In Asbestos and Disease by Selikoff IJ, 1978

2

Asbestos Minerals: Nature, Occurrence, and Properties

As indicated in Chapter 1 (Historical Background), the term asbestos was given to naturally occurring fibrous materials, later found to be minerals, which showed the properties of relative indestructibility and resistance to fire. That pragmatic definition could be applied to a number of minerals. Today we would limit it to naturally occurring, commercial, fibrous minerals of the serpentine or amphibole series. Fibrous forms of other minerals, such as wollastonite, fibrous brucite, or fibrous forms of calcite or gypsum would not be included (108). Even so, a certain heterogeneity is seen in the minerals encompassed, and some difficulty is experienced in fitting the commercial names for various varieties of asbestos to chemical or mineralogical classifications.

Asbestiform minerals fall into two major subdivisions: chrysotile, which belongs to the serpentines, and the amphiboles, including crocidolite, actinolite–tremolite, amosite, and anthophyllite (686). A large number of trade and mining terms have been applied to the asbestos minerals. For example, names that have been used for crocidolite vary greatly with the variety and location: potential crocidolite, asteriated crocidolite, amorphous riebeckite rock, asteriated mass–fiber riebeckite, acicular crocidolite, griqualandite, and tiger-eye, not to mention the well known blue asbestos; the scientific mineralogical names are now the rule (686). [A]

The crystalline structure of chrysotile is that of a layer of magnesium oxide–hydroxide octahedra bonded to a layer of silicon dioxide tetrahedra in somewhat mismatched fashion that produces a curvature in

the sheet (265,708). The sheet, consequently, tends to roll itself into a hollow tube or possibly a tight spiral (708) with the magnesium hydroxide on the outer surface. This hollow tube constitutes the basic fibril of chrysotile. Fibrils, bonded together, constitute fibers and the fibers in turn may be banded together to build up the macroscopic material. Theoretically any given piece of chrysotile can be successively split until the ultimate fibrils are reached, but the ease of fiberization varies with the particular ore.

In contrast with the chrysotile crystal, amphiboles consist of double chains of linked silicon–oxygen tetrahedra lying parallel to the vertical crystallographic axis and bound laterally by metallic ions (Fig. 2–1). There is no tendency for such layers to roll into tubes. The Si–O bonds along the chain are much stronger than the metallic ion bonds between chains, so that the amphiboles break lengthwise with ease, giving a fibrous appearance. In the occasional incorrect use of the term "fibril" for amphiboles writers presumably are referring to assemblages of a small number of molecular aggregates.

GEOLOGICAL FORMATION

Although the amphiboles are major participants in rock formation, asbestiform amphiboles rarely occur in concentrated deposits that can be economically developed. Chrysotile, on the other hand, is not a common rock-forming mineral, but it does occur in a number of large scale deposits. Details of the origin of the asbestos deposits have not been completely resolved. The present account, intended as background to discussions of asbestos use and its biomedical effects, has been drawn from a number of reviews which should be consulted for further information and specific references (108,328,628,686,708).

Chrysotile was apparently formed in fractures in serpentine rocks. These rocks were formed over geological time from the interaction of hydrothermal solution and pressure. Hot, mineralized water entered the fractures and dissolved the serpentine host. As the temperature and pressure dropped, fibrous crystals of hydrous magnesium silicate began to grow out of solution from both sides of the fissure. Where the rocks remained immobile relative to each other, the crystals continued to grow at right angles to the walls, forming what is now called the "cross-fiber" form of chrysotile. But if the rocks on either side moved laterally, the fibers were constrained towards an orientation parallel to the surfaces, to produce the "slip-fiber" form. In this form the fibers tend to be longer, but may have been physically weakened by the

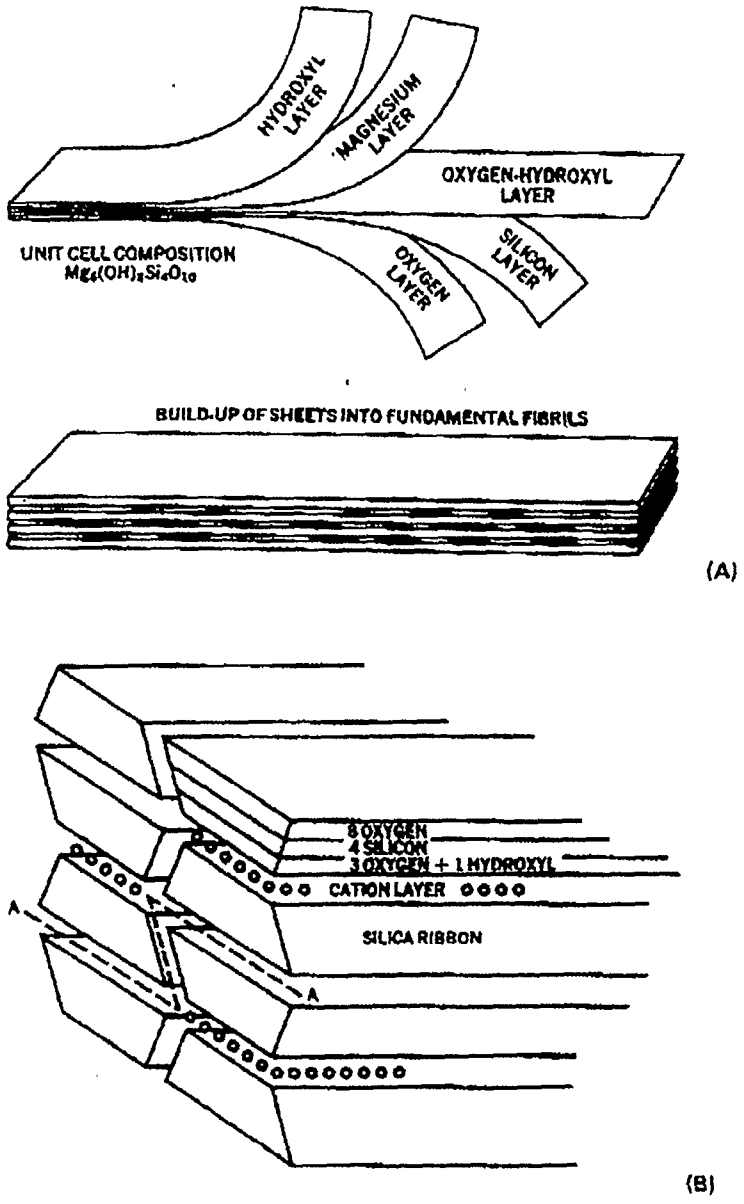

Fig. 2-1. Fundamental crystalline structure of asbestos minerals: (A) chrysotile; (B) amphibole (708). Reproduced with the kind permission of S. Speil.

stresses. In an intermediate form, the fibers became somewhat bent in the middle as the shear progressed, with the development of a weakness at the point of flexion. As may be expected, the fractures, and thus the veins of chrysotile, follow an erratic pattern, sometimes running independently for various distances, at other times forming a fairly

dense network (stockwork). Sometimes the fibers were formed in a hollow space of limited dimensions to produce lenticulated masses of fibers with rather random orientation that are referred to as "mass-fiber" forms. Sedimentary rocks, in addition to igneous rocks, may have been serpentinized with a later formation of chrysotile (686). Chrysotile is found in most countries which mine asbestos, except Finland.

In contrast to chrysotile deposits, the amphiboles crocidolite and amosite are found in altered sedimentary rocks often referred to as banded ironstones. The minerals in this case seem to have been formed *in situ* by a chemical rearrangement and recrystallization under heat and pressure. The veins may lie in parallel bands or bedded planes. The cross-fiber form is typically found, but mass-fiber forms occur. Amosite is found largely in South Africa; some deposits are known recently in India. Crocidolite occurs in significant amounts in South Africa, China, Australia, and Bolivia.

Actinolite–tremolite and anthophyllite are usually found in the mass-fiber form in pockets in either igneous or metamorphic rocks. The first pair also occur in limestone or dolomite that has undergone recrystallization, in which case they may be associated with talc or mica. Commercial deposits of anthophyllite are found in Finland, Bulgaria, and the United States. Italy and Japan produce some tremolite. More extensive notes on the occurrence are given in the "Asbestos Fact Book" (35).

CHEMICAL CHARACTERISTICS

Attention will be given here to the more general aspects of asbestos chemistry, with some detail of those aspects that may enter into the problem of identification or into the biomedical reactions to be discussed in later chapters. Considerably more detail can be found elsewhere (71,108,708,790).

Chemical Composition

Table 2–1 gives the ranges of gross composition of the asbestiform minerals. It will be seen that chrysotile shows less variability than the amphiboles. Crocidolite and amosite contain more silica and much more of the iron oxides, but much less magnesium oxide than chrysotile. Anthophyllite, tremolite, and actinolite also contain more silica than chrysotile but are intermediate in their content of mag-

TABLE 2-1

Chemical Composition of Asbestos Types[a,c]

	Amosite	Antho-phyllite	Crocidolite	Actinolite–Tremolite[b]		Chrysotile
SiO_2	49–53	56–58	49–53	51–56	55–60	41.8–42.0
Al_2O_3	—	0.5–1.5	0–0.2	1.5–3	0–2.5	0.1–0.5
Fe_xO_x	—	—	17–20	0–3	0–0.5	0.2–1.3
FeO	34–44	3–12	13–20	5–15	0–4	0.1–1.6
MgO	1–7	28–34	0–3	15–20	21–26	41.8–42.8
CaO	—	—	0.3–2.7	10–12	11–13	0–0.1
Na_2O	trace	—	4–8.5	0.5–1.5	0–1.5	0–trace
K_2O	0–0.4	—	0–0.4	0–0.5	0–0.6	0–0.1
H_2O	2.5–4.5	1–6	2.5–4.5	1.5–2.5	0.5–2.5	13.6–14.0

[a] Common trace elements (ppm): Ag, Ba, Ce, Co, Cr, Cu, Li, Mo, Nb, Mn, Ni, Su, Sr, Th, V, Zr. Based on superior analyses of museum quality representative fibers.
[b] Compositions at the actinolite and tremolite ends of a continuous series.
[c] With kind permission of International Agency for Research on Cancer.

nesium oxide. [Data given by various compilers agree in broad features but may vary in detail. See, for example, the tables prepared by the Commission of the European Communities (809).] [A]

The comparative composition is indicated in the three-dimensional diagrams of Fig. 2–2.

The general formula for chrysotile may be written: $Mg_3Si_2O_5(OH)_4$. By contrast, the chemical composition of the amphibole species is extremely complex. A theoretical general formula might be written as follows: $(Ca,Na,Mn)_{2-3}\cdot(Mg,Fe,Ti,Al,Mn)_5\cdot(Si,Al)_8\cdot O_{22}\cdot(OH,F)_2$, the elements within a parentheses being somewhat interchangeable (790). The relationships of the amphibole compositions are indicated in the three-dimensional diagrams of Fig. 2–2.

A large number of minerals may be found in physical admixture with the asbestos fibers in the ores as mined. These cannot be removed by simple cleaning processes in the treatment of the ores and may affect the usefulness of the product. The exact composition of the final product may be a matter of great importance for special use. For example, magnetite intergrowths may adversely affect the operation of a transformer or other electrical equipment if present in large quantities in asbestos coverings (71). [A]

Surface Characteristics

The outer surface of chrysotile fibers, as mentioned earlier, consists largely of $Mg(OH)_2$ and behaves as such. The equilibrated pH in carbon

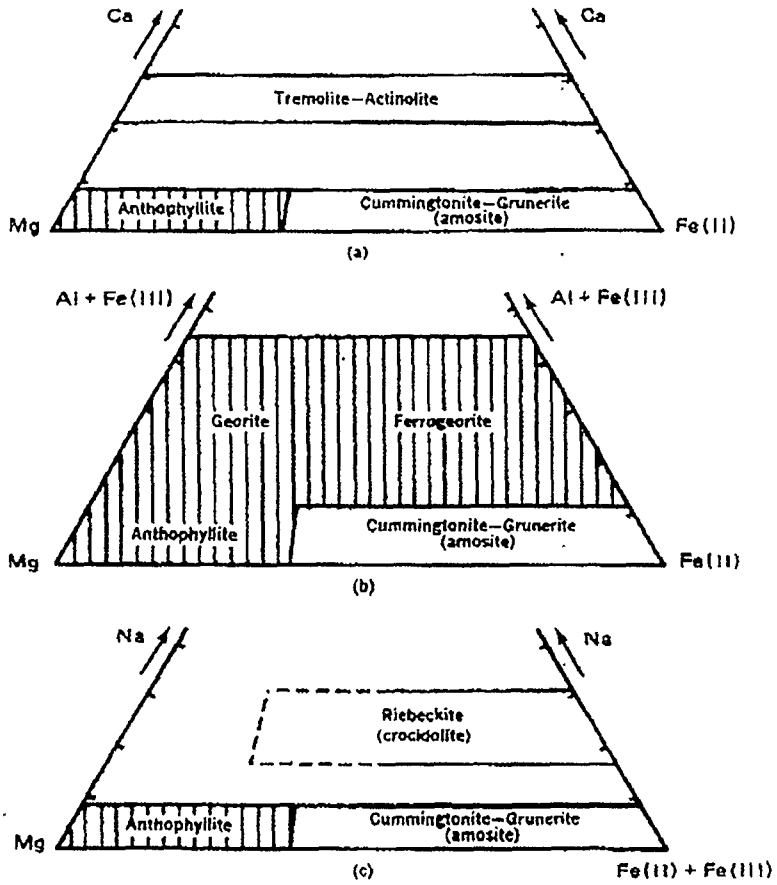

Fig. 2–2. Schematic diagrams of three-component fields for the composition of amphiboles. The values plotted are the relative numbers of the ions specified expressed as percentages of their sum (790). Reproduced with the kind permission of E. J. W. Whittaker and the publishers of *Acta Crystallographica*.

dioxide free distilled water is 10.33. The surface charge in water is positive at a pH lower than 11.8 and rises to a maximum at a pH of 3. With higher acidities the charge falls off rapidly as magnesium ions are removed and the silica surface is exposed (708). This positive charge renders chrysotile attractive to most other materials in solution which carry a negative charge. The surface of amphiboles, on the other hand, is like that of silica and carries a small negative charge in water.

The specific surface area of chrysotile varies with the extent to which the fibers are pulled apart, from 4 m^2/g in fibers pulled manually from a block of ore to 50 m^2/g when individual fibers are separated. The specific surface area of amphiboles is lower, varying from 5 to 15 m^2/g as the sample is fiberized (708). By comparison, the specific surface area of

organic fibers varies for 0.3 m^2/g for nylon to 0.98 m^2/g for viscose rayon (628).

As might be expected from its large specific surface area and its molecular configuration, chrysotile adsorbs gases fairly readily, particularly those which have highly polar molecules such as water. In a liquid, adsorption can be complicated by competition between the solvent and the solute. The affinity of chrysotile for liquid organic compounds, in decreasing order, is ethanol, butanol, benzene > naphthalene > anthracene > hexane. The adsorptivity of amphiboles seems not to have been well studied (708), except for some recent papers from the National Institute of Occupational Safety and Health (287,288).

Metal impurities may be associated with asbestos not only as chemical substitutes in the crystalline structure, but also as fragments of the host rock or as additions to the surface by various processing equipment. Table 2–2 gives the ranges of contamination with trace metals

TABLE 2–2

Ranges of Trace Metal Contamination in Asbestos Samples from Different Regions (524)[a]

Type	Fe (%)	Cr (ppm)	Co (ppm)	Mn (ppm)	Ni (ppm)	Sc (ppm)
Chrysotile	0.6–4.8	317–1390	43–110	231–720	540–1820	0–12
Amosite	massive	31–35	7–11	11800–13350	33–100	0–5
Crocidolite	massive	16–20	0.4–10	140–880	8–100	0–0.6
Anthophyllite	2.0–4.4	584–870	24–50	986–1060	414–1360	0–5

[a] With kind permission of A. Morgan and *IARC*.

reported at the 1972 meeting of the Working Conference of the International Agency for Research on Cancer (524).

Other surface properties affecting biological reactions will be discussed in Part III.

Chemical Reactivity

The concept of asbestos as being relatively indestructible cannot be extended to the application of chemical agents, particularly in the case of chrysotile. After treatment with 1 *N* HCl for 1 hour at 100°C, the typical X-ray diffraction pattern of chrysotile completely disappears, but was found to be unchanged after 6½ hours of treatment with 0.12 *N* HCl at 37°C, although there was 50% decomposition of the fibers (784). Apparently under the less drastic conditions, a sufficient number of the inner layers of the fibrils remain to continue to give the typical diffraction pattern.

When crocidolite was treated with 5 *N* HCl at 100°C, 20% was destroyed in 3 minutes, but the reaction slowed thereafter, possibly because of the formation of a protective coat of polymerized silica (735). In general, the amphiboles are less affected by acids than is chrysotile; with crocidolite, tremolite and anthophyllite the most resistant (Table 2–3). Amosite and actinolite apparently show an intermediate reactivity.

TABLE 2–3

Solubility of Asbestos Minerals in 25% Acid and Caustic (708)[a]

	% Loss in weight, refluxing 2 hr with				
Type	HCl	CH_3COOH	H_3PO_4	H_2SO_4	NaOH
Chrysotile	55.69	23.42	55.18	55.75	0.99
Crocidolite	4.38	0.91	4.37	3.69	1.35
Amosite	12.84	2.63	11.67	11.35	6.97
Anthophyllite	2.66	0.60	3.16	2.73	1.22
Actinolite	20.31	12.28	20.19	20.38	9.52
Tremolite	4.77	1.99	4.99	4.58	1.80

[a] With kind permission of S. Speil.

Amosite and actinolite are also somewhat susceptible to the action of strong alkalies, but the remaining asbestiform materials are resistant. The resistance of asbestos to reagents other than acids is good up to 100°C, but decreases rapidly at higher temperatures.

The following extract from the paper by Speil and Leineweber continues into chemisorption and chemical reaction what was said above about adsorptivity:

> In general, organic compositions possessing acidic functional groups dissolved in nonpolar or slightly polar solvents, such as benzene and methyl ethyl ketone [MEK], exhibit a strong tendency either to chemisorb or to slowly react with chrysotile. Long-chain aliphatic acids, such as stearic acid, oleic acid, and palmitic acid are chemisorbed by dry fiber. Aromatic-type acids, such as benzoic acid and related compounds, are also chemisorbed as are dibasic aliphatic acids, such as adipic acid. Although the unsaturated six-carbon sorbic acid appears to be chemisorbed by chrysotile, the related shorter carbon chain acrylic, crotonic acids show some evidence of slow reaction with the dry chrysotile even in nonpolar solvents and there is a tendency for the adsorbed layer to show an affinity for water. Maleic acid reacts with the bulk fiber.
>
> If the fiber contains adsorbed water, the interaction of an organic acid in benzene or MEK solutions differs markedly from that with the dry fiber. The long chain aliphatic acids, e.g., stearic, oleic, when dissolved in nonpolar or slightly polar solvents, show little or no tendency to sorb on fibers containing adsorbed water. Acids such as adipic, benzoic, or sorbic, which have some slight affinity for water, react with the bulk fiber structure instead of chemisorbing as they do on dry fibers. (708)

Chrysotile reacts with water, as suggested by the pH value 11.8 that develops in a suspension as mentioned above. It is slowly soluble under conditions of continuous extraction, even without heat. When boiling water is used, magnesium and orthosilicic acid appear in increasing concentrations over the first few hours. Sea water, as may be expected, brings about decomposition of chrysotile (304). From crocidolite, 4% of the silica and 6% of the sodium are removable by extraction with water (735).

As will be seen later, in Chapter 4 on identification, bombardment with an electron beam causes damage or even destruction of chrysotile fibers. Some deterioration has been reported in asbestos used in electrical insulation (686).

Although asbestos is not flammable, it is affected by heat and may need to be replaced in materials so exposed. The following changes are described by Rosato (628). The hygroscopic moisture in asbestos, as distinct from that incorporated in the molecule, is directly related to the relative humidity (R.H.) of the air with which it is in equilibrium and varies from approximately 1% by weight in air at 49% R.H. to 2.5% at 95% R.H. It is easily removed by subjecting the asbestos to a temperature of approximately 212°F (100°C), without damage to the fiber. But at higher temperatures it loses its water of crystallization and the mechanical properties such as mechanical strength may be changed. At about 800°F (427°C) amphibole asbestos generally loses a considerable part of the relatively small amount of its combined water and becomes extremely brittle. Chrysotile, on the other hand, loses only about 15% and retains its flexibility. Table 2–4 gives the percentages of loss in weight versus temperatures up to 1,800°F (982°C).

Further details on thermal disintegration are given in Speil and Leineweber's paper (708).

TABLE 2–4

Effect of Temperature on Loss in Weight of Asbestos Fibers (628)[a]

Temperature (°F) for 2 hr	Percentage loss in weight				
	Amosite	Anthophyllite	Chrysotile	Crocidolite	Tremolite
400	0.23	0.05	0.30	0.08	0.04
800	0.98	0.38	2.17	0.73	0.22
1,000	1.16	0.44	3.99	0.86	0.29
1,200	1.39	0.54	12.75	1.04	0.37
1,400	1.43	0.54	13.43	1.03	0.47
1,800	1.53	2.30	13.77	0.77[b]	2.18

[a] With kind permission of Reinhold Publishing Co., New York, and D. V. Rosato.
[b] Iron changing in weight by oxidation.

PHYSICAL CHARACTERISTICS

Color, Texture, and Flexibility

There is a good deal of variability in the color of asbestos, particularly of chrysotile, depending upon the exact content of cations and water of crystallization as is indicated in Table 2–5 taken from Berger (71). Data given by different compilers may vary in details (e.g. in 809).

TABLE 2–5

Pleochroism and Refractive Indices of Asbestos (71)[a]

Type	Alpha	Beta	Gamma	Refractive index
Chrysotile	Colorless/greenish yellow; all conceivable shades as axial and intermediate colors, depending on the composition		Green, yellow	1.50–1.57
Crocidolite	Green/light blue	Brown	Green, light blue	1.69–1.71
Amosite and anthophyllite	Yellow/colorless	Brown	Light yellow/ colorless	1.55–1.64
Tremolite	Green/yellow		Green	1.60–1.62

[a] With kind permission of Chemical Publishing Co., New York.

The texture of chrysotile varies from silky to quite harsh; that of crocidolite from soft to harsh. Amosite may be coarse or pliable; tremolite and anthophyllite vary from soft to harsh (328). Harshness is linked to the flexural modulus of the fibers; those with high values being harsh and relatively stiff and giving an open, bulky, and fairly porous mass. Flexible, soft fibers tend to form stringy and denser masses. Harshness has been variously related to the water content of the fiber, fine mineral intergrowths in the bundles, and the relative proportions of two crystallographic forms (708). The characteristics of soft and harsh chrysotile are given in Table 2–6. The important commercial property of susceptibility to spinning depends upon a combination of flexibility and length of the fiber. It is highest with the softer forms of chrysotile, fair for crocidolite and some amosites, and poor for other amphiboles.

Fiber Dimensions

The length of the fibers varies from very short to about 2 in. (5 cm) for chrysotile, from short to 3 in. (8 cm) for crocidolite, short to long for

TABLE 2–6

Characteristics of Soft and Harsh Chrysotile[a]

Property	Soft fiber	Harsh fiber
Fiber bundle		
Feel	Smooth, silky	Harsh, splintery
Tenacity (flexibility)	Flexible, may be bent at >90° without rupture	Stiff, ruptures at less than 90°
Size reduction (length)	Poor, resists fiber axis break	Good, easily broken across fiber axis
Fibrilization of bundle	Excellent to good, easily opened	Poor, tends to remain in tight bundles
Surface area (equal amount of materials identically size reduced)	Average Canadian sample = 23 m^2/g; some as high as 80 m^2/g	Average harsh = 11 m^2/g; some as low as 4 m^2/g
Individual fibrils		
Appearance under electron microscope	Fibrous, thin filaments moderately translucent	Lathlike, electron-dense bundles
Individual fibrils	Empty to partially filled capillary	Filled capillaries
Electron diffraction pattern	Arced reflections, disordered interfibril relationships	Single round or streaked reflections, ordered interfibril relationships
Physical properties (bulk sample)		
Porosity	High	Low
Filter rates	Slow	Fast
Filtrate clarity	Clear	Cloudy
Conductivity (2.9% suspension)	22.2 $ohms^{-1}\ cm^{-1}$ ($\times 10^4$) for average Arizona soft	11.9 $ohms^{-1}\ cm^{-1}$ ($\times 10^5$) for average Arizona harsh
Mg leach (% NaCl equivalent)	0.27	0.10
Chemical properties (bulk samples)		
Structural water (dry weight)	12.5–14.5%	11.0–12.5%
CaO content	Trace to nil (Arizona soft)	Trace to minor oxide (Arizona harsh)
Al_2O_3 content	Trace to minor oxide (Arizona soft)	Trace to nil (Arizona harsh)

[a] With kind permission of International Agency for Research on Cancer.

actinolite and tremolite, and very short and weak for anthophyllite. Extremely long fibers, from 0.5 to 6 in. (1–15 cm), and even up to 12 in. (30 cm), occur in amosite (686). A table of percentage distributions of fiber lengths for various types of asbestos is given in Berger's book (71). With processing of course, the fibers may be fragmented and considerably shortened in length from their original state.

The individual fibril of chrysotile is the finest natural fiber known as is indicated in Table 2–7, but the dimensions of the fibers obtained in

TABLE 2–7

Comparative Diameters of Fibers[a]

Material	Diameter	
	Microns (10^{-3} mm)	"Thous" (10^{-3} in.)
Chrysotile fibril	0.02–0.04	0.0007–0.0012
Chrysotile fibers	0.75–1.5	
Amphibole "fibril"	0.1–0.2	
Amphibole fibers	1.5–4.0	
Glass fibers	1–5	0.26
Rock wool	4–7	0.14–0.28
Slag fibers	3–5	
Flax, hemp, etc.	12–80	0.96
Cotton	10	0.40
Wool	20–28	0.80–1.10
Rayon, nylon	7–7.5	0.30
Spider web	7	
Human hair	40	1.60

[a] Based on data given in Berger (71). With kind permission of Chemical Publishing Co., New York.

practice, and particularly of amphiboles which do not have a natural fibrillar structure, depend upon the degree of separation achieved in processing. The diameters given for other natural fibers must, of course, be given a certain latitude as well. (One could rightfully ask whose hair or what wool is meant.)

Tensile Strength

The tensile strength of asbestos varies considerably with the length and diameter of the constituent fibers (708). Maximum values have been obtained for chrysotile and crocidolite of about 60,000 kg/cm^2, compared to a theoretical value of 100,000 kg/cm^2 (628). These values are

of the same order as those given for glass fiber and carbon steel and are somewhat greater than those for cotton and rock wool. Lindell has recently given somewhat different figures (461): 450,000 lb/in.^{2} for chrysotile, 500,000 lb/in.^{2} for glass fiber, 155,000 lb/in.^{2} for carbon steel, 73,000–89,000 lb/in.^{2} for cotton fiber, and 60,000 lb/in.^{2} for rock wool (lb/in.^{2} = 0.073 kg/cm^2) (see also 809). When chrysotile is heated to 300°C or above, the tensile strength is diminished; after 3 min at 650°C the strength may be reduced to one-third. Crocidolite may be durable up to 800°C (628). The tensile strength of tremolite and anthophyllite is generally weak. When rupture takes place, it is apparently due to failure of bonds between fibrils or molecular sandwiches, rather than disruption of those fundamental structures.

Thermal Insulative Value

The asbestos fiber itself does not have a low thermal conductivity, but when the fibers are separated they can trap air which has a very low conductivity and so provide insulation that, for heat flows in a constant direction, is comparable to that provided by similar materials made from other fibers. For heat loads that take place in alternate directions, such as on a roof exposed to the sun, the moderately high density of the material combines with the low conductivity to give one of the lowest values for thermal diffusivity, the governing physical attribute under these conditions. Table 2–8 gives the relative values of thermal conductivity and diffusivity for typical insulating materials, as compared with those for the metal over which they may be laid. Insulative value, of course, varies inversely with thermal conductivity and diffusivity.

TABLE 2–8

Comparative Insulative Properties (437)

Material	Thermal conductivity (cal cm^{-1} sec^{-1} °C^{-1} × 10^{-3})	Thermal diffusivity (cm^2 sec^{-1})
Air	6	0.2000
Cork	7–13	0.0013
Asbestos insulation	19–40	0.0007
Dry clay	200	0.0035
Steel	10,000–20,000	0.1282

As with most conventional materials other than polished metals, the emissivity of asbestos insulating materials for long infrared radiation at usual working temperatures is over 90% (628). If transmitted heat is to

be conserved or prevented from radiating to persons or surrounding objects, a layer of polished metal is needed on the surface.

Other Physical Properties

In Table 2–9 it will be seen that chrysotile provides less electrical insulation than do amphiboles, probably because of its high proportion

TABLE 2–9

Electrical Properties of Asbestos (71)[a]

Property	Chrysotiles	Amosite	Crocidolites	Anthophyllite
Aqueous extract (50 g fibers, 500 cm^3 water)				
Ionizable salts (equivalent % NaCl)	0.06–0.38	0.04–0.08	0.01–0.06	0.02–0.06
Electrical conductivity ($10^{-6}/\Omega$ cm)	120–560	75–160	75–125	25–115
Electrical conductivity ($10^{-6}/\Omega$ cm)	0.3–1.8	1.3	0.8	0.6
Dielectric constant (220V/60 cycles per sec)	33.7	—	6.7	8.4
Insulating ability [(Ω/cm) 15% relative humidity air, 22°C; 100 V/cm]	1.1×10^6	—	—	124×10^6
Specific resistance (MΩ/cm)				
Dry	1–2100	8,000–30,000	48,000–109,000	190,000–900,000
50% Relative humidity (air)	0.01–1.0	14–1400	34–95	1700–2100
91% Relative humidity (air)	<0.01–0.4	<1–1360	0.6–2.3	6–19
Electrical charge	positive	—	negative	—

[a] With kind permission of Chemical Publishing Co., New York.

of water-soluble materials. The marked drop with increasing relative humidity of the surrounding air is of great importance if asbestos is to be used with electrical equipment.

Asbestos insulating material provides excellent sound absorption unless the fibers are densely packed. It should be remembered, however, that supporting structures such as studs and beams can transmit a very significant proportion of the sound incident upon a structure, particularly in the low frequencies, and so detract from the insulation provided by the asbestos.

X-ray diffraction patterns and other optical properties will be taken up in connection with identification techniques to be discussed in Chapter 4.

GRADING

Since the reader of this text will undoubtedly come across references to the grades of asbestos, something should be said about the systems in use, as they are various and confusing. In applying the Canadian Standards Classification, as explained in Rosato's book (628), 16 oz (453 g) of the material is placed in the top of a system of three successive boxes, each containing a screen, through which it is sieved with the finest material being collected in a pan at the bottom. The screens have successive meshes of 2, 4, and 10 to the inch (to 2.5 cm). Agitation is maintained for 2 min. The greater the quantity of material left on the screen, and the higher the screen in the series, the longer the fiber and thus the better the quality (of chrysotile). The classification based on this procedure is given in Table 2–10.

Other commonly used and less complicated classifications are given in Table 2–11, and in the "Asbestos Fact Book" (35).

TALC

A final word must be said about talc. To the mineralogist, talc is a hydrated magnesium sheet silicate consisting mainly of platelike crystals, but also containing fibrous forms. Geological deposits of talc often coexist with other hydrated magnesium silicate minerals, some of which are fibrous (621). Tremolite is a common contaminant, anthophyllite often occurs, and chrysotile is occasionally found. Commercial talc deposits may consist of fine-grained, intimate mixtures of minerals,

TABLE 2-10

Classification of Some Types of Chrysotile Asbestos According to Groups (628)[a]

	Crude Asbestos
Group No. 1, Crude No. 1	Consists basically of crude ¾ in. and longer staple
Group No. 2, Crude No. 2	Consists basically of crude ¾ in. to ¾ in. staple
	Milled Asbestos
Standard designation of grades	Guaranteed minimum shipping test[b]
Group No. 3 (spinning fibers)	
3D	10.5– 3.9– 1.3– 0.3
3Z	0 – 8 – 6 – 2
Group No. 4 (shingle fibers)	
4D	0 – 7 – 6 – 3
4Z	0 – 1.5– 9.5– 5
Group No. 5 (paper fibers)	
5D	0 – 0.5–10.5– 5
5R	0 – 0 –10 – 6
Group No. 6 (waste)	
6D	0 – 0 – 7 – 9
Group No. 7 (shorts or refuse)	
7D	0 – 0 – 5 –11
7W	0 – 0 – 0 –16
Group No. 7 (floats)[c]	
7RF	No test
7TF	No test
Group No. 8 (sand and gravel)	
8S	Less than 50 lb per ft³ loose measure
8T	Less than 75 lb per ft³ loose measure
Group No. 9	
9T	More than 75 lb per ft³ loose measure

[a] With kind permission of Reinhold Publishing Co., New York, and D. V. Rosato.

[b] Ounces remaining on successive screens and in pan from standard agitation of 16 ounces.

[c] The suffix "F" designates "floats" in the case of the 7R and 7T grades.

including the fibrous, that are very difficult to separate in the mining and milling processes. Talc, it has been said, is a word used in industry to refer to a property rather than a mineral species.

The mineral talc is soft and may be reduced to fine particles with high surface areas, good sorption characteristics, and low frictional resistance, but mineralogical analyses of commercial talcs rarely show pure composition. In 51 common "talcs" analyzed at Mount Sinai, the talc

mineral content averaged 51%. The asbestos content, in particular, may range as high as 87%. However, the talc used in Britain, which comes from Italy, is much purer. The contaminants Ni, Cr, and Co are also much higher in the talcs used in the United States.

As will be seen in Part II, persons exposed to talc may show evidence

TABLE 2-11

Various Other Classifications of Asbestos (628)[a]

Type	Characteristics
	Northern British Columbia (the Cassair Asbestos Grades)
Crude 1	Basically, a crude ¾ in. and longer staple
AAA	Extra long textile fiber
AA	Long textile fiber
A	Textile fiber
AC	Long shingle fiber
AK	Medium long shingle fiber
AS	Shingle fiber
AX	Short shingle fiber
	African Chrysotile
From mines in the Shabani district of Rhodesia	
C and G1	Long, crude textile fiber
C and G2	Textile fiber
C and G3	Long shingle fiber
C and G4	Shingle fiber
C and G5	Short shingle fiber or paper stock
From the Mashaba district of Rhodesia	
VRA/–2	Textile fiber
VRA/–3	Long shingle fiber
VRA/–4	Shingle fiber
	Australian Chrysolite
Grade 4	2 in. and longer fibers
Grade 3	1 in. to 2 in. fibers
Grade 2	¼ in. to 1 in. fibers
Grade 1	¼ in. to ¼ in. fibers
	African Amosite
Group 1	Produced from hand-selected long fiber at Penge Mine only
D3	Long, more than 3 in. in length
Group 2	Produced at Penge from "run-of-mine" fiber after longest had been hand-selected
D11	¾ in. to less than 3 in.
GW	From Weltevreden Mine

TABLE 2–11 *Continued*

Russian Chrysotile			
Grade	Type	Texture	Mark according to U.S.S.R. Standard January 1, 1952
1	Textile	Hard (coagulated)	J-1
2	Long shingle	Hard	J-2
		Semihard	P-2
3	Shingle	Hard	J-3
		Semihard	PJ-3
			P-3
		Soft	M-3
4	Short shingle	Hard	J-4
	and paper	Semihard	P-4
	stock	Soft	M-4
5	Paper stock	Hard	J-5

[a] With kind permission of Reinhold Publishing Co., New York, and D. V. Rosato.

of clinical effects, notably pulmonary fibrosis closely resembling that produced by exposure to asbestos dust. These effects could be due to the contaminating asbestos, but the fibrous form of the talc itself may also play some part. Even the platelike crystals can be taken up by tissue phagocytes and are thus potentially reactive (327).