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August 23, 1977

Mr. F. H. Ancker
Union Carbide Corp.
Chemicals & Plastics
P. O. Box 670
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Dear Mr. Ancker:

Many thanks for the articles and information on treated Calidria fiber in plastics. Enclosed is a draft of the state-of-the-art report on Asbestiform Filler requested by Dr. Ray Seymour for the American Chemical Society book on Additives for Plastics: State of the Art. Please note use of the data in Table 10-A and 10-B taken from your article in PLASTICS ENGINEERING, July 1974. Please review the data and the written part referring to it.

Apparently, Academic Press requires permission in some form of writing in order to use data already published (judging from the sample permission request attached). Please send me written permission as soon as possible. Without it, your data cannot be included. Please return the enclosed copy to me. The edited version will be sent to you later.

Your report on structural foam was excellent. I hope to refer to it in the ACS 1978 Symposium on research and development of Additives for Plastics which will parallel and complement the "state of the art" publication. Any other non-proprietary R&D data, references, etc., would be helpful.

Your cooperation is appreciated.

Very truly yours,

Jack

John H. Kietzman

Enclosure

please return
at your convenience

ASBESTIFORM FILLERS

J. H. Kietzman

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CONFIDENTIAL

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Historical Background

The use of asbestos in plastics goes back to the early days of reinforced thermosets, soon after the discovery of phenol-formaldehyde resins by Baekeland. Since then its use has grown in a wide variety of both thermoset and thermoplastic composites. Thermosets require fibrous reinforcement for molding and cured strength. Asbestos fibers provided dimensional stability, durability, impact strength and heat resistance required for many uses.

In thermoplastics, development of floor tile also required the use of asbestos for dimensional stability and durability as well as hardness. Until recent years use of fibrous minerals in thermoplastics has been limited to resins products that require stiffness at elevated temperature such as polypropylene.

The first widespread interest in mineral fibers for thermoplastics was generated by the resin shortages of 1973-74 for potential use as a resin extender. The interest now appears to be increasing for other reasons; the new emphasis on flame resistance, potential cost reduction, and most recently the problem of long-term moisture susceptibility of glass fibers in thermoplastics.

Description

Asbestiform is used to describe naturally occurring inorganic minerals that when mechanically processed, form fibrous or acicular (needle-like) structures. Asbestiform minerals currently used in plastics include asbestos, talc, and wollastonite. All are silicates of magnesium, calcium or combinations of sodium, iron and magnesium. (Table 1). They vary widely in structure, that is, fiber length and diameter, particle size, and surface area as illustrated visually in Figure 1 by micrographs of the most fibrous grades of each type. These physical differences account for most of their relative effects on composite properties, including processing, dispersion, strength, and stability. Each of the three types of fibrous minerals is produced in various grades with a wide variety in particle structure for specific and different end uses. The most fibrous of each may provide fiber reinforcement in proportion to fiber length and diameter (Figure 1). The least fibrous or non-fibrous forms of each can best be described as reinforcing fillers.

The generic name asbestos includes chrysotile (a fibrous form of serpentine) and a variety of amphibole fibers. Chrysotile accounts for about 95 percent of commercial asbestos. Both chrysotile, and to a much lesser degree, crocidolite (an amphibole) are used in plastics at the present time. Other forms of amphibole fibers, such as anthophyllite and tremolite, are much less fibrous and in very limited supply. Commercial grades of chrysotile are classified by fiber length distribution measured by a *dry screening test*.(1) Often, a designation

will be added to indicate a special degree of openness or fiber separation. Amphibole fibers are classified by other systems based on length, color, or purity.

Chrysotile is, by far, the most fibrous mineral (Figure 1A) since it contains the highest number of fibers per unit weight. Although individual fibrils are approximately one millionth of an inch in diameter, most of the fibers in all grades are made up of unopened bundles of fibrils, varying in diameter from 10 to 1000 microns, depending on fiber grade. Average length/diameter ratios vary from 100 in very short grades to more than 500 in longer or open grades. Primary use of asbestos in plastics continues to be in phenolics for friction materials, molding compounds, etc., and floor tile.(2)

Talc is a more complex hydrous silicate. True talc is not fibrous, but platey. It is included in the asbestiform group because many commercial grades contain significant quantities of asbestos fiber, tremolite, anthophyllite or chrysotile, which accounts for their fibrous structure. Several sources of talc are completely non-fibrous. Talc (as well as asbestos) contains iron and other metal impurities. Talc is a relatively new reinforcing filler, used in polypropylene for high temperature strength, improved color, processing and stability characteristics. It is also used as a filler with glass fiber.

Wollastonite is a pure, non-hydrous, calcium silicate with varying particle shape. The most acicular form, Figure 1C, can provide significant reinforcement. Other grades with low aspect ratios are non-fibrous fillers that do not contribute to composite strength. Wollastonite has been used for several years with asbestos as an extending filler in phenolic molding compounds for cost reduction. Perhaps its newest use is in Nylon, giving special advantages in color, moisture resistance, and costs because it permits high loadings.

The marked difference in aspect rations-length/diam of the fibrous minerals (Table 1) is illustrated visually in Figure 1. Chrysotile has aspect ratios in the order of 30 times that of wollastonite. Aspect ratio of the fibrous fraction of talcs depends on the type of asbestos that it contains. The talc shown in Figure 1-B contains tremolite and anthophyllite, with fiber diameters about 1/10 that of wollastonite but much lower in aspect ratio.

Scope

Mineral fibers available and currently used in commercial plastic composites are described, with illustrations, intended for comparing the different types and grades, the bases for their selection, and advantages or disadvantages of each related to end use. Information on anthophyllite is included only in reference to past use. Its current availability and use are very limited.

The data presented are representative of average values under standard test conditions, but do not necessarily reflect the effect of differences related to specific fiber grades, commercial resins or proprietary additives.



FIG. 1-A
CHRYSOTILE
X 5000 MAGNIF.

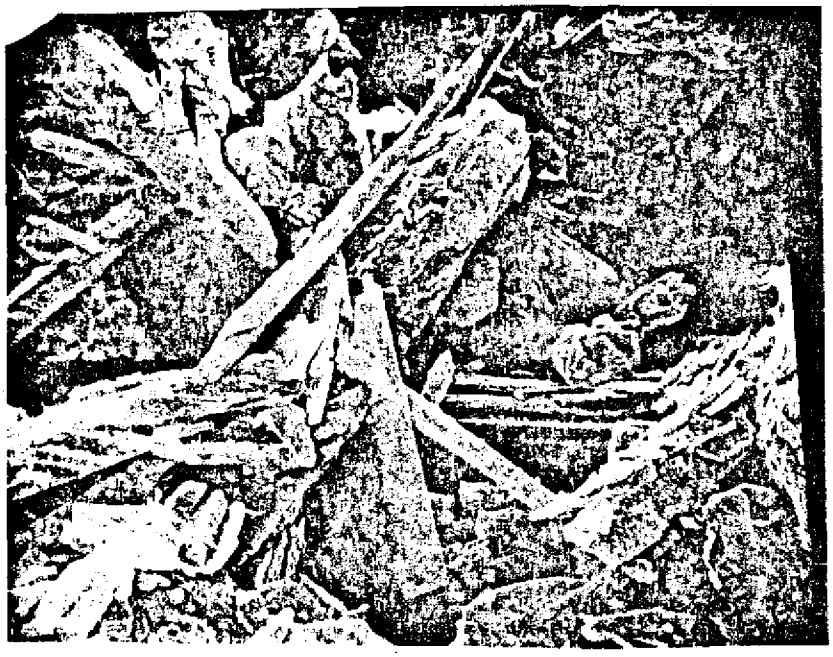


FIG. 1-B
FIBROUS TALC
X 5000 MAGNIF.

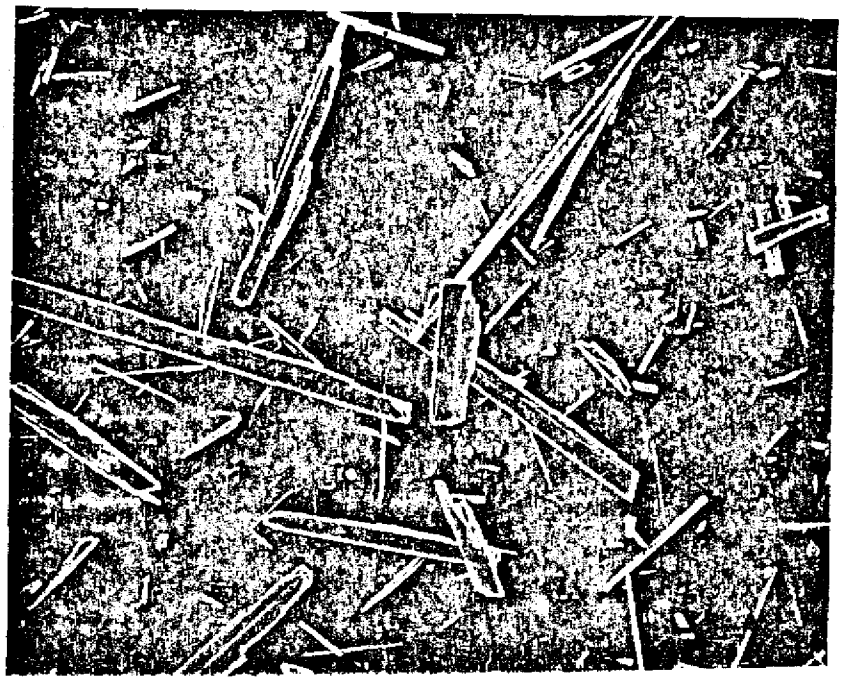


FIG 1-C
WOLLASTONITE
(ACICULAR)
X 200 MAGNIF.

TABLE 1. PROPERTIES OF FIBROUS MINERALS

	Asbestos			
	Chrysotile	Crocidolite	Talc	Wollastonite
Composition	$Mg_6[(OH)_4Si_2O_5]$	$Na_2MgFe_5[(OH)Si_4O_{11}]_2$	$Mg_{12}Si_{16}O_{40}(OH)_8$ or $Mg_3(Si_2O_5)_2(OH)_2$ If fibrous, contains asbestos	$CaSiO_3$
Specific Gravity, g/cc	2.6	3.2	2.8	2.9
pH (in water)	10.3	9.1	9.3	9.9
Hardness (Moh's Scale)	2.5 - 4.0	4.0	4.0	4.5
Aspect Ratio l/d	100 to 500+			Min 3:1 Max 15:1
Fiber Diam, microns (minimum)	0.02 - 0.03	0.06 - 0.09		5 (Acicular grades)
Flexibility	High	Good	Semi-rigid (platelets)	Semi-rigid
Surface Area, m^2/g (commercial grades)	17 to 60	3-15	3.5 to 10.0	1.5
Tensile Strength, psi	281,000 to 436,000	469,000 to 605,000		
Affinity for H_2O Surface Adsorption	High	High	Medium	Low
Price Estimates $/lb (fob source) U.S. or Canada Africa	0.03 - 0.09	0.25	0.03 - 0.06	0.03 - 0.04

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II-A. BASIC PROPERTIES

Comparison of Fibrous Minerals in Composites

The difference in size, shape, and fibrous structure accounts for the differences in composite strength illustrated in Figures 2 and 3. The wollastonite in these composites was a non-acicular grade and normally used as a fiber extender. Used with asbestos fiber in polypropylene, this grade did show synergistic benefits (Reference 3). Table 2 compares grades of three types of mineral fibers intended as reinforcing fillers. The formulation used would depend on the properties pertinent to end use, ductility or impact strength, modulus, dielectric strength, etc. The general comparisons in Table 3 include other characteristics that relate to use in thermoplastics.

In many major applications where fibrous minerals serve as reinforcing fillers, ultimate strength is secondary in importance to one or more other properties, such as high temperature strength, dimensional stability, flame resistance, processing and costs. Deflection temperature is of critical importance in polyolefins composites (Figure 2). Dimensional stability is a primary requirement for heat resistant phenolic molding compounds (Table 4). A related effect reduces mold shrinkage and moisture expansion and contraction.

Flame resistance is becoming more and more important with new product specification (automotive, construction, etc.). Simply by replacing resin by high loadings of inorganic fillers decreases the percent of combustibles. But fibrous mineral can also give a marked decrease in flame spread. Highly open grades of short chrysotile are capable of forming a fine fibrous web that maintains structural integrity (Table 5) at flame temperature and preventing drippage of melted resin (Reference 3). The growing use of talc in polypropylene is associated with a balance of properties (4, 5): improved cycle time (mold fillers), low stabilizer content, and adequate deflection temperature.

Stability

Heat stability is an important concern in some thermoplastics. It is a factor in processing of styrene and in durability of polypropylene. Adding any untreated fibrous mineral to these resins requires higher stabilizer contents, in direct proportion to the fiber surface area. Special low cost stabilizers that act as peroxide decomposers have been found to be very effective (Reference 6).

Iron components in asbestos and talc do not have a significant effect on stability of polypropylene composites, although they may impart dark gray coloration to the resin.

Fiber treatments or coatings can greatly improve heat stability of thermoplastics, especially PVC, to the extent that they reduce interface friction and lower flux or melt viscosity.

FIGURE 2

FLUXING VISCOSITY Vs. HEAT DEFLECTION

Mineral Filled Polypropylene

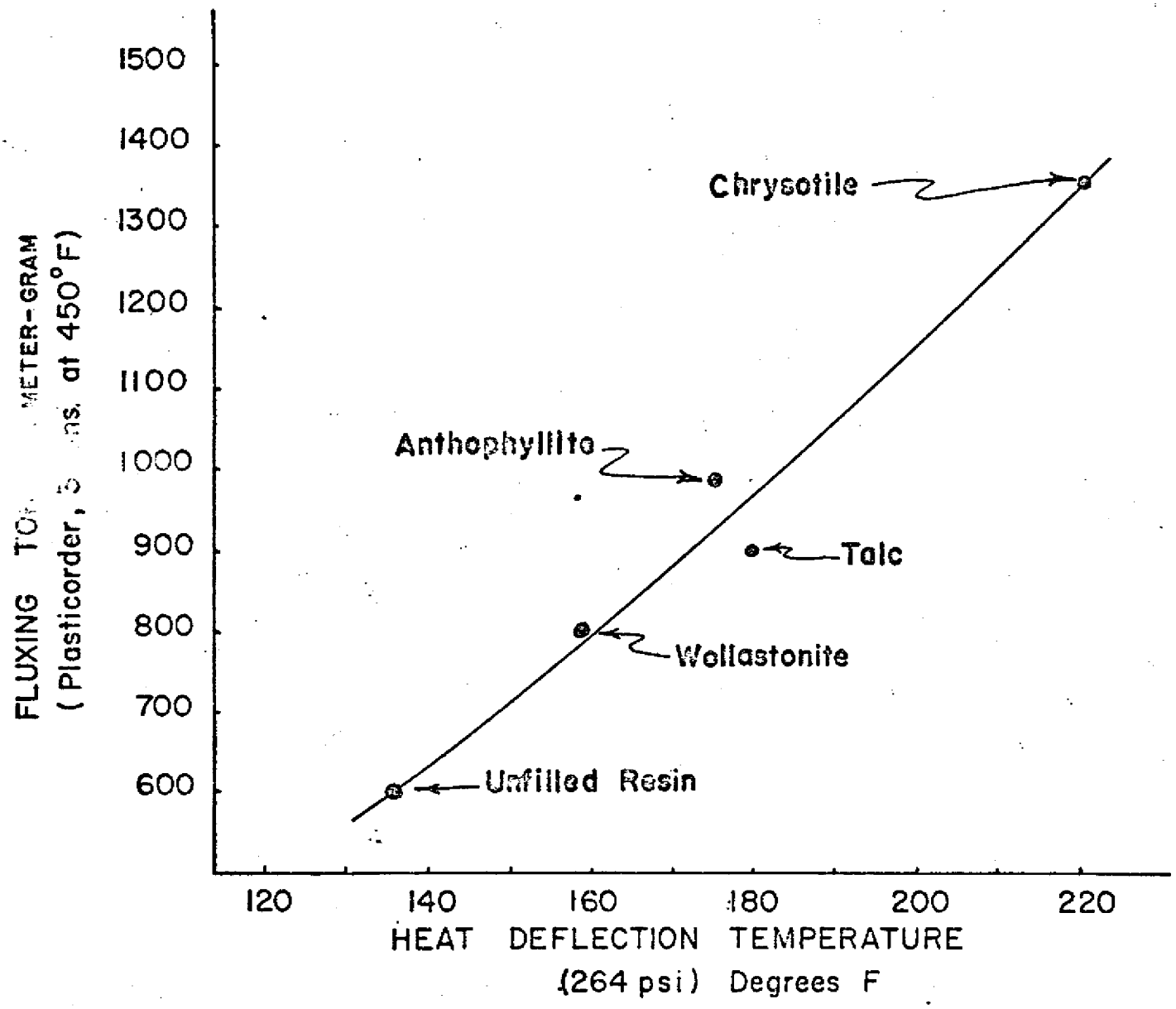


FIGURE 3

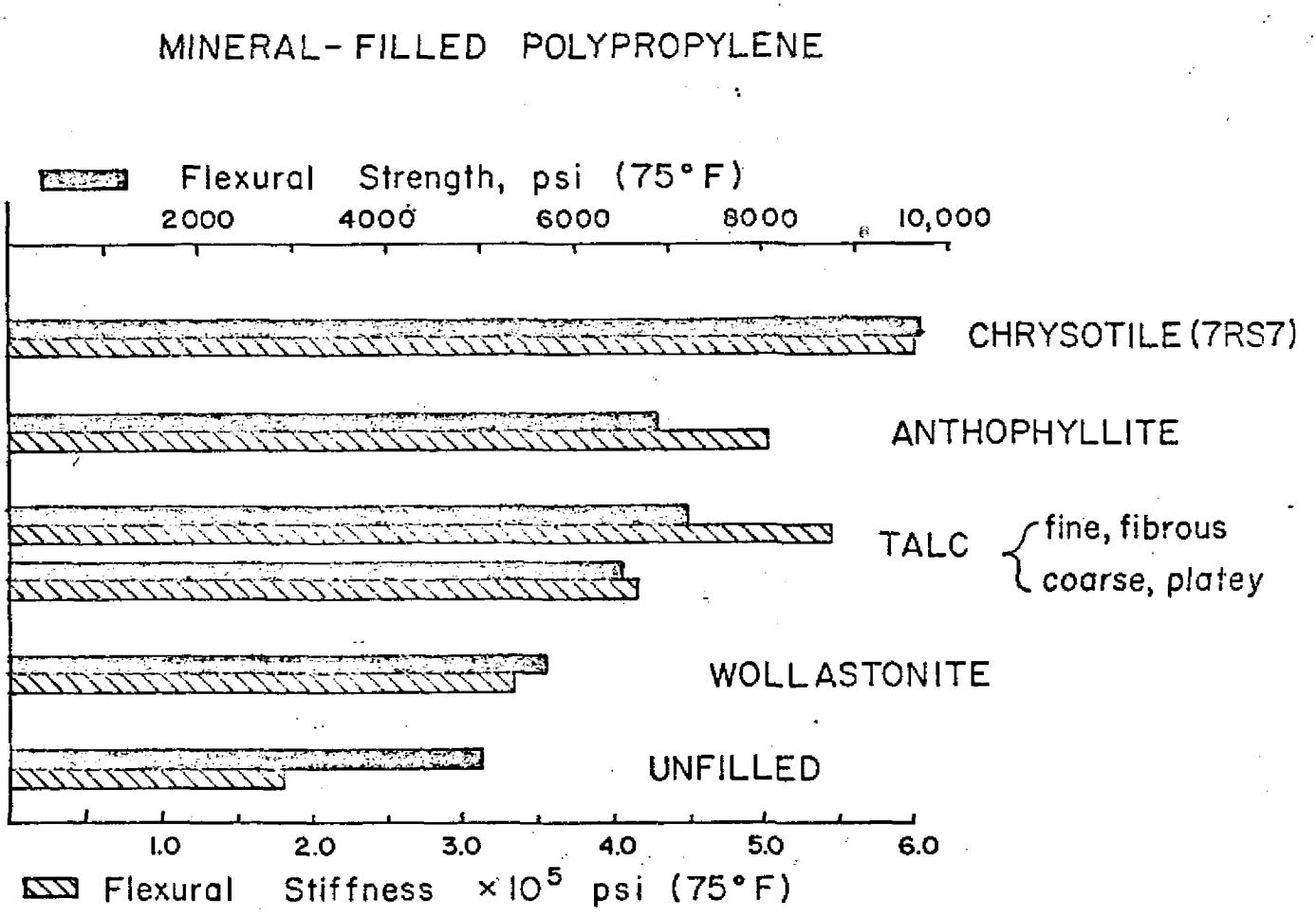

MINERAL-FILLED POLYPROPYLENE
Flexural Strength, psi (75°F)
2000
4000
6000
8000
10,000
CHRYSOTILE (7RS7)
ANTHOPHYLLITE
TALC
fine, fibrous
coarse, platey
WOLLASTONITE
UNFILLED
1.0
2.0
3.0
4.0
5.0
6.0
Flexural Stiffness $\times 10^5$ psi (75°F)

TABLE 2

COMPARISON OF REINFORCING FILLERS
IN POLYPROPYLENE*

	Wollastonite 40%	Anthophyllite (asbestos) 40%	Talc 40%
Flexural Modulus, psi x 10^{-5}	4.4	6.0	5.2
Izod Impact (Notched) ft lb/in. of notch	0.73	0.56	0.56
Heat Deflection Temp (66 psi), °F	277	288	276
Tensile Strength, psi	4000	4300	4100
Elongation, %	4.2	1.6	1.9
Dielectric Strength, volts/mil	700	515	650

*Data provided by Interpace Corporation

TABLE 3. COMPARISON OF MINERAL FIBERS IN PLASTICS

PROPERTY	HIGHEST	INTERMEDIATE	LOWEST
FIBROUS STRUCTURE	CHRYSOTILE	TALC ANTHOPHYLLITE	WOLLASTONITE (ACICULAR)
SURFACE AREA	CHRYSOTILE	TALC CHRYSOTILE (FLOATS) ANTHOPHYLLITE	WOLLASTONITE TALC
FIBER REINFORCEMENT VALUE IN PLASTICS	CHRYSOTILE	CHRYSOTILE (FLOATS) ANTHOPHYLLITE TALC	WOLLASTONITE TALC
EASE OF COMPOUNDING IN THERMOPLASTICS AND OPTIMUM LOADING	TALC (PLATEY) WOLLASTONITE	TALC (FINE, FIBROUS) CHRYSOTILE (FLOATS) ANTHOPHYLLITE	CHRYSOTILE
RESISTANCE OF FILLED POLYPROPYLENE TO HEAT DEGRADATION	WOLLASTONITE	TALC ANTHOPHYLLITE	CHRYSOTILE

TABLE 4. DIMENSIONAL STABILITY OF PHENOLIC MOLDING COMPOUNDS

	General Purpose	Heat Resistance
Filler	Wood Flour	7T Chrysotile
Specific Gravity	1.34	1.58
Moisture Stability		
2 weeks in water		
Swelling (length), %	0.21	0.09
Absorption, %	2.0	0.6
Strength Loss (flexural), %	15.1	+0.6
Heat Stability		
Shrinkage (length), %	0.048	0.005
Strength Loss, % (flexural)	29	12
Izod Impact		
ft lb/in.	0.32	0.29-0.32

TABLE 5. RADIANT PANEL FLAMMABILITY TEST ON FILLED POLYETHYLENE

Filler	Flame Spread Factor, Fs	Flame Spread Index Is = FsQ
40% $CaCO_3$	19.6	213
40% 7RS7 (chrysotile)	4.3	62

II.B - CHRYSOTILE

This type of asbestos is the most versatile and widely used mineral fiber because it can be produced in grades capable of being formed into paper, woven into cloth, shorter grades for reinforcing fibers, or extremely short grades called floats that serve as reinforcing fillers. The latter grades are most widely used in plastics because of low cost, processing characteristics (dry mixing compound, dispersion, mold fill-out, etc.).

The relatively low price of all grades allows selection to obtain composite properties desirable for specific use. Using reinforcing grades of chrysotile with glass fiber is economically feasible and, at higher loading, capable of giving reinforcement equivalent to glass fiber (Table 6).

Processing

In thermoset resin such as polyester, simple compounding procedures can have a great effect on product strength after molding (Table). The normal procedure with glass strand reinforced polyester is adding fiber last to guard against attrition. By contrast, the chrysotile (asbestos) fibers are not susceptible to attrition during compounding (3). This permits premixing of the fiber with resin before adding filler, the effect of which can be much greater reindorcement (Table 7), 40 percent increase in flexural strength and 400 percent increase in impact strength. This premixing allows use of lower resin content with substantial cost savings. For very short grades of fiber at higher loadings, premixing styrene monomer can give the same benefit.

In thermoplastics wet-out of fiber by resins is largely dependent on fiber grade, melt viscosity, and fiber loading.

CHRYSOTILE

(Theory and Reinforcing Mechanisms)

Chrysotile, without treatment, gives surprising reinforcement in non-polar resins, such as polypropylene, where no chemical bonding at the interface can occur (Table and Figures 2 and 3). The reinforcing mechanism appears to be internal friction at the interface and between adjacent fibers. This theory is supported by the general correlation between fluxing torque during compounding and heat deflection temperature after molding (Figure 2). At ambient conditions, temperature shrinkage of the resin during cooling produces tangential stresses around the fiber which would multiply interfacial ~~interfacila~~ friction. In thermosets, curing shrinkage should give even greater frictional bonding. The net effect would be not unlike the old "chinese finger puzzle" on a microscopic scale.

The increase in ultimate strength of asbestos reinforced plastic is normally much less than flexural modulus or heat deflection, both of which are measured at lower stress levels. At higher stress levels, interfibril separation within the asbestos can occur, causing pull-out. A similar effect can occur between weakly bonded layers in talc platelets. This may in part explain why coupling treatment of chrysotile gives much less improvement in ultimate composite strength than glass fiber (Table), despite the fact that tensile strengths of chrysotile and glass fibers are the same. Effective coupling treatment of chrysotile normally gives about 25 to 30 percent increase in composite strength (3) (Table 8) in some instances by fiber incapsulation. True coupling of glass fiber improves composite strength by 50 to 100 percent, depending on fiber content. With chrysotile additives that improve dispersion or resin wet-out can give as much strength increase as fiber coupling (Table 8).

To achieve full use of fiber strength requires use of asbestos paper laminates (Table 9) or impregnated cloth where proximity of adjacent fibers in two-dimensional or parallel orientation optimizes inter-fiber bonding (7, 8).

The interfibril separation of asbestos fibers may benefit some properties and could account for the improvement in impact strength of thermosets when asbestos is added. The effect would minimize stress concentrations inherent in the brittle matrix caused by shrinkage.

Interfibril pull-out could theoretically be prevented by mechanical separation of chrysotile into fiberils which should allow effective coupling. This is confirmed by the RG-600 fiber (Table 10) (Reference 9). Adding coupling agent to polyolefins without fiber shows no strength benefit, but as a pre-treatment on chrysotile fibrils, effective coupling is indicated by composite strength. As used commercially, this form of coupled is limited only by fiber length, that is, aspect ratio (Reference 10).

Fiber dispersion is perhaps the single most important factor in optimizing fiber reinforcement in thermoplastics and thermosets. Although dispersion is difficult to measure, micrographs of RG-600 composites (Reference 9) suggest that superior dispersion may account in part for improved reinforcement. For reasons that can bond chemically to the fiber, attempts to improve strength by pre-opening fiber to improve dispersion can have the opposite effect (Table 9) for longer grades.

Adding granular fillers such as calcium carbonate together with fibrous fillers in polyester premixes increases composite strength synergistically. This is most likely the result of better fiber dispersion.

Resin penetration into the fiber bundles, fiber wet out or displacement of air runs a close second in importance to dispersion, especially in fiber grades that are not inherently well opened. In practice, the effect of two factors are often inseparable since both are affected by melt viscosity, compounding intensity - shear, pressure, etc.

II-C. TALC

The many sources and grades of talc represent different combinations of, silicate composition, particle size and shape-platey and fibrous. Non-fibrous sources contain no asbestos fibers. All grades classify as reinforcing fillers.

Most grades of talc greatly improve both flexural modulus and deflection temperature of polypropylene (Table 11). Comparing talc from a given source, the finer grades impart greater reinforcement than coarser-grades. This does not hold true when comparing grades of the talc from different sources because of the over-riding effect of platey and fibrous structure. Although fibrous talc is believed to give better reinforcement than non-fibrous talc, some fine, platey grades can be superior to the fibrous types. Among fibrous types, a key factor is the type of fiber in the talc, that is, tremolite, anthophyllite, or chrysotile, the latter giving superior reinforcement value.

As with all fibrous minerals, talc can affect ductility of some thermoplastics and tend to cause embrittlement. This effect can be overcome by treatment to reduce interfacial friction. Stearate treated talcs are available and used commercially. The effect of stearate treatment benefits ductility and impact strength of composites, but also may decrease flexural modulus.

In general, the lower surface area of talc makes it easier to process than asbestos, and better heat stability than most grades of asbestos. Both properties give a cost advantage.

Wollastonite

The coarser particle size of wollastonite and relatively low aspect ratio (Table 1) makes it a filler or fiber extender since it does not contribute to composite strength in the untreated forms. The most acicular grades with the highest aspect ratios (Figure 1-C) give better composite strength. Its commercial use includes silane coupling achieved either as a pre-treatment or by integral blending with the resin. The latter minimizes cost of coupling, but is less effective than pretreatment.

The effect of coupling is outstanding in some resins, such as Nylon[11] (Table 12). In nylon coupled wollastonite represents a reinforcing filler since it contributes significantly to composite strength. With other resins, some physical properties, though greatly improved by coupling, remain equivalent to the unfilled resin (12) (Table 13).

Use of wollastonite as a filler in plastics is based on factors other than composite strength. Advantages include high loading, up to 70 percent, purity and brightness, low oil and moisture adsorption, and good electrical properties.

TABLE 6

CHRYSOTILE IN POLYSTYRENE

Fiber		Flexural Strength psi	Flexural Modulus psi x 10^{-5}	IZOD (notched) ft lb/in.	Deflection Temperature ^{o}F
Type and Grade	Amount				
None	--	5,200	2.9	1.4	179
Long fiber	40%	5,180	6.2	1.1	201
7D (short fiber)	40%	7,410	6.0	0.6	194
1/4 in. Glass Strand (uncoupled)	20%	5,900	4.9	0.7	194

TABLE 7

EFFECT OF MIXING PROCEDURE ON POLYESTER PRE-MIX

Mixing Method	Resin Content	Fiber (equal proportions)	Flex Strength psi	Flex Modulus psi x 10^{-5}	IZOD Notched ft lb/in.	IZOD Unnotched ft lb/in.
I. Filler premixed with resin before adding fiber	30	Organic and Glass Strand	10,000	11.9	2.3	3.5
	30	Chrysotile and Glass Strand	7,800	10.8	0.8	1.3
	35	Chrysotile and Glass Strand	14,200	11.6	1.9	7.1
II. Asbestos premixed with polyester before adding filter	30	Asbestos and Glass Strand	11,400	11.8	1.5	6.8

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TABLE 8

EFFECT OF FIBER COUPLING VS. ADDITIVE

(30 Percent Chrysotile)

	Flexural Strength psi	Flexural Stiffness x 10^5 psi
Additive		
None	5,990	3.6
5% Barium Trimellitate	7,160	3.6
Fiber Treatment		
None	4,800	4.1
2% Y-5712 Thermocoupling Agent	5,990	5.3

TABLE 9

EFFECT OF FIBER ORIENTATION
ON POLYESTER COMPOSITES

(45 Percent Chrysotile)

Fiber Form	Fiber Orientation	Flex Strength psi	Flex Modulus psi x 10^5	IZOD Impact	
				Notch. ft lb/in.	Unnotch ft lb/in.
4T As Rec'd	3-dimension	11,800	10.3	0.4	1.4
4T Mechanically opened	3-dimension	9,150	10.2	0.3	1.0
Wick Paper (5 paper laminate)	2-dimension	22,900	15.8	1.6	3.9

TABLE 10

EFFECT OF COUPLING TREATMENT ON FIBRIL REINFORCEMENT

A. High Density Polyethylene

Fiber (Chrysotile)	Additive	Tensile		Deflection Temperature °F
		Strength psi	Modulus psi x 10^5	
None	--	3,050	1.32	111
None	2% coupling agent	2,900	1.35	100
RG-144				
Untreated (18.6%)	--	4,200	2.80	140
RG-600				
Treated 20%	--	6,850	5.00	196

B. Polypropylene

Fiber (Chrysotile)	Additive	Tensile		Deflection Temperature °F
		Strength psi	Modulus psi x 10^5	
None	--	4,590	1.96	136
None	2% coupling agent	4,560	2.01	128
RG-144				
Untreated (18.6%)	--	4,910	3.04	154
RG-600				
Treated (20%)	--	6,220	4.31	232

*Data supplied by Union Carbide Corporation

TABLE 11

EFFECT OF PARTICLE STRUCTURE AND SOURCE OF TALC ON FILLED POLYPROPYLENE

TYPE	SOURCE	SHAPE	PARTICLE SIZE, % +325 M	FLEX. STRENGTH PSI	FLEX. MOD. PSI X 10^{-5}	IZOD (NOTCHED) FT LB/IN.	DEFLECTION TEMP ^{o}F
NONE (UNFILLED)		--	--	5,200	1.9	0.5	136
TALC	CALIFORNIA	PLATEY (LOW FIBER)	2.1	7,200	5.9	0.5	204
		FIBROUS	20.9	6,500	4.3	0.5	186
	CALIFORNIA	FIBROUS	5.2	7,100	5.3	0.4	176
		FIBROUS	18.1	7,000	5.0	0.4	170
	MONTANA	PLATEY (NON-FIBROUS)	2.0	6,600	5.4	0.4	195
	NEW YORK	VERY FIBROUS	0.7	7,200	4.8	0.5	158
		VERY FIBROUS	0.4	6,400	4.8	0.5	170
	EASTERN	FIBROUS	11.5	6,800	4.7	0.5	194
		FIBROUS	7.7	6,700	4.6	0.6	198

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TABLE 12

EFFECT OF SILANE TREATMENT ON
WOLLASTONITE IN NYLON 6 COMPOSITE

	Base Resin	Wollastonite-Filled (70%) Untreated	Wollastonite-Filled (70%) Treated with Union Carbide A-1100
Flexural Strength, psi			
Dry (35% RH)	12,500	12,200	21,000
Wet (16 hr immersion)	6,700	6,100	16,300
Flexural Modulus, psi x 10^{-5}			
Dry (35% RH)	2.7	9.6	9.9
Wet (16 hr immersion)	1.1	3.6	6.4
Deflection Temp., (264 psi), °F	133	349	356
Dart Impact in lb	> 600	< 4.5	11
Water Absorption, wt % (16 hr immersion)	3.14	0.97	0.68

*Data provided by Union Carbide Corporation [11]

TABLE 13 (12)

EFFECT OF SILANE ADDITIVES ON WOLLASTONITE - FILLED RESINS (50 PERCENT FILLER)

	Unfilled Resin	50 Percent Wollastonite	
		Untreated	Treated (resin/silane)
Epoxy			
Flexural Strength, psi			
Dry	18,100	15,800	18,100
Wet	16,000	9,800	13,300
Cross-Linked Polyethylene			
Tensile Strength, psi	2,400	1,700	2,200
Elongation, Percent	550	50	170

Data supplied by Union Carbide Corp

III. COMMERCIAL APPLICATIONS

III-A. ASBESTOS

Chrysotile accounts for about 95 percent of commercial asbestos fiber. Its primary uses in thermoset composites include:

PHENOLIC

1. Friction materials(2): brake blocks, drum liners, bushings and clutch facing.
2. Molding Compounds(13, 14, 15): electrical parts for computers, aircraft, guided missiles, communication circuits, boards, commutator rings, etc.
3. Aerospace Products(8): rocket nozzles, nose cones and heat shields.

A typical brake lining formula includes 60 percent chrysotile (Group 6 and 7), 15 percent friction modifiers such as brass or other metals and 25 percent phenolic resin. Phenolic molding compounds are highly developed and proprietary. They might include, for instance, chrysotile or crocidolite, reinforcing filler such as wollastonite, lubricants, surfactants, and reactive resins. Table 14 illustrates properties of commercial phenolic molding compounds. Aerospace products for heat shields with up to 60 percent chrysotile show flexural strengths as high as 26,000 psi with no significant strength loss under continuous exposure up to 350F ( ).

POLYESTER

1. Moldings Compounds: heater housings, wash basins, shower stalls, etc.

A typical polyester molding compound formula is given in Table 15.

LAMINATES(7)

Asbestos fabric and paper products are used as reinforcers for phenol, urea, melamine, diallylphthallate, polyester and silicone resins to make laminated structures. Asbestos-phenolic laminates show flexural strengths as high as 50,000 psi.

Commercial applications for chrysotile in thermoplastics include:

PVC

1. Floor tile (vinyl asbestos).
2. Sheet products for boats, mobile homes, etc. (Europe).
3. Plastisols.

Miscellaneous uses include PE, PP, and fluorocarbon molding compounds (16).

A vinyl/asbestos floor tile might include 15 per cent chrysotile (group 7), 68 per cent granular filler (calcium carbonate), 2 per cent plasticizer and 15 per cent PVC resin.

III-B. TALC

Talc is a new, but well established, reinforcing filler for "mineral-filled" polypropylene. Product uses include many injection molded automotive parts (Ref. 16, 17). Other automotive uses include talc and glass fiber (25/15) reinforced Nylon for grill opening panels, miscellaneous under-the-hood parts, as well as fender extensions, louvers, headlight closures, etc. Use in compartment headliners is also reported (Reference 18).

III-C. Wollastonite

Wollastonite has been used as an extender in phenolic molding compounds and polyester premixes together with reinforcing fibers--asbestos or glass. Its newest use is in mineral filled nylon. for a variety of automotive products, for example, air conditioning components (18).

Wollastonite is used in vinyl/asbestos floor tile, vinyl sheeting, and vinyl plastisols where it offers color advantages (Ref 17). It is also an effective filler in melamine, epoxy, and urethane composites (Ref 16).

TABLE 14

ASBESTOS-PHENOLIC MOLDING COMPOUNDS*

Designed Properties	Heat Resistance Processible on all types of equipment	Flame and Heat Resistance Dust free, fast pouring	High Strength High Impact	High Flame Resistance
Screw Processibility	Yes	Yes	Under spec. conditions	Limited
Shrinkage, Comp: Trans. in./in.	.002:.004	.002:.004	.001:.002	.002-.0045
Flexure Strength, psi	12,000:14,000	11,000:12,000	11,000	12,000:13,000
Stiffness Modulus psi x 10^6	1.8	1.8	2.3	2.0
Impact** ft lb/in. notch	0.9	0.64	2.0	1.4
Deflection, Temp. °F	500	580	475	500
Continuous Use Temp, °F	475	350	450	450
H_2O Absorption*** 24 hr, %	0.5	0.5	0.3	0.6
Application (typical)	Commutators	Replacement for small die castings		Carburetor transmission - Replacement for cast metal parts

*Data supplied by Rogers Corp.
**Minimum values
***Maximum values

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TABLE 15

POLYESTER PREMIX FORMULA

Material	Type	Percent Total Wt
Resin	G.P. Polyester (20 percent styrene monomer)	30 to 35
Catalyst	Benzol Peroxide	0.5
Lubricant	Zinc Stearate	1.2
Whitener	TiO_2	1.5
Filler	Marble Dust, etc.	40 to 60
Fiber	Fibrous Minerals, (chrysotile, etc.) Glass Strand, Organic Fiber	10 to 20

III PROCESSING

Processing Thermoset Composites (22, 23)

Because mineral fibers have been used in thermosets since their original development and commercialization, the technology is a fairly well developed one. Fiber wet out (coating) by the resin during compounding is very important in the polyesters but apparently less so for phenolics. High intensity precompounding, required for phenolics, is possible for chrysotile because of its resistance to attrition.(in contrast to glass fiber). The combined use of fillers and fibers with low resin contents in thermoset molding compounds suggests that micro-packing has long been a part of this technology.

Processing Thermoplastic Composites (22, 24)

Processing of fibrous minerals in thermoplastic resins is relatively new and based mainly on use of equipment designed for unfilled resins. The high flux torque and melt viscosity with untreated mineral fibers requires high intensity precompounding for injection molding and most twin screw extruders. Compounding extruders must include vacuum venting for pellet densification. Temperature profile is important; normally temperature is increased at the feed end.

Single screw extruders do not necessarily require precompounding. Forced feed systems required by screw design makes it possible to control melt torque and densification. The newer segmented turn screw extruders such as the Bitruder combine precompounding and product extrusion - pipe or profile - into one step for many mineral filled thermoplastics.

Injection molding has in some cases proved to be less of a problem with fiberous minerals than glass fiber in thermoplastics with respect to fiber orientation or dispersion. A producer of large polyolefin composites reports use of talc or asbestos to avoid warpage of molded parts made with glass fiber reinforcement (ref---)

Current development of fiber treatments, lubricants, etc. is expected to facilitate processing of higher fiber loadings and perhaps precompounded fiber/resin concentrates.

III. MARKET VOLUME AND AVAILABILITY (~~Cont~~.)

The 1976 usage of fibrous minerals in plastics products is shown in Table 16, together with predictions of the 1986 use (Reference 19, 20) of the 200,000 tons of chrysotile, roughly 1/3 was used in phenolic friction materials and 1/3 for vinyl floor tile. Consumption forecasts show shortages (21) in certain chrysotile grades. The availability of chrysotile grades used in plastics, however, should be able to meet future demand.

Approximately 50,000 tons of talc were used in plastic products in 1976, mostly in polypropylene. Future availability appears to be assured. Current increase in production of wollastonite is aimed at supplying future demand.

TABLE 16. MARKET VOLUMES

Fibrous	1976 Use in Plastic Products, Tons	1986 Estimated Use in Plastics Products, Tons
Chrysotile	199,000[20]	360,000[19]
Talc	50,000 (Est.)	100,000**
Wollastonite	10,000*	20,000**
Anthophyllite	Negligible	Negligible

*Supplier's estimate.

**Estimate of 100 percent increase in filler use[19].

IV. COST FACTORS IN THE DESIGN OF PLASTIC PRODUCTS

The relatively high specific gravity of all mineral fibers gives no cost advantage in low cost thermoplastics such as polypropylene or PVC until fiber loading exceeds 40 percent. This is the result of the increase in unit volume weight. For instance, adding 30 percent by weight of reinforcing fibrous filler (grades) requires about 20 percent increase in weight for equivalent volume. The cost of precompounding ($.06)/lb plus the extra cost of stabilizers, additives and handling would exceed the original materials costs of the unfilled resin. Commercial use of mineral fibers and fillers in thermoplastics to date has for this reason been restricted to products that require improved properties-high temperature strength, etc. Recent use of wollastonite in Nylon illustrates this point. The high loading permitted (70 percent) can give more than 25 percent materials cost savings (ref 25).

Processing cost is another important design consideration. The use of talc to replace asbestos in polypropylene offers lower stablizer costs and improved cycle time (ref 16).

However, for composite strength requirements cost/strength factors must also be considered. That is, fiber costs/unit volume strength, as illustrated in Table 17 for flexural modulus requirements (ref 26) Many product designs would also include cost/impact together with cost/flex modulus factors in selecting the type of fiber. Adaptability of a composite mix to existing equipment vs cost of new or modified equipment is another important consideration in choosing a fibrous mineral.

V. NEW TECHNOLOGY

Technical developments include: fiber treatments and lubricants to restore ductility (ref 27); in-situ fiber/resin coupling to minimize fiber treatment costs; fiber reinforced structural foam to reduce unit volume costs; (ref 28) combined use of fillers and fibers with and without treatments to optimize Micro-packing and minimize costs; and equipment modification to fit composite formulations. Recent developments and the potential for future plastic composites is the subject of report to be presented at the ACS symposium in April 1978.

TABLE 17-A

FLEXURAL MODULUS (STIFFNESS)

Material	Flex Modulus (psi x 10^C)
30 Percent Glass/Nylon 6	1.20
25 Percent Asbestos/Polyestyrene	1.18
30 Percent Glass/Nylon 6.6	1.15
45 Percent Asbestos Polypropylene	0.85
30 Percent Glass/Coupled Polypropylene	0.62
40 Percent Asbestos/Polypropylene	0.60
40 Percent Talc/Polypropylene	0.50
Nylon 6.6	0.43
Polystyrene	0.42
Nylon 6	0.40
High Impact Polystyrene	0.25
Polypropylene	0.20
HD Polyethylene	0.15

TABLE 17-B

COST/FLEXURAL MODULUS

Material	Cost/Unit of Flex. Modulus (p/in.^{3})
25 Percent Asbestos/Polystyrene	0.34
Polystyrene	0.43
30 Percent Glass/Coupled Polypropylene	0.49
45 Percent Asbestos/Polypropylene	0.74
40 Percent Asbestos/Polypropylene	0.83
40 Percent Talc/Polypropylene	0.90
High Impact Polystyrene	1.00
30 Percent Glass/Nylon 6	1.17
30 Percent Glass/Nylon 6.6	1.26
Polypropylene	1.30
HD Polyethylene	1.67
Nylon 6.6	2.55
Nylon 6	2.75

VI. ENVIRONMENTAL CONTROL

In recent years concern about asbestos and health has led to a reluctance on the part of manufacturers and molders of plastics to use asbestos reinforced or filled materials. Current OSHA regulations limit exposures to a time weighted average of 2 fibers per cubic centimeters of air. The current use of approximately 200,000 tons of asbestos in plastic products confirms the fact that manufacturers can and are meeting the low fiber dust limits set by OSHA. (Reference 29, 30).

Medical research has associated occupational exposure to asbestos fiber with increased risks of four human diseases: Asbestosis, Bronchogenic (lung) Cancer, Mesotheliomia and Gastrointestinal Cancer. Except for some isolated cases, asbestos-related health risks appear to be confined to occupationally-related environments.

All the diseases mentioned have relatively long latent periods, therefore, the incidences of asbestos-related disease being recorded today can be traced to the high exposures encountered years ago. Also with almost no exceptions, lung cancer has been found only in asbestos workers who smoke cigarettes regularly.

To lessen the chances for occupational exposure, asbestos suppliers have made significant improvements in packaging and shipping methods for asbestos. Automatic mechanical bag openers can be used to open bagged fiber after which it can be conveyed in a closed system to a weigh bin and a mixer. Dust collection systems and fabric filter bag houses can be used to minimize dust in the plant during processing operations. Once safely "locked" into a product by a resin or similar binder, the fiber cannot easily be released during the use of the product, thus products containing "locked-in" asbestos represent no danger to the general public. The same is true of fibrous talc, which contains asbestos fibers.