ASBESTOS

Asbestos is a generic term describing a variety of naturally formed hydrated silicates that, upon mechanical processing, separate into mineral fibers. There are two fundamental varieties of asbestos: serpentine and the amphiboles. Serpentine asbestos is known as chrysotile and the amphiboles include five species identified as anthophyllite, amosite, crocidolite, actinolite, and tremolite. Each of these varieties of asbestos differ from each other chemically as illustrated in Table 1.

Asbestos fibers are unique minerals combining unusual physical and chemical properties which make them useful in the manufacture of a wide variety of residential and industrial products. Of mineral origin, asbestos does not burn, does not rot, and, dependent on variety, possesses extremely high tensile strength as well as resistance to acids, bases, and heat. Similarly, when processed into long, thin fibers, asbestos is sufficiently soft and flexible to be woven into fire-resistant fabrics.

Historical records show that asbestos has been known for more than 2000 years. Applications of this noncombustible fiber are mentioned by Plutarch and Pliny, particularly with reference to asbestos textiles used for cremation cloths, oil lamp wicks, etc.

The asbestos industry *per se* had its inception in the 18th century in the Russian Ural mountains and by the mid-19th century both Italian chrysotile and tremolite varieties were mined and processed into commercial products. At the same time asbestos was discovered and mined on a commercial scale at Thetford Asbestos in Quebec, Canada. To this day, these Canadian and Russian locations are the major producers of chrysotile asbestos.

The amphibole asbestos industry is of more recent origin. Blue asbestos, crocidolite, was discovered in South Africa about 1803 to 1806, but it was not until 1893 that this variety was commercially exploited. Production, sale, and use of the amosite species from the Transvaal followed in the early 20th century (1).

Origin and Occurrence

Through the years, the origin of asbestos has been the subject of extensive geological research. Serpentine asbestos occurs under widely differing geological conditions from the amphiboles. Similarly, the modes of occurrence or the manner in which the fibers are physically imbedded in the host rock also differ widely. The current opinion is that chrysotile fiber resulted from two separate metamorphic reactions in ultrabasic

Table 1. Asbestos

Species	CAS Registry Number	Variety	Chemical composition
chrysotile[a]	[12007-29-5]	serpentine	$3MgO.2SiO_2.2H_2O$
anthophyllite	[17068-78-9]	amphibole	$7MgO.8SiO_2.H_2O$
amosite[a]	[12172-73-5]	amphibole	$11FeO.3MgO.16SiO_2.2H_2O$
actinolite	[13768-00-8]	amphibole	$2CaO.4MgO.FeO.8SiO_2.H_2O$
tremolite	[14567-73-8]	amphibole	$2CaO.5MgO.8SiO_2.H_2O$
crocidolite[a]	[12001-28-4]	amphibole	$Na_2O.Fe_2O_3.3FeO.8\ SiO_2.H_2O$

[a] Asbestos species of major commercial significance.

rocks of igneous origin. The initial hydrothermal reaction altered the olivines and pyroxenes to serpentine. At a subsequent point the serpentine was redissolved and the mineral-rich solutions flowed into cracks and crevices in the host rock where chrysotile fiber was reprecipitated.

In this reprecipitation process, asbestos fiber was usually deposited in a cross-vein mode of occurrence; ie, the fiber is arranged perpendicular to the wall rock as illustrated in Figure 1.

In some cases, chrysotile was either deposited or affected by earth movements such that the fibers lie principally parallel to the wall rock as illustrated in Figure 2. This mode of occurrence is referred to as slip fiber.

The third and unusual mode of occurrence of chrysotile is referred to as a massive or agglomerated form wherein the fibers have been deposited as platelets having no specific fiber orientation. This unique formation has been found and commercially mined in the New Idria serpentine deposits of California (2) and at Stragari, Yugoslavia. In these cases the asbestos content of the ore is abnormally high, but the fiber length is very short as compared to commercially useful cross-vein or slip fiber deposits. This mode of occurrence is illustrated in Figure 3.

The origin of the amphibole varieties of asbestos are not as clearly defined as those of chrysotile. The two commercially significant amphibole fibers, crocidolite and amosite, occur in metamorphosed sedimentary strata known as banded ironstones. These sedimentary formations vary considerably in composition which accounts for the compositional variations of the associated amphibole fibers (1).

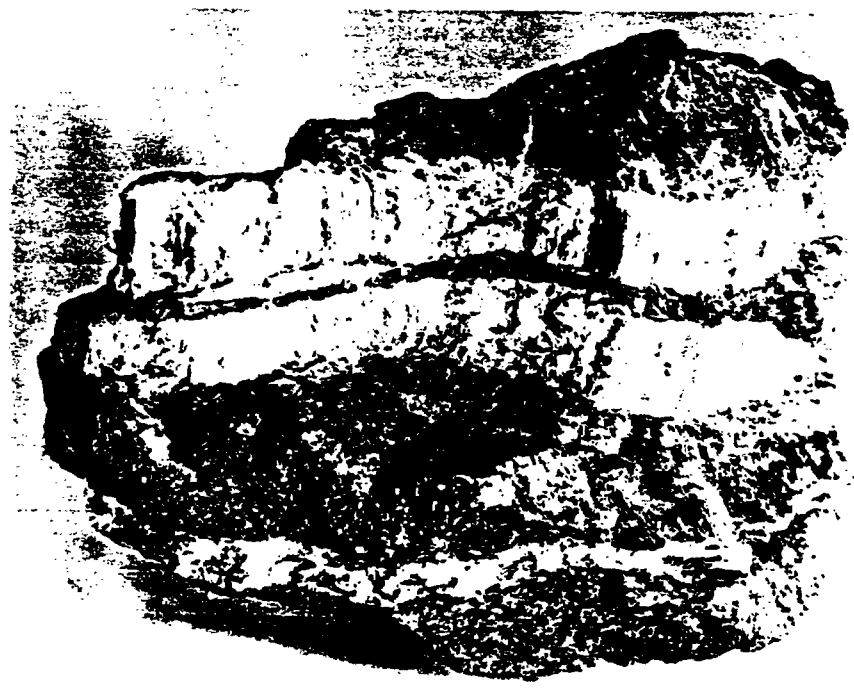

Figure 1. Cross-vein chrysotile (Courtesy of Johns-Manville Research Center).

Figure 2. Slip fiber chrysotile (Courtesy of Johns-Manville Research Center).

Crocidolite and amosite species of asbestos occur in cross-vein modes and the anthophyllite and tremolite species often occur in slip modes although both of the latter can also occur in a massive mode wherein the fibers are nonoriented. Actinolite, a noncommercial species of amphibole asbestos, is most often found as brittle, acicular, or bladed forms in a massive mode.

In its generic connotation, asbestos is a mineral found all over the world. In most cases, however, the asbestos species most easily located are those having limited or no commercial utility such as actinolite, anthophyllite, or tremolite. In 1977, Canada and Russia are the major producers of chrysotile asbestos, and Africa, China, and the United States provide modest quantities. The major producing area of the important amphiboles, crocidolite, and amosite is Africa. In fact, the only deposits of amosite known to date are in the Eastern Transvaal.

Chrysotile Asbestos

Crystal Structure. The mineral species associated with the serpentine group, serpentine [*12168-92-2*], chrysotile, lizardite [*12161-84-1*], and antigorite [*12135-86-3*], although differing structurally, are compositionally almost identical. All have the approximate chemical composition of $Mg_3(Si_2O_5)(OH)_4$. The crystal structure of chrysotile is layered or sheeted similarly to the kaolinite group [*1318-74-7*] (3–4). It is based on an infinite silica sheet $(Si_2O_5)_n$ in which all the silica tetrahedra point one way (see Silica). On one side of the sheet structure, and joining the silica tetrahedra, is a layer of brucite, $Mg(OH)_2$, in which two out of every three hydroxyls are replaced by oxygens at the apices of the tetrahedra. The result is a layered structure illustrated in Figure 4 (1,5).

Figure 3. New Idria (Coalinga) chrysotile platelets (Courtesy of Johns-Manville Research Center).

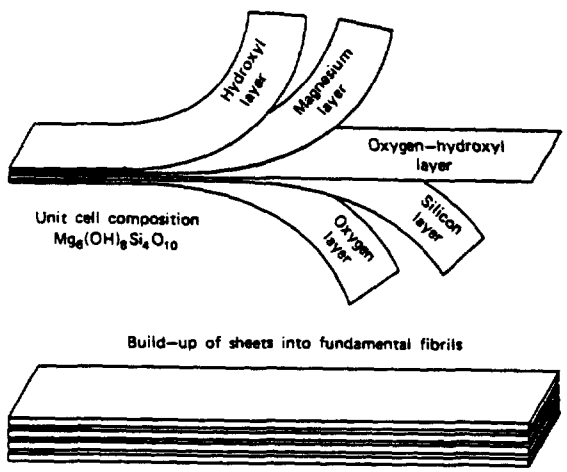

Figure 4. Fundamental sheet of a chrysotile structure.

Mismatches and strains between the layers cause the structure to curve and form cylinders or fibers (6–7). Individual chrysotile fibers have ultimate diameters of 0.02–0.03 μm. X-ray and electron microscope studies have confirmed this cylindrical form and diameter range. In fact, the first electron microphotographs indicated a tubular structure as illustrated in Figure 5 (8–10). This characteristic appearance has now become one of the more definitive identification techniques for chrysotile.

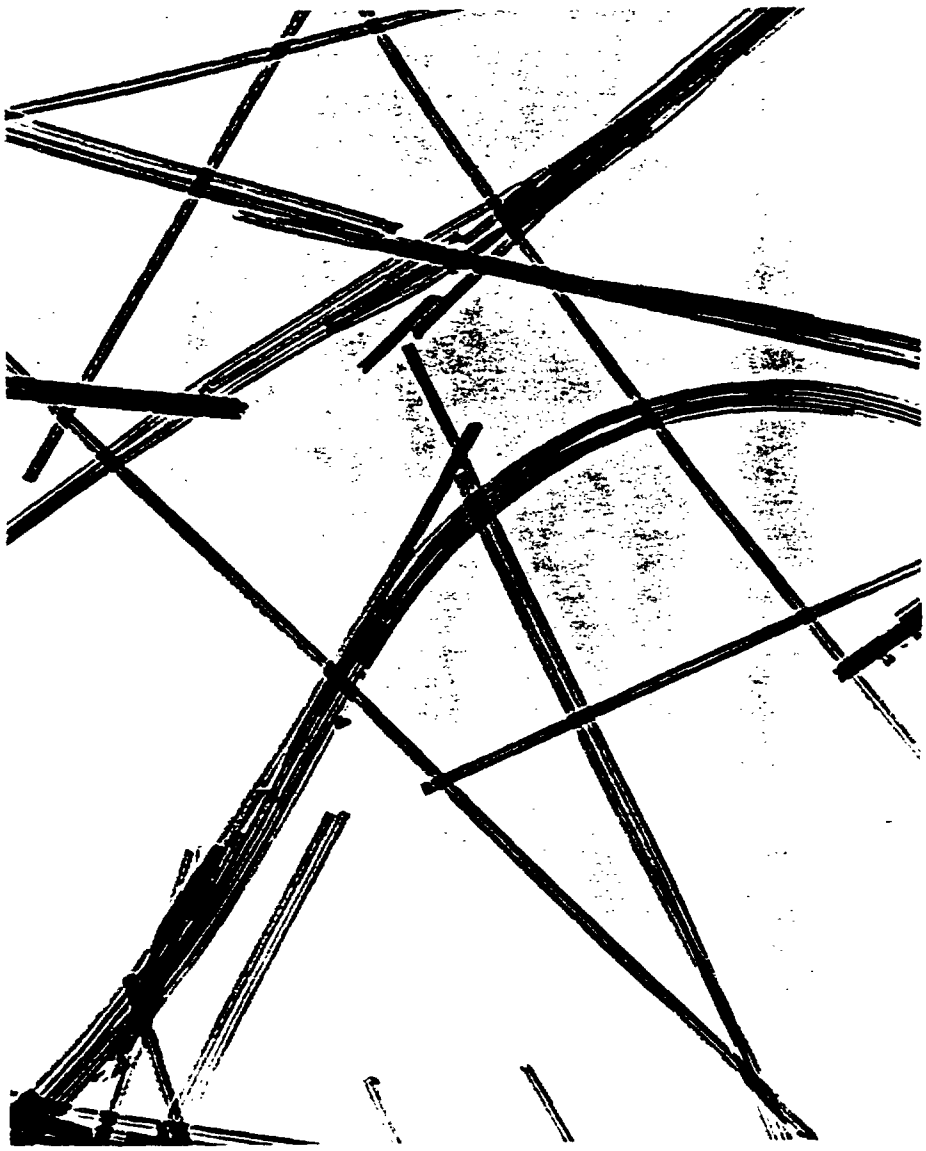

Figure 5. Electron photomicrograph (80,000×) of chrysotile (Courtesy of Johns-Manville Research Center).

Electron microphotographs have shown most chrysotile fibers with a hollow cylindrical form and a single magnesia–silica sheet rather than the earlier double-layer concept (11–12). The lattice planes have a multispiral arrangement as suggested by earlier x-ray studies (13).

Chemical and Surface Properties. Chrysotile asbestos is a naturally formed mineral. The chemical compositions vary somewhat, depending on deposit location, from the idealized composition of $Mg_3(Si_2O_5)(OH)_4$. Chemical analyses of chrysotile range approximately as follows: SiO_2, 37–44%; MgO, 39–44%; FeO, 0–6.0%; Fe_2O_3, 0.1–5.0%; Al_2O_3, 0.2–1.5%; CaO, trace–5.0%; H_2O, 12.0–15.0%. Variations in chemical analyses may be due to either associated mineral impurities or to isomorphic substitutions in the crystal lattice. Common mineral impurities found in commercial grades of chrysotile from various locations include magnetite, chromite, brucite, calcite, dolomite, and awaruite. Within the chrysotile lattice, nickel and iron can occur as minor isomorphic substitutions for magnesium (14–17). Chrysotile, a hydrated silicate, is subject to thermal decomposition at elevated temperatures. This thermal decomposition is a two-stage reaction consisting first of a dehydroxylation phase and then a structure phase change. Dehydroxylation or the loss of water occurs at 600–780°C. At 800–850°C the anhydride breaks down to forsterite and silica. These reactions are irreversible and are illustrated by the typical differential thermal analysis shown in Figure 6.

Structural changes in chrysotile can occur under conditions of intense grinding. As a result of these effects the structure can become amorphous and no longer identifiable by either x-ray diffraction or electron microscopy. These structural changes apparently occur because of localized temperature surges in the fibrils with accompanying dehydroxylation as they absorb the tremendous impact energies, eg, extensive dry ball milling results in an amorphous mass and wet ball milling results in short fibrils that retain their crystallinity (16).

Because of its hydroxyl outer layer, chrysotile is readily attacked by acid and will, ultimately, completely dissolve the magnesium component, leaving essentially a fibrous, but fragile, silica structure. Similarly, because of its alkaline surface, chrysotile is not readily attacked by caustic solutions except under conditions of extreme alkali concentration and elevated temperatures (18–19).

Dispersions of chrysotile fiber in carbon dioxide-free distilled water exhibit al-

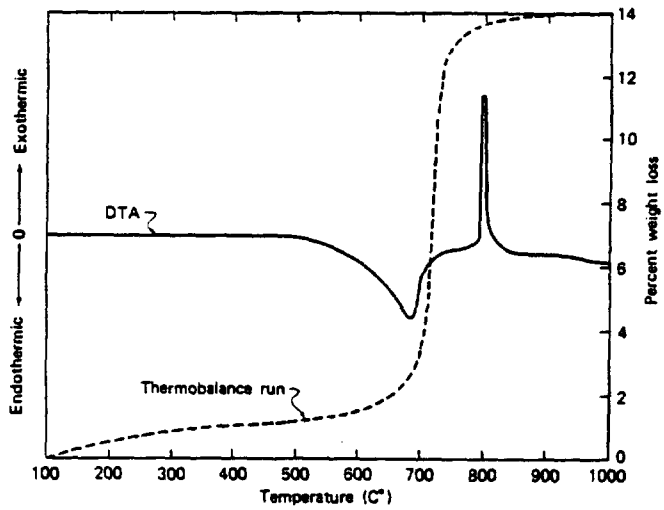

Figure 6. Typical differential thermal analysis of chrysotile.

kaline properties. Such suspensions will reach a pH of 10.33 as with magnesium hydroxide suspensions tested under the same conditions. Solubility product constants for chrysotile fibers range from 1.0×10^{-11} to 3×10^{-12}, indicative of the magnesium hydroxide outer layer (20–22).

The electrokinetic behavior of chrysotile is also related to its surface characteristics. Normally, below its isoelectric point of approximately pH 11–12, chrysotile exhibits a positive charge. Above this pH range, it demonstrates a negative charge. Exceptions to this general behavior have been noted with chrysotile fibers from certain locations (23).

Because of its very small fiber diameter, its high specific surface area and its relatively reactive surface, chrysotile is a selectively adsorptive material. Commercial grades of chrysotile adsorb as much as 2–3 wt % moisture from saturated air. Adsorption studies of a variety of organic compounds from both vapor and liquid media show that chrysotile has a greater affinity for polar molecules. Heats of adsorption have been measured ranging from 38 kJ/g (9 kcal/g) for hexane to 67 kJ/g (16 kcal/g) for water (5,24–27). Chrysotile also adsorbs iodine from solutions in a manner similar to magnesium hydroxide or brucite. This adsorption characteristic is often used as a staining technique for the detection of chrysotile asbestos (28).

Physical Properties. The common physical properties of chrysotile asbestos are given in Table 2.

Asbestos fibers are used in composite materials (qv) to provide reinforcement. Tensile strength of the fiber is, therefore, an important and highly significant physical property. Unfortunately, because of their extremely fine diameter and the complicating factor of the effect of sample length on strength determinations, it is extremely difficult to measure the tensile strengths of asbestos with precision. Most recent information indicates typical chrysotiles have tensile strengths in the order of 3727 MPa (5.4×10^5 psi) which exceeds corresponding values for steel piano wire and fiber glass. A comparison of typical strength values for the different asbestos varieties is given in Table 3. Since all these measured values are far less than the theoretical value of over 10,000 MPa (1.45×10^6 psi) attributable to silicate chain structures, the values given should be considered as relative for the different varieties rather than specific (1,29–31).

Physical strengths of asbestos are adversely affected by elevated temperatures. Table 4 shows decreasing tensile strength as dehydroxylation takes place (1).

What visually appears to be a single fiber in commercial grades of asbestos is in actuality a bundle of a large number of individual fibrils. These bundles can be subdivided into a multitude of finer bundles, but only with special processing can a large portion of fiber mass be divided to its ultimate fibril diameter. The specific surface areas of commercial asbestos fibers vary with the extent of mechanical defibrillation. Surface areas by nitrogen adsorption tests on samples teased by hand from chrysotile crude are 4–12 m^2/g; however, when aggressively milled or fiberized, surface areas of 30–50 m^2/g result (32). Chrysotile asbestos can be separated into smaller diameter fibrils (higher specific area) more readily under wet processing conditions than under dry mechanical milling. For this reason many asbestos product manufacturing processes utilize wet opening techniques to provide improved fiber reinforcing efficiencies.

The term harshness in the asbestos industry refers to the fiber's brittleness, flexibility, form, and modulus of elasticity. Commercial grades of chrysotile are usually

Table 2. Properties of Asbestos Fibers

	Chrysotile	Anthophyllite	Amosite (ferroanthophyllite)	Crocidolite	Tremolite	Actinolite
structure	in veins of serpentine, etc	lamellar, fibrous asbestiform	lamellar, coarse to fine fibrous and asbestiform	fibrous in iron-stones	long, prismatic and fibrous aggregates	reticulated long prismatic crystals and fibers
mineral association	in altered peridotite adjacent to serpentine, and limestone near contact with basic igneous rocks	in crystalline schists and gneisses	in crystalline schists, etc	in iron-rich silicious argillite in quartzose schists	in Mg limestones as alteration product of highly magnesian rocks, metamorphic and igneous rocks	in limestone and in crystalline schists
origin	alteration and metamorphism of basic igneous rocks rich in magnesium silicates	metamorphic, usually from olivine	metamorphic	regional metamorphism	metamorphic	results of contact metamorphism
veining	cross and slip fibers	slip, mass fiber unoriented and interlacing	cross fiber	cross fiber	slip or mass fiber	slip or mass fiber
essential composition	hydrous silicates of magnesia	Mg silicate with iron	silicate of Fe and Mg, higher iron than anthophyllite	silicate of Na and Fe water	Ca and Mg silicate with some water	Ca, Mg, Fe, silicates, water up to 5%
crystal structure	fibrous and asbestiform	prismatic, lamellar to fibrous	prismatic, lamellar to fibrous	fibrous	long and thin columnar to fibrous	long and thin columnar to fibrous
crystal system	monoclinic (pseudoorthorhombic?)	orthorhombic	monoclinic	monoclinic	monoclinic	monoclinic

crystal structure	fibrous and asbestiform	lamellar to fibrous	fibrous		fibrous	columnar to fibrous
crystal system	monoclinic (pseudoorthorhombic?)	orthorhombic	monoclinic	monoclinic	monoclinic	monoclinic
color	white, gray, green, yellow	gray–white, brown, gray, or green	ash gray, green, or brown	lavender, blue	gray–white, green, yellow, blue	green
luster	silky	vitreous to pearly	vitreous, somewhat pearly	silky to dull	silky	silky
hardness, Mohs	2.5–4.0	5.5–6.0	5.5–6.0	4	5.5	*ca 6*
specific gravity	2.4–2.6	2.85–3.1	3.1–3.25	3.2–3.3	2.9–3.2	3.0–3.2
cleavage	010 perfect	110 perfect	110 perfect	110 perfect	110 perfect	110 perfect
optical properties	biaxial positive extinction parallel	biaxial positive extinction parallel	biaxial positive extinction parallel	biaxial extinction inclined	biaxial negative extinction inclined	biaxial negative extinction inclined
refractive index	1.50–1.55	ca 1.61	ca 1.64	1.7 pleochroic	1.61	1.63 weakly pleochroic
fusibility, Seger cones	fusible at 6, 1190–1230°C	infusible or difficult to fuse	fusible at 6, loses water at moderate temperatures	fusible at 3, 1145–1170°C	fusible at 4, 1165–1190°C	fusible at 4, 1165–1190°C
flexibility	very flexible	very brittle, nonflexible	good, less than chrysotile	fair to good	generally brittle, sometimes flexible	brittle and nonflexible
length	short to long	short	5–28 cm	short to long	short to long	short to long
texture	soft to harsh, also silky	harsh	coarse but somewhat pliable	soft to harsh	generally harsh, sometimes soft	harsh
acid resistance	soluble up to approximately 57%	fairly resistant to acids	fairly resistant to acids	fairly resistant to acids	fairly resistant to acids	relatively insoluble in HCl
spinnability	best	poor	fair	fair	generally poor, some are spinnable	poor
specific heat, J/(kg·K) [or Btu/(lb·°F)]	1113 [0.266]	879 [0.210]	908 [0.217]	841 [0.201]	887 [0.212]	908 [0.217]

Table 3. Tensile Strength of Asbestos[a]

	Tensile strength, MPa (psi × 10^3)	Young's modulus, GPa (psi × 10^6)
chrysotile, Arizona, USA	3780 (548)	145 (21.1)
chrysotile, Thetford, Canada	3640 (528)	146 (21.2)
crocidolite, Koegas, Cape Province, Africa	2840 (413)	147 (21.3)
crocidolite, Koegas, Cape Province, Africa	3090 (448)	151 (21.9)
crocidolite, Pomfret, Cape Province, Africa	4660 (675)	169 (24.5)
crocidolite, Pomfret, Cape Province, Africa	3550 (515)	175 (25.3)
crocidolite, Cochabambo, Bolivia	1440 (209)	170 (24.6)
amosite, Penge, Transvaal, Africa	2580 (374)	143 (20.8)
amosite, Penge, Transvaal, Africa	1980 (287)	143 (20.8)
anthophyllite, Paakilla, Finland	2450 (356)	156 (22.6)

[a] See ref. 1.

Table 4. Effect of Temperature on Tensile Strength of Asbestos[a]

	Percentage of original tensile strength		
Temperature, °C	Chrysotile	Crocidolite	Amosite
200		100	100
320	91.6	70	58
430	73.3	32	32
550	59.5	20	15
670	32.0		
period of heat soak	3 min	4 h	4 h

[a] See ref. 1.

classed as soft or nonharsh. Commonly, they are silky, of fine diameter, and extremely flexible. Contrary to chrysotile, the commercial amphiboles are harsh fibers. They are relatively stiff, brittle, coarser in diameter, and rodlike in appearance under the microscope. These differing physical characteristics account for the different operating characteristics exhibited in the manufacture of various asbestos-containing products. For example, soft chrysotiles can be more readily spun into textiles than the amphiboles but they have poorer drainage properties when used in wet manufacturing processes. However, several fiber treatments have been developed to improve the filtration or drainage properties of chrysotile and thereby increase the production rate of wet machines manufacturing asbestos–cement products (33–37).

Amphibole Asbestos

Crystal Structure. The structure of all the amphiboles consists of two chains or ribbons based on Si_4O_{11} units separated by a band of cations. Seven cations form the basal unit. Two hydroxyl groups are attached to the central cation in each unit cell. These hydroxyls, unlike the chrysotile structure, are contained entirely within the amphibole structure. The final structure is composed of stacks of these sandwich ribbons as illustrated in Figure 7 (1,5). The bonding between these ribbons is rather weak and the crystals are easily cleaved parallel to the ribbons along cleavage line A-A. If the cleavage is very facile, the result is an asbestiform mineral (1,5). Amphiboles

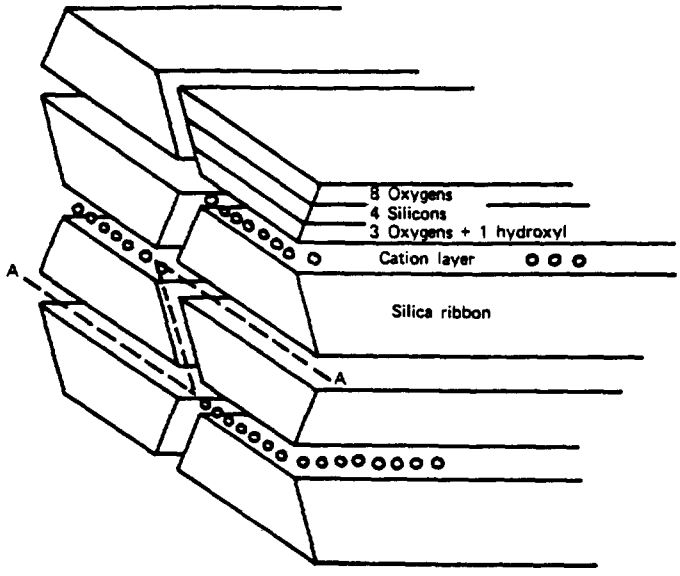

Figure 7. Amphibole structure.

can also occur in nonfibrous forms (38) which may result because of structural disorder (39). The dominant cations are Mg^{2+}, Fe^{2+}, Fe^{3+}, Na^{+}, and Ca^{2+} (see Table 1). Minor isomorphic substitutions of Al^{3+}, Ti^{4+}, K^{+}, and Li^{+} also occur. Because of the wide compositional range, the amphiboles are often assigned to three generic series; ie, the anthophyllite–cummingtonite [*17499-08-0*] series, the calcic amphiboles and the soda amphiboles.

Chemical and Surface Properties. The chemical compositions of the amphibole fibers are more complex and variable than chrysotile. Typical compositions are shown in Table 5.

Like chrysotile, the amphibole asbestos fibers dehydroxylate and decompose at elevated temperatures. The presence of large quantities of iron (particularly ferrous iron) makes the decomposition or thermal analysis determinations particularly complex and very dependent on the composition of the atmosphere. Table 6 is an

Table 5. Typical Chemical Compositions of Amphibole Asbestos

	Crocidolite, %	Amosite, %	Anthophyllite, %	Actinolite, %	Tremolite, %
SiO_2	49–53	49–53	56–58	51–52	55–60
MgO	0–3	1–7	28–34	15–20	21–26
FeO	13–20	34–44	3–12	5–15	0–4
Fe_2O_3	17–20			0–3	0–0.5
Al_2O_3	0–0.2		0.5–1.5	1.5–3	0–2.5
CaO	0.3–2.7			10–12	11–13
K_2O	0–0.4	0–0.4		0–0.5	0–0.6
Na_2O	4–8.5	trace		0.5–1.5	0–1.5
H_2O	2.5–4.5	2.5–4.5	1–6	1.5–2.5	0.5–2.5

Table 6. Decomposition Reactions of Amphiboles Under Neutral Conditions[a]

Amphibole variety	Dehydroxylation DTA peak, °C	Structural breakdown, °C	Decomposition products
crocidolite	610	800	Na–Fe pyroxene, magnetite, silica
amosite	780	600–900	Fe–Mg pyroxene, silica
anthophyllite	950	950	Mg–Fe pyroxene, magnetite, silica
actinolite	1040	1040	CaMgFe pyroxene, silica

[a] See ref. 1.

oversimplification of the thermal decomposition reactions of the amphibole fibers (1,40).

Compared to chrysotile, the amphibole fibers are relatively acid resistant. However, under boiling conditions and high acid concentrations the amphiboles can exhibit weight losses of approximately 2–20%. Relative order of acid resistance is:

tremolite > anthophyllite > crocidolite > actinolite >

amosite >>> chrysotile

Amphibole fibers have a negative charge as contrasted to chrysotile's usual positive charge. The magnitude of the charge exhibited by the amphiboles is substantially lower than chrysotile's.

Physical Properties. See Table 2 for the more common physical properties and characteristics of the various amphibole fibers. In general, amphibole fibers are harsh, springy, and brittle as compared to the chrysotile variety. These physical properties make the amphiboles fast draining and bulky when used in manufacturing processes.

As illustrated in Table 3, the tensile strengths of amphibole asbestos fibers differ widely. The typical tensile strengths of asbestos fibers have the order:

crocidolite > chrysotile > amosite > anthophyllite >

tremolite > actinolite

As shown in Table 4, the amphiboles also lose their strength with increasing temperature.

Amphibole fibers do not divide into fibrils as fine in diameter or as symmetrical as the chrysotile variety. Ultimate diameters of amphiboles have been reported to be about 0.1 μm (1) and the surface areas of amphibole asbestos are considerably smaller than chrysotile. Fully fiberized commercial grades of crocidolite, for example, have surface areas by gas adsorption of 3–15 m^2/g compared to the 30–50 m^2/g values of chrysotile (2,41).

Milling

Imbedded asbestos fibers are removed from the ore by a repeated series of crushing, fiberizing, screening, aspirating, and grading operations (milling). A typical, greatly simplified asbestos mill is shown in Figure 8. The ore is crushed, dried, and fiberized in a variety of impact mills. The short fiber and granular material is removed by screening the fiberized mass. The oversized fractions are stratified on a screen where the spherical, granular material of high density seeks the screen's surface and the fluffy, low-density fiber rises to the top of the bed. At the end of the screen, the fiber is separated from the rock by an aspirating hood. The coarse granular fractions that still contain veins of chrysotile fiber, are refiberized and rescreened to recover shorter fibers. Fibers recovered from these primary screening operations are rescreened to remove entrapped granular material and classified into grades by fiber length.

The recovery of milled asbestos fiber from ore is fairly low. In general, a 5% recovery is typical. The chrysotile mines in California are notable exceptions where 50% recoveries are common from agglomerated ores (Fig. 3). The fibers, however, are very short and are normally sold as reinforcing fillers (qv).

Conventional asbestos milling uses large quantities of air both for separating the fibers as they are freed from the ore and for dust control. Approximately 130 m^3/s (275,000 cfm) are used to process one metric ton of ore (42). Preconcentration of ore includes selective grinding, screening, and magnetic techniques (43–45).

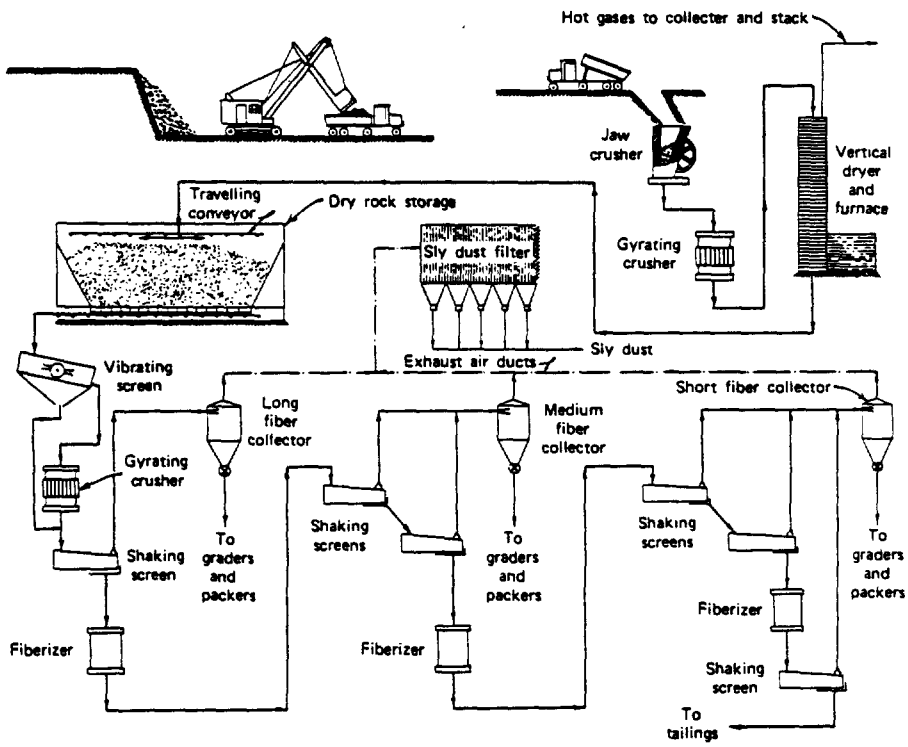

Figure 8. Schematic of a typical asbestos milling flowline.

Production and Usage

In 1977, 80% of the world's chrysotile was produced by Canada and Russia. Most of the Canadian production is from Quebec and the balance from Newfoundland, British Columbia, and the Yukon Territory. Russian production is predominantly in the Bazhenovo District in the Central Urals, the Dzhetygara area northwest of Kazakhstan, and the Aktourak deposits near the Yenisei River.

Crocidolite and Amosite are produced in significant quantities only in South Africa. Main producing areas are at Bosrand, Cornheim, Ouplaas, Owendale, the Kuruman area in the Cape Province, and the Lydenburg District in the Transvaal (46).

Production statistics vary widely with the source of information. Table 7 summarizes ranges given by various authorities (47–53).

The largest use of asbestos is in asbestos–cement for products such as pipes, ducts, and flat and corrugated sheets. Pipe products find use in water supply, sewage disposal, and irrigation systems. Asbestos–cement sheets are used in a wide variety of construction applications. Other uses of asbestos include fire-resistant textiles, friction materials (see Brake linings), underlayment and roofing papers, and floor tiles. Table 8 shows the uses of asbestos in the United States (the largest consumer) and the world. The United States usage patterns differ considerably from the rest of the world (54–56).

Standards and Test Methods

Classification. Canadian chrysotile crudes are classified as follows:

crude #1:	1.9 cm staple and longer
crude #2:	0.95 cm to 1.9 cm staple
crude run of mine:	unsorted crudes

Table 7. 1976 Asbestos Production

Type and location	Thousands of metric tons
Chrysotile	
Canada	1537
USSR	2285
South Africa	111
Rhodesia (estimate)	239
China (estimate)	150
Europe	321
USA	104
South America	69
Australia	66
others	45
Total chrysotile	*4927*
Amphiboles (South Africa)	
crocidolite	178
amosite	79
anthophyllite	2
Total amphiboles	*259*
Total asbestos	*5186*

Table 8. Asbestos Usage by Product Line Estimated Percent of Production

Product line	United States consumption, %	World consumption, %
asbestos–cement	23–30	65–70
asbestos papers	26–38	7–8
floor tile	13–21	4–7
friction materials	6–8	2–3
roof coatings	4–7	2–3
textiles	1–2	1–4
plastics	1–2	trace–1
miscellaneous	12–20	13–15

Milled Canadian fibers sold from Quebec are classified by a dry screen technique known as the Quebec Standard Asbestos Test. This test method grades fibers roughly by fiber or staple length. Minimum test values are guaranteed for each grade and a numerical classification system has been established for fibers ranging from Group 3, the longest grade, to Group 7, the shortest grade.

Chrysotile fibers produced outside Quebec are graded or controlled by screening test methods differing from the Quebec Screen Test; however, these basically identify grade by staple length.

Test Methods. The major properties of concern are length, granular content, degree of openness or effective surface area, drainage or filtration rate, color, absorption, electrical resistivity, bulk density, and strength-giving properties (57).

Fiber length is most reliably measured by wet screening techniques. Fiber openness is commonly measured by air permeability surface area methods. A variety of filtration tests are used to estimate a fiber's operating performance in asbestos–cement wet machines or paper machines. Granular content is often determined by a dry screening test where the fibrous material is aspirated from the granular impurity remaining on the various screen meshes.

The most complex measurement is the determination of the strength-giving property of a fiber for use in asbestos–cement products. In this case, small pressed sheets are made from a slurry of fiber and cement. After curing, the sheet strength is determined and the reinforcing effectiveness or value of the fiber is calculated.

Health and Safety Factors

The inhalation of excessive quantities of free asbestos fibers over prolonged periods of time can increase the risk of developing certain diseases of the lung within 20 or 30 years. The three diseases associated with the inhalation of asbestos are: asbestosis, a nonmalignant fibrotic lung condition; bronchogenic (lung) carcinoma; and mesothelioma, a rare cancer of the lining of the chest or abdominal cavities (58).

Reduction of asbestos dust exposure is at present the only known method of preventing disease among asbestos industry workmen. When dust levels are low, risk to employees and the incidence of asbestos-related disease drop sharply. Cigarette smoking greatly increases the risk of developing bronchogenic cancer among persons encountering heavy asbestos exposure. Nonsmoking asbestos workers show no greater incidence of bronchogenic cancer than the average nonsmoker.

There are governmental regulations (OSHA) that describe the allowable airborne fiber levels in work areas. Extensive dust control together with corrective work practices are used to implement these regulations and medical examinations are regularly provided to assure worker protection (see Air pollution control methods; Industrial hygiene and toxicology).

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