainly serpentine rock. The reddish colour probably was due to weathering of the small amount of iron present.

During recent years the X-ray diffraction patterns of serpentine have been fairly well indexed and identifications have been made easier. The pattern of Sample 1 showed clearly the typical ring structure of serpentine with a considerable amount of crystalline brucite. These two diffraction lines are identified in Figure 1.

The chemical analysis showed an excess of MgO over the amount required to combine with SiO_2 to form serpentine, $H_4Mg_3Si_2O_9$; this excess of MgO crystallized in the form of brucite, $Mg(OH)_2$, which is intimately associated mechanically with the serpentine. The absence of evidence in the diagram of the presence of other minerals is due to the fact that any compounds formed by the minor constituents shown by the chemical analysis are not in sufficient quantity to yield definite X-ray diffraction patterns. The brucite is so closely associated with the serpentine that it could not be removed by mechanical means but it could be dissolved out chemically.

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(1) Cooke, H. C., Mem. 211, Geol. Survey, Dept. of Mines and Resources, Ottawa, 1937.

(2) Cooke, H. C., Roy Soc. Can., Trans., Sec. IV, 3rd Series, Vol. XXIX, 1935.

*The descriptions and chemical analyses of samples 1 to 21 are reproduced from *G.S.C. Memoir* 211, by Dr. H. C. Cooke. Numbering of the samples is the same as in that report.

Sample 2

Sample 2 represented the same material as in Sample 1, but it exhibited "material blackened over a zone a foot wide and flanking a dyke about a foot wide". Chemical analysis (Table 1) showed the presence of Al_2O_3, Fe_2O_3, and FeO in quantities that indicated other minerals than serpentine must be present as impurities.

The X-ray diffraction patterns did not reveal the presence of brucite, thus confirming the chemical analysis, which showed sufficient SiO_2 to combine with all the MgO to form serpentine; hence, no excess MgO remained to form brucite or any other magnesia mineral. Although the chemical analyses showed the presence of aluminum and iron compounds, they were not identified in the X-ray pattern because they are present only in very small amount.

Sample 3

Sample 3, which represented "chrysotile asbestos taken from the King mine", is typical of the fiber from that area. The chemical analysis (Table 1) disclosed a composition equivalent to that of chrysotile asbestos, with small traces of impurities. Dr. Cooke, in his re-calculation of the analysis, deduced the possible presence of minerals such as chlorite, talc, and periclase as impurities associated with the chrysotile asbestos.

X-ray diffraction lines did not indicate the presence of brucite, but they did show a trace of quartz. Although the chemical analysis, when re-cast in terms of minerals, indicated the presence of chlorite, talc, and periclase, lines for these minerals were not visible in the X-ray pattern.

This sample was also analyzed quantitatively by emission spectroscopy* with known oxide mixes as standards; the data obtained, on an ignited basis, showed the presence of Al_2O_3, 0.10%; Fe_2O_3, 1.3%; and CaO, 0.11%. If the iron in the original sample was in the form of Fe_3O_4, it would have been oxidized to Fe_2O_3 by the treatment preceding to the spectroscopic examination.

The total amounts of Al_2O_3, Fe_2O_3, and CaO by spectroscopic

*Emission spectroscopy is not a means of identifying compounds but can be used as a supplement to ordinary wet chemical analysis.

TABLE 1.—ANALYSES, SAMPLES 1 TO 4

	1	2	3	4
SiO_2	34.40	40.42	42.05	43.48
Al_2O_3 ...	0.50	2.24	Nil	1.41
Fe_2O_3 ...	0.82	2.11	0.96	0.60
FeO	3.79	4.26	0.39	2.36
CaO	0.02	0.29	0.05	0.12
MgO	42.36	39.44	43.30	39.50
H_2O+ ...	15.17	11.11	12.52	12.69
H_2O- ...	0.47	0.10	0.75	0.45
TiO_2 ...	Nil			
MnO	0.94			
CO_2	0.38			
Cr_2O_3 ...	0.48			
NiO	0.35			
Total	99.68	99.97	100.02	100.61

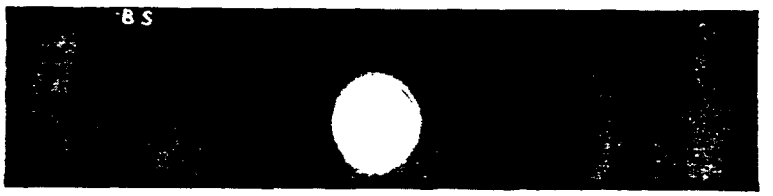

Figure 1.
S—serpentine line; B—brucite line.

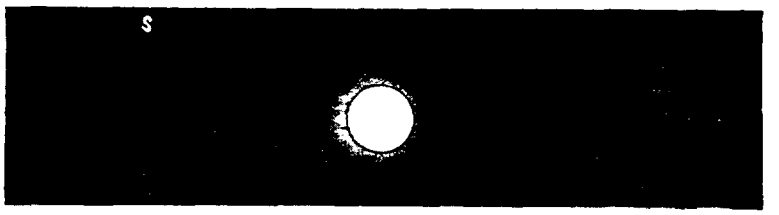

Figure 2.
S—serpentine line.

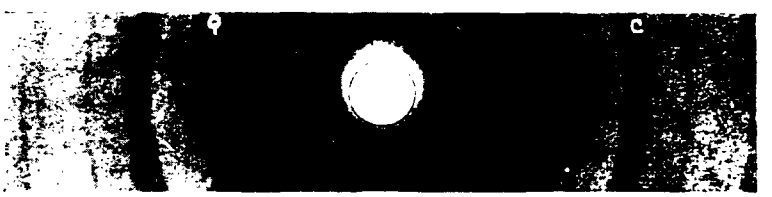

Figure 3.
C—chrysotile line; Q—quartz line.

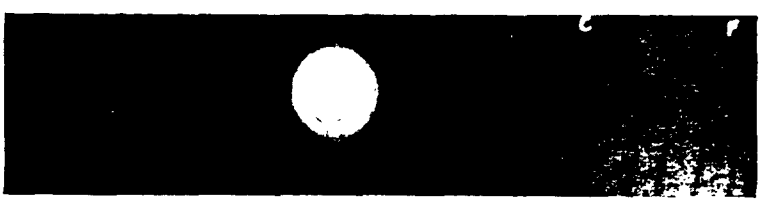

Figure 4.
C—chrysotile line; F—iron line.

analysis did not quite agree with the chemical analysis; this points to the difficulty of interpreting the chemical data.

Sample 4

Sample 4 represented a chrysotile fiber from the Johnson mine which was "darkened and made brittle apparently by the blackened zone close to the acid dyke". The chemical analysis (Table 1) indicated chrysotile asbestos, with Al_2O_3 and FeO and an excess of SiO_2 present. The data, when recast into minerals, showed the possible presence of chlorite, brucite, and silica.

The X-ray diagram did not show brucite, silica as quartz, or chlorite. The chemical analysis, however, indicated an excess of SiO_2 over the amount required by the MgO to form asbestos. This SiO_2 may have been in the form of amorphous SiO_2, which would not show in the X-ray diagram; or it may have been in combination with the minor constituents shown by the chemical analysis, and the compounds thus formed are not in sufficient quantity to produce an X-ray diagram. The X-ray film did indicate iron as Fe_3O_4 or Fe_2O_3.

Emission spectroscopy of this sample showed the presence of Al_2O_3, 0.20%; Fe_2O_3, 4.2%; and CaO, 0.03%. These spectroscopic data did not agree with the chemical analysis, again pointing to the difficulty of identifying the true minerals present.

Sample 7

Sample 7 represented a so-called "high-grade chrysotile asbestos taken from the Beaver mine". The chemical analysis (Table II) showed minor amounts of iron and aluminum, possibly indicative of the presence of other minerals. The re-cast data indicated chlorite, brucite, and periclase.

The X-ray diagram did not show lines for brucite, chlorite, or periclase; although the chemical analysis indicated a slight excess of MgO it was not identified in the X-ray diagram. Iron as Fe_2O_3 did appear in the X-ray diagram. Emission spectroscopy showed the presence of Al_2O_3, 0.12%; Fe_2O_3, 1.70%;; and CaO, 0.03%.

Sample 8

Sample 8 represented a "high-grade chrysotile asbestos taken

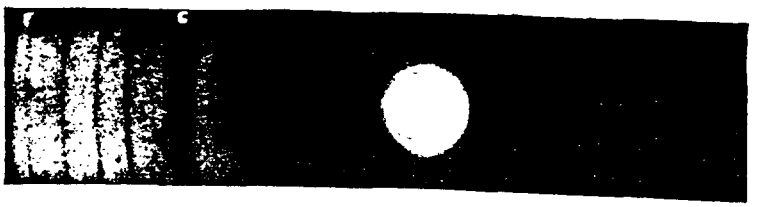

Figure 5.
C—chrysotile line; F—iron line.

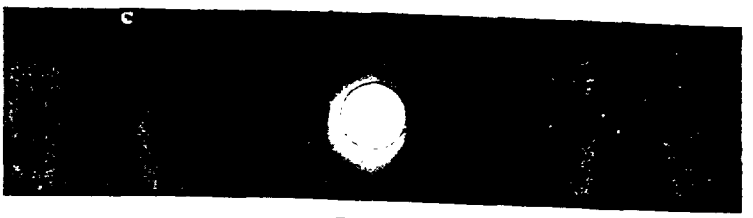

Figure 6.
C—chrysotile line.

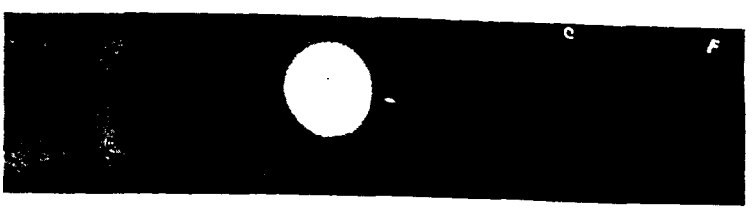

Figure 7.
C—chrysotile line; F—iron line.

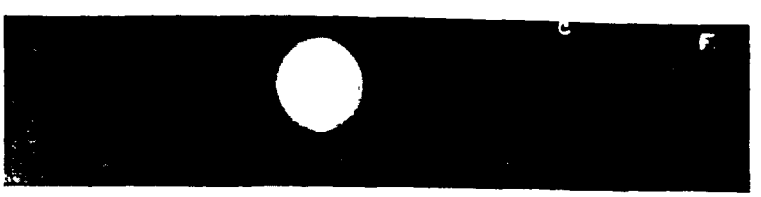

Figure 8.
C—chrysotile line; F—iron line.

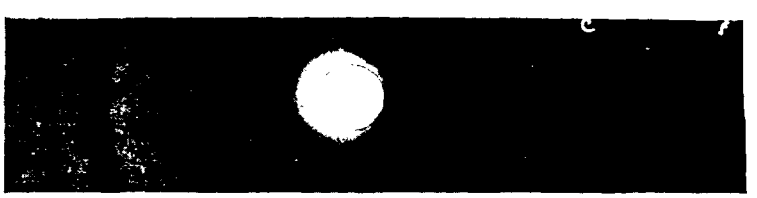

Figure 9.
C—chrysotile line; F—iron line.

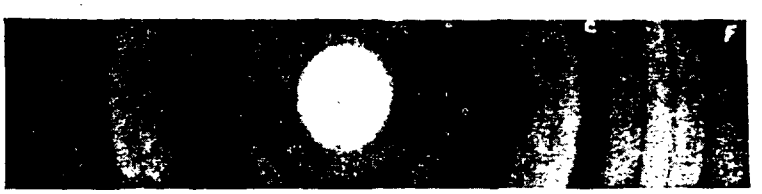

Figure 10.
C—chrysotile line; F—iron line.

from Deloro township, Province of Ontario". The chemical analysis (Table II) showed the presence of Al_2O_3, Fe_2O_3, FeO, and CaO as impurities. The re-cast data indicated the possible presence of chlorite, talc, and periclase.

The X-ray diagram did not show chlorite, talc, brucite, or periclase. If these minerals were present, the quantities were insufficient to produce an X-ray diffraction pattern. Emission spectroscopy demonstrated the presence of Al_2O_3, 0.07%; Fe_2O_3, 1.0%; and CaO, 0.02%; amounts which differ from the chemical analysis.

Sample 9

Sample 9 is a chrysotile fiber from the "British Canadian mine at Black Lake". The fiber is further identified as a semi-harsh type, *i.e.*, not actually brittle, but not soft and silky. The chemical analysis (Table II) showed small amounts of Al_2O_3, Fe_2O_3, and CaO, and almost 2 per cent FeO. Calculated in terms of minerals, the presence of chlorite, talc, and periclase was indicated.

The X-ray diagram did not reveal the presence of brucite, chlorite, or periclase, but it did show small amounts of Fe_3O_4.

Emission spectroscopy showed the presence of Al_2O_3, 0.16%; Fe_2O_3, 4.4%; and CaO, 0.02%. If Fe_3O_4 were present originally it was probably oxidized to Fe_2O_3 by the ignition process in preparing the fiber for this test.

Sample 10

Sample 10 is an extraordinary chrysotile asbestos fiber of harsh texture bordering upon a brittle nature. It is from the "Vimy Ridge mine in Coleraine township". The chemical analysis (Table II) indicated a low MgO-SiO_2 ratio, a low combined water content, as well as a high percentage of Fe_2O_3. Recast in terms of minerals, the presence of chlorite, talc, and periclase was indicated.

The X-ray pattern did not show lines for brucite, talc, periclase, or chlorite. If these minerals were present they must have been in very small quantities, not detectable by the X-ray technique.

Emission spectroscopy showed Al_2O_3, 0.52%; Fe_2O_3, 3.0%; and CaO, 0.03%; amounts which do not agree with the chemical data.

TABLE II.—ANALYSES, SAMPLES 7 TO 10

	7	8	9	10
SiO_2....	41.13	42.40	41.80	42.95
Al_2O_3...	0.80	0.14	0.64	Nil
Fe_2O_3...	1.01	0.97	0.80	2.08
FeO....	0.58	0.19	1.89	0.84
CaO....	0.03	0.14	0.14	0.19
MgO....	43.24	43.09	42.18	41.60
H_2O+...	12.74	12.60	12.07	10.26
H_2O-...	0.45	0.45	0.20	1.61
Totals.	99.98	99.98	99.72	99.53

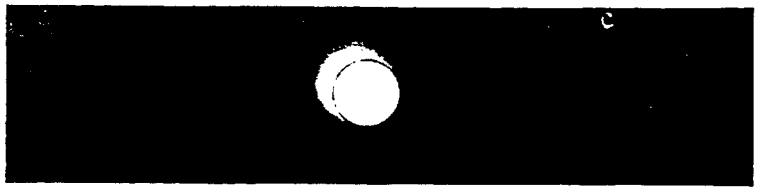

Figure 11.
C—chrysotile line.

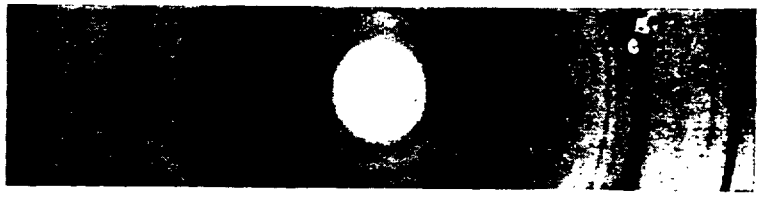

Figure 12.
B—brucite line; C—chrysotile line (barely visible).

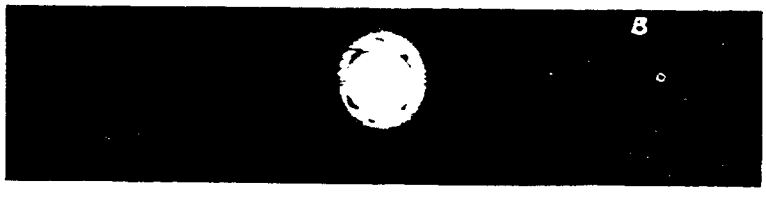

Figure 13.
B—brucite line.

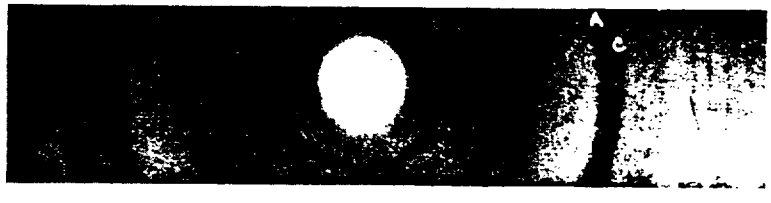

Figure 14.
C—chrysotile line; A—antigorite line.

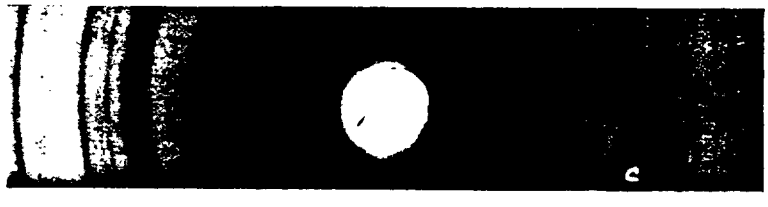

Figure 15.
C—chrysotile line.

Sample 15

Sample 15 represented a type of "slip serpentine taken from a broad fault-zone, drift 505X, King mine, Thetford". The analysis (Table III) showed some impurities, such as Fe_2O_3 and FeO. Re-cast in terms of minerals, chlorite, brucite, and periclase were indicated.

The X-ray diagram showed no trace of brucite, periclase, or chlorite; however, the diffraction lines for chrysotile and iron are clearly defined.

Sample 16

Sample 16 is another specimen of "slip serpentine taken from a fault-zone in drift 504X of the King mine, Thetford". The analysis (Table III) showed that the SiO_2 was slightly low, and the MgO rather high, for serpentine. Minor constituents were Al_2O_3, Fe_2O_3, FeO. and CO_2. The data, re-cast as minerals, suggest the presence of chlorite, brucite, and hydromagnesite.

The X-ray diagram showed no trace of brucite, chlorite, or hydromagnesite. It did show, however, chrysotile, and iron as Fe_3O_4.

Sample 17

Sample 17 represented a "tough, stringy fiber from a fault, drift C502E, near D505X, King mine, Thetford". Chemical analysis (Table III) showed substantial amounts of Fe_2O_3 and FeO. Re-cast of the analysis in terms of minerals indicated the presence of chlorite, brucite, and periclase.

The X-ray diagram showed no trace of chlorite, brucite, or periclase, but the chrysotile line is well defined.

Sample 18

Sample 18 was a "soft, chrysotile asbestos fiber taken from drift 304, King mine, Thetford". It was further identified by Dr. Cooke as a fault fiber. The chemical analysis (Table III) showed relatively large amounts of Al_2O_3, Fe_2O_3, and FeO, indicating considerable contamination. SiO_2 was extremely low, H_2O very high, and MgO unusually high, indicating a peculiar fiber composition. Re-calculated data indicated that the minerals present might be brucite, chlorite, and periclase, with brucite comprising 57.61 per cent of the sample. This is an interesting sample for further investigation.

The X-ray diagram showed a very high percentage of brucite, with some chrysotile present. No evidence of chlorite or periclase was indicated by the X-ray diagram.

TABLE III.—ANALYSES, SAMPLES 15 TO 21

	15	16	17	18	19	20	21
SiO_2	42.45	39.24	40.61	14.97	0.59	42.16	40.63
Al_2O_3	Nil	0.03	0.49	1.58	0.57	0.41	2.27
Fe_2O_3	0.56	1.13	1.49	1.61	0.93	1.99	1.78
FeO	1.13	0.55	1.07	2.61	6.09	1.72	2.53
CaO	0.09	0.07	trace	0.07	0.19	0.09	0.32
MgO	42.78	42.93	42.31	56.69	62.01	40.00	39.88
H_2O+	12.98	14.20	13.27	22.46	28.76	12.08	12.47
H_2O-	0.39	0.36	1.36	0.76	0.14	0.37	0.47
MnO					0.32		
NiO							
TiO_2							
CO_2		1.49				0.47	
Total	100.38	100.00	100.60	100.75	99.60	99.29	100.35

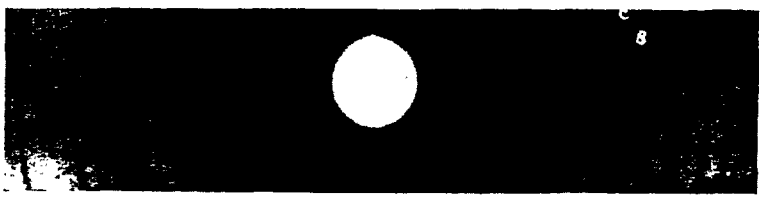

Figure 16.
C—chrysotile line; B—brucite line

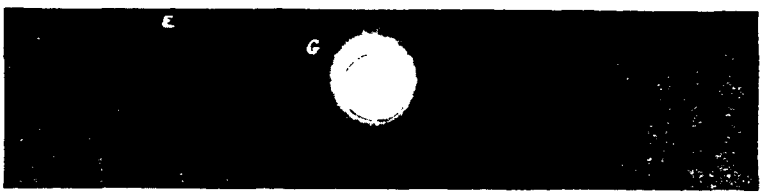

Figure 17.
G—grammatite line; E—epidote line.

Sample 19

Sample 19 was a "fault fiber taken from the Beaver mine at Thetford". Chemical analysis (Table III) indicated only small amounts of SiO_2, Al_2O_3, Fe_2O_3, and CaO, but a relatively high percentage of FeO. The MgO content (62 per cent), and the combined H_2O (28.76 per cent), indicated the presence of some magnesium mineral other than asbestos or serpentine. The re-calculated data by Cooke showed about 95 per cent brucite together with small amounts of chlorite, periclase, and magnetite.

The X-ray diagram showed that the specimen was practically all brucite. The diagrams displayed no evidence of chlorite, periclase, or magnetite.

Sample 20

Sample 20 was identified as a "green, fibrous picrolite taken from a fault plane at the 300-foot level in the King mine in Thetford". Chemical analysis showed (Table III) SiO_2 and MgO, the chief constituents, were in about the right proportion to form serpentine, but the presence of relatively large amounts of Fe_2O_3 and FeO suggested an admixture of other minerals.

Re-calculated data indicated the presence of chlorite, talc, periclase, and hydromagnesite.

The X-ray diagram showed the material to be chrysotile and antigorite. No evidence of chlorite, talc, periclase, or hydromagnesite was observed.

Sample 21

Sample 21 was described as a "semi-fibrous picrolite filling vein at the 300-foot level in the King mine at Thetford". Chemical analysis showed (Table III) that it contained appreciable amounts of Al_2O_3, Fe_2O_3, and FeO denoting the presence of other minerals than picrolite. Re-cast of the analysis indicated that there might be chlorite (19.12%), talc (2.23%), and periclase (0.92%).

The X-ray diagram did not show lines for brucite, chlorite, talc, or periclase, but it did show the diffraction line for chrysotile.

*Sample 50**

Sample 50 was described as a "tough stringy fiber forming cross-fiber veins at drift 505X in the King mine, Thetford". It was more specifically identified as a soft-chrysotile fiber. Chemical analysis (Table IV) showed the presence of Al_2O_3, Fe_2O_3, FeO, and CaO, as well as a small amount of Na_2O and K_2O. Re-cast by Dr. Cooke in terms of mineral composition the analysis indicates that chlorite 8.01%, and brucite 9.19%, may be associated with the chrysotile in this sample.

The X-ray diagram disclosed the presence of chrysotile and brucite, but no chlorite.

*Sample 63**

Sample 63, described as "pseudo-asbestos", represented fibrous veins in the footwall of the Federal pit near Robertsonville, Quebec. The analysis is given in Table IV. This specimen was an interesting sample for X-ray analysis since it showed a high percentage of Al_2O_3, Fe_2O_3, FeO, and CaO, with MgO exceedingly low.

The X-ray diagram showed lines corresponding to grammatite (tremolite) and epidote.

Conclusion

Chemical analyses of chrysotile, picrolite, and other varieties of serpentine invariably, or almost invariably, show that, in addition to the MgO, SiO_2, and H_2O necessary to form chrysotile of theoretical composition $H_4Mg_3Si_2O_9$, they contain

TABLE IV.—ANALYSES, SAMPLES 50 AND 63*

	Sample 50	Sample 63
SiO_2	37.44	46.36
Al_2O_3	0.58	11.39
Fe_2O_3	1.23	9.30
FeO	0.54	3.18
CaO	0.20	18.47
MgO	43.49	8.94
H_2O+	14.60	1.87
H_2O-	1.71	0.12
TiO_2	—	0.05
MnO	—	0.61
NiO	—	0.15
Na_2O	0.28	—
K_2O	0.05	—
	100.12	100.44

also a small, or in some specimens a very appreciable, percentage of Al_2O_3, Fe_2O_3, FeO, etc. By re-casting the analyses in terms of minerals these may be assigned to various minerals such as brucite, chlorite, periclase, and hydromagnesite, which may or may not actually be present admixed with the chrysotile. Except when in very small amount, definite verification of the presence of one or more of these minerals can be made by application of X-ray diffraction, emission spectroscopy, or petrographical methods of examination. These methods, and in particular the X-ray diffraction method, have been used in the present investigation of specimens of serpentine from a number of asbestos mines in the Eastern Townships of Quebec, and of one from Deloro township, Ontario. A critical study of chemical, and re-cast mineral, analyses of the specimens had been made earlier by Dr. H. C. Cooke, who very kindly supplied the writers with the material used in their investigation.

For some specimens, the X-ray diffraction patterns confirmed the mineral composition as derived by Dr. Cooke in his mineral re-cast of the chemical analysis; for some others, in which the extraneous mineral or minerals were in very small amount, diffraction lines for these did not appear. Clearly, with a sample containing two or more minerals, only those present in sufficient quantity to give diffraction lines can be definitely identified as being present.

Samples of the latter type were analyzed by emission spectroscopy and in a general way, though not quantitatively, the results were in agreement with those derived by Dr. Cooke from his study of the chemical analyses. Petrographic examinations under the microscope were also helpful in cases where doubt existed.

This investigation has indicated that no one method is adequate in itself for complete and positive identification of all the minerals present in a sample. For this it is necessary to resort to a combination of several methods. For complete identification of all the minerals present in samples obtained in prospecting or in drill cores of asbestos bodies, not only chemical analyses but also the results of X-ray diffraction, spectrograhic, and petrographic studies are necessary.

Acknowledgments

Chemical data used in this paper were taken from G.S.C. *Memoir* 211, by the late Dr. H. C. Cooke, and from a paper by him in the *Transactions* of the Royal Society of Canada, Volume XXIX, 1935.

This investigation was initiated six years ago after a discussion with Dr. Cooke, in Ottawa, on the use of X-ray technique for identification of minerals. Dr. Cooke supplied all samples used in the investigation.

The assistance of Mr. Charles Whinfrey, formerly of the Johns-Manville Research Center, who made the preliminary X-ray studies, is appreciated.

*The descriptions and chemical analyses of samples 50 and 63 are reproduced from the paper by Dr. H. C. Cooke in Volume XXIX, 1935, of the *Transactions* of the Royal Society of Canada. Numbering of the samples is the same as in that paper.