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MINISTRY OF TECHNOLOGY

**EXPLOSIVES RESEARCH
AND DEVELOPMENT ESTABLISHMENT**

TECHNICAL REPORT No. 2

Fibre - Filled Thermoplastics: Part 1: Asbestos

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K.J. Ledbury
D. Sims**

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Fibre-Filled Thermoplastics: Part 1: Asbestos

by

B.E. Erokenbrow
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SUMMARY

A range of graded and ungraded chrysotile and amosite asbestos fibres have been examined as reinforcing fillers for thermoplastics. Methods of incorporating the fibre have been examined and the effects of incorporation and processing on the fibre length has been studied. The tensile properties of the asbestos fibre reinforced materials have been measured and compared with the properties of glass reinforced materials.

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1. INTRODUCTION

Thermoplastics are a class of materials lending themselves through easy fabrication to the mass production of many articles. However for many engineering applications they have insufficient strength and rigidity. Their strength and stiffness can be increased by the incorporation of fibrous fillers and during the past six years glass reinforced thermoplastics have developed as engineering materials.¹ Glass reinforced materials exhibit markedly improved strength and rigidity, lower mould shrinkage, better dimensional stability and in some cases better impact behaviour. Although glass fibre has satisfactory tensile properties, its stiffness is rather low and a number of alternative fibres are now available (Table 1).

For use as a reinforcement in thermoplastics a fibre must be cheap and have a high specific stiffness (high stiffness, and/or low density). Chrysotile asbestos, the cheapest fibre, has twice the stiffness of glass and almost the same density. Silicon carbide, silicon nitride, boron and carbon fibre although possessing far superior properties, are as yet unattractive due to their cost. The work described in this report is therefore concerned with the incorporation of asbestos fibres into thermoplastics and investigates the incorporation, moulding and evaluation of asbestos-filled materials. Work with other fibres will be reported separately.

2. MATERIALS

Asbestos is a name given to a group of naturally occurring fibrous silicates. There are six species of asbestos-type materials, five of these being amphiboles and one serpentine (Tables 2 and 3, Plates 1 - 4). Chrysotile, often called white asbestos, is the only member of the serpentine group and is by far the most common of all the asbestos species. Next to chrysotile in abundance is the amphibole crocidolite normally called blue asbestos. This is coarser than chrysotile and more brittle, it also has been reported to possess carcinogenic hazards and has therefore not been evaluated. The only other asbestos of importance is amosite. This is a coarse fibre and is also very brittle. However amosite is superior to chrysotile in chemical resistance and occurs as long fibres up to six inches (150 millimetres) long.

All asbestos within a class are, however, characteristic of a particular mine or seam and large differences in properties can occur between nominally similar fibres from different mines.

At the mine the asbestos ore is crushed and the asbestos removed. The fibres are further milled to open up the fibre bundles and are then graded by a dry process according to length. The material from the mine we have referred to as crude asbestos even though it has been roughly graded.

At ERDE the asbestos has been further graded by a patented² rotating wet sieve process. This process produces the five grades of asbestos listed

/below:

below:

- Grade 1 - fibres retained on a 6 mm screen.
- Grade 2 - fibres passing 6 mm but retained on a 2 mm screen.
- Grade 3 - fibres passing 2 mm but retained on a 0.5 mm screen.
- Grade 4 - fibres passing 0.5 mm but retained on a 100 mesh static screen.
- Grade 5 - fibres passing 4 but retained on a second 100 mesh static screen.
- Grade (1-4) - all fibres retained on a single 100 mesh static screen; this grade is similar to Grades 1 + 2 + 3 + 4.

The types of asbestos used in this work are given in Appendix A.

Four thermoplastics have been used for the bulk of the experimental work, nylon 6, toughened polystyrene, ABS and polypropylene. A full list of materials used is given in Appendix A together with the grades and manufacturer.

3. EXPERIMENTAL

The basic experimental problems are:

- (a) incorporation of the asbestos fibre into the thermoplastic; and
- (b) minimising the effects of incorporation and processing on the fibre.

Associated problems are the optimum initial fibre length, the best type of asbestos and the best loading.

Three methods of incorporation have been investigated:

- (a) polymerisation of a suspension of fibres in a suitable monomer;
- (b) mixing the fibre into a solution of the polymer; and
- (c) direct mechanical incorporation of the fibre into the polymer melt.

3.1 Polymerisation

The polymerisation of caprolactam and styrene in the presence of fibres was studied. Typically for the polymerisation of caprolactam to nylon 6, fibres were stirred into a melt of dried caprolactam under nitrogen, catalyst was added and the polymerisation allowed to proceed under nitrogen. Three catalysts were examined, water, metallic sodium and lithium hydride/acetyl caprolactam. Only the lithium hydride/acetyl caprolactam system gave satisfactory products in a short time/temperature cycle (15 - 20 minutes at 150°C). After reaction, the product was cooled, granulated and unreacted caprolactam removed by extraction with boiling methanol.

In the presence of asbestos fibres polymerisation only proceeded to a limited extent, as shown by the very high extractables content of the product (Table 4). This limitation, thought to be due to absorption of the catalyst onto active sites on the asbestos surface, was largely overcome by pretreating the asbestos fibres with silane coupling agents or with soluble nylon.

/However

However the process was still not attractive.

A similar procedure was adopted for the polymerisation of styrene, using AZDN or benzoyl peroxide as catalyst. With either catalyst in the presence of asbestos fibres, polymerisation did not produce a solid product. In the light of these results further attempts to polymerise styrene in the presence of fibres were abandoned.

3.2 Solution Incorporation

In this method the fibres were dispersed in a solution of the polymer in a suitable solvent by slow speed stirring, the slurry added to a precipitant and the product filtered, washed, and dried. It was found that the fibres dispersed easily in lower viscosity solutions and a large number of small scale mixes were made by this technique. The method is suitable for small scale evaluation work but is not attractive commercially except in those cases where the polymer is produced in solution (polystyrene and polycarbonate). The method has the advantage that the fibre length is not degraded during the mixing process and with nylon 6 and 66 it avoids the oxidative degradation which can occur on direct mixing at high temperatures ($> 260^{\circ}\text{C}$).

3.3 Direct Mixing

This is the most practical method of incorporating fibres on the large scale. During this work, compounding in extruders, a Frenkel mixer, a Buss Ko-neader and a Banbury type internal mixer was assessed. The small extruders and Frenkel mixer proved difficult to feed uniformly and gave poor products. This difficulty however does not necessarily exclude larger sizes of these machines for large scale production. The Buss Ko-neader produced a uniform product which contained somewhat broken down fibres. However the results were much better than compounding in the extruder or Frenkel mixer. Oil heated double cam mixers of the Banbury type gave consistent uniform products and although the end result was a large lump of material which proved difficult to handle, this type of mixer was used to prepare most of the materials evaluated.

3.4 Sample Preparation and Testing

Mixes were granulated using a Spruemaster granulator and after the granulate was dried the mix was injection moulded into suitable test specimens using either a 10 g automatic ram injection moulding machine (a) having an injection pressure of 10,000 psi or a 100 g reciprocating screw machine (b) having an injection pressure of 17,000 psi.

The moulding conditions used were similar to those recommended for the corresponding glass filled compounds. No large differences in properties were detected between samples moulded on the two machines.

Tensile strengths were measured at a rate of 1 in (25 mm)/min according to ASTM D 638 - 64. Flexural strengths and moduli were measured according to ASTM D 970 - 66.

/Densities

-
- (a) Austin Allen Ltd., Harold Wood, Essex.
 - (b) Ankerwerke V17/65, Hamilton Sales Ltd., Uxbridge.

Densities were measured by ASTM D 792 - 66 and were very close to the calculated values.

3.5 Fibre Length Determination

A small piece of the moulded material was placed in a muffle furnace at 500°C in a stream of oxygen and the plastic burnt off. The asbestos remaining was dispersed in glycerol on a microscope slide. The fibres were photographed at a magnification of x 20. Individual fibres on a portion of the slide were identified and the slide rephotographed at a magnification of x 100 to obtain the fibre diameters. By measuring the fibre lengths and dividing by an average value for the diameter a distribution curve of the length to diameter ratio (L/D, the aspect ratio) was determined.

4. RESULTS AND DISCUSSION

The polymerisation of monomer around asbestos fibres has already been shown to be difficult and unattractive. The comparison of properties of those composites made by direct melt mixing and the solution method (Table 5) shows that some difference in properties occurs in the respective mouldings, the solution mixed materials having somewhat better properties. However the solution process is not industrially attractive and most results have been obtained on direct mixed materials.

The effects of time of mixing is given in Table 6 and Figs 1 and 2 give typical viscosity mixing time curves as obtained from the small (50 g) oil heated mixer (Brabender Plastograph). With C & GOB chrysotile and amosite the viscosity of the mix is at a maximum at the point of adding the asbestos, rapidly falling almost to a plateau. The tensile properties of polystyrene show a maximum value at a mixing time between 2½ and 5 minutes, subsequently falling (Table 6). The behaviour of Canadian and South African chrysotile was rather different with the viscosity of the mix just falling then showing a slight rising tendency. These chrysotile fibres were difficult to disperse uniformly and these two effects, the increase in viscosity and the poor dispersion, are almost certainly related to the physical shape of the fibres. Unlike C & GOB and amosite the other types are not straight needle-like fibres but tend to be bent and kinked (Plates 1 - 8).

The effect of grading asbestos is shown for three plastics in Table 7. It can readily be seen that grading produces considerable improvements in both strength and rigidity of the filled materials when using C & GOB. However there was little difference between the results for Grades 1 to 4. This observation has been satisfactorily explained by measuring the fibre lengths in the moulded samples. All samples containing Grades 1, 2, 3 or 4 had a similar fibre length/diameter distribution and this corresponded quite closely to the length/diameter ratio of Grade 4 asbestos (Fig. 3). With the other types of chrysotile and with amosite grading was not so beneficial.

The tensile properties of four plastics, polypropylene, toughened polystyrene, ABS and nylon 6 containing different types of asbestos are given in Table 8 and Fig. 4. Rhodesian chrysotile (C & GOB) produces the largest increases in tensile strength and stiffness in the four polymers examined. The other types

/of

of chrysotile produce composites with similar but lower properties. Amosite, although giving again similar properties on a weight/weight basis, is somewhat better than the other chrysotiles when account is taken of its high density and results are compared on a volume basis.

The poor behaviour of Canadian and South African chrysotiles can be explained by examination of the recovered fibres from moulded specimens (Plates 9 - 12). These show that the Canadian and South African materials are much more broken down and less fibrous after the processing cycle than C & GOB (Plate 5) and have therefore a much lower L/D (length to diameter) ratio. It is this latter property (L/D) which has been shown to govern the amount of reinforcement obtained in a composite.⁶

C & GOB asbestos reinforces all the thermoplastics examined giving useful increases in tensile strength and large increases in stiffness (Table 9, Figs 5 and 6). The properties of corresponding glass-filled materials are given in Table 10, and a comparison with the asbestos-filled materials shows that asbestos gives lower tensile strengths but higher rigidities at the same weight loading.

5. CONCLUSIONS

A form of chrysotile asbestos (C & GOB) has been shown to have superior reinforcing properties to other grades of chrysotile and amosite when compounded into thermoplastics. The fibre properties required for good reinforcement are a straight fibre, large L/D ratio and the ability to survive compounding (non-brittle behaviour).

A comparison with glass-filled materials shows that asbestos-filled thermoplastics have somewhat higher rigidities but lower tensile strengths at the same loading.

6. REFERENCES

1. Anon "Glass Fibre Reinforced Plastics" Engng. Mater. Des., 8, 324 (1965)
2. Brit. Pat. Appl. 282866
3. Lavengood, R.E., Anderson, R.L. S.P.E. 24, 20 (1968)
4. Mumford, C.J. Ministry of Technology Unpublished Report
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APPENDIX A

THERMOPLASTICS USED IN THIS WORK

Plastic	Trade Name	Grade	Manufacturer	Temperature of Melt Incorporation
Nylon 66	Maranyl	A100	ICI Ltd.	Solution mixed (5 minutes) 260°C
Nylon 6	Maranyl	F113	ICI Ltd.	
Toughened polystyrene	Bextrene	XL750		" " 220°C
Polypropylene	Propathane	HWM25	ICI Ltd.	" " 210°C
ABS	Cyclolac	GSM 558		" " 260°C
GP polystyrene	Lustrex	Crystal	Monsanto	" " 210°C
PMMA	Diakon	MO	ICI Ltd.	" " 210°C
SAN	Tyrl crystone	R5800C	Dow Chemicals	" " 210°C
TPX	TPX	-	ICI Ltd.	" " 210°C
EVA	EVA	DPD6169	Bakelite Ltd.	" " 210°C
Surllyn A	Ionomer		Du Pont	" " 210°C
Bakelite phenoxy			Bakelite Ltd.	Solution mixed
Polysulphone	Polysulphone		Bakelite Ltd.	" "
CAB	Tenite Butyrate		Eastman Kodak	" "

TYPES OF ASBESTOS USED IN THIS WORK

Type	Grade	Distributor	Location of Mine
Chrysotile	C & GOB	Turner Bros.	Rhodesia
"	KB 7D	Asbestos Corporation	Canada. King Beaver Mine
"	N 562 5R	" "	" Normandie Mine
"	CT	Turner Bros.	" Clinton Mine
"	5R and 6D	Central Asbestos	South Africa
"	Calidra 144	Union Carbide	California (Ref. 5)
"	Calidra 244	" "	California
Amosite	S/33/65	Cape Asbestos	South Africa
"	RK	" "	South Africa

/TABLE 1

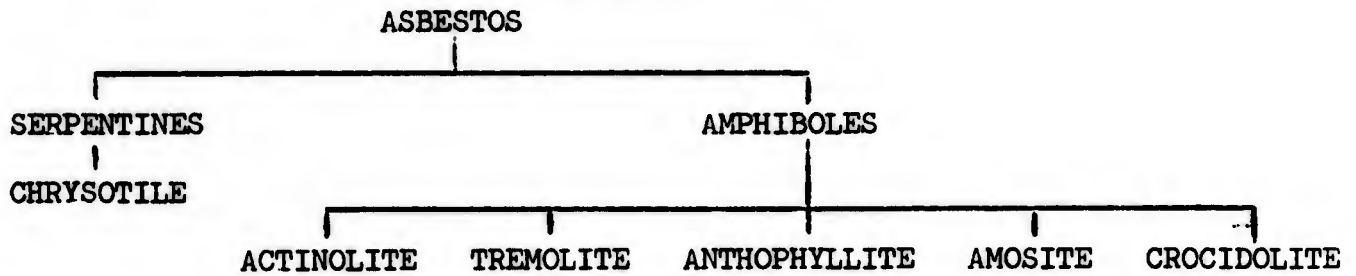
TABLE 1

Properties of Fibres

Fibre	Density, g/cm ³	Tensile Strength, psi × 10 ⁵	Flexural Modulus, psi × 10 ⁶
E glass	2.5	5	10
S glass	2.5	7	12
Asbestos Chrysotile	2.5	4 - 8	21 - 23
Amosite	3.2	3 - 4	21 - 23
Silicon nitride	3.2	7	40
Silicon carbide (ERDE origin)	3.2	14	70
Carbon type I (RAE origin)	2.0	3	55
Carbon type II " "	1.7 - 1.8	4	33
Boron	2.5	4	60

TABLE 2

Varieties of Asbestos



/TABLE 3

TABLE 3

Physical Properties of Asbestos Fibres

Property	Chrysotile	Crocidolite	Amosite
Fibre length, mm	0.7 - 25	3 - 75	3 - 150
Fibre diameter, μm	0.02	0.1	0.1
Cross section	Tubular	Striplike	Striplike
Density, g/cm^3	2.4 - 2.7	3.2 - 3.3	3.1 - 3.3
Tensile strength, psi	850,000 (Arizona) 520,000 (Thetford)	670,000 (Pomirett) 411,000 (Koegas)	370,000
Modulus, $\text{psi} \times 10^6$	20 (Arizona) 21 (Thetford)	24 (Pomfrett) 21 (Koegas)	21
Chemical resistance			
acid	poor	good	fair
alkali	good	good	fair
Cost, d/lb	6 - 60	12 - 20	8 - 80

TABLE 4

Polymerisation of Caprolactam in the Presence of Fibres

Filler, % by weight	Polymerisation		Extractables, % by weight	Tensile Strength, psi
	Temperature, $^{\circ}\text{C}$	Time, minutes		
0	150	15	8.1	9,500
10% asbestos	150	20	73.2	-
10% asbestos ¹	150	15	14.3	13,000
10% asbestos ²	150	15	31.2	-

¹C & GOB asbestos fibres pretreated with soluble nylon.

²C & GOB asbestos fibres pretreated with silane coupling agent.

/TABLE 5

TABLE 5

Comparison of Tensile Properties of
Direct and Solution Mixed Composite

Material	Tensile Strength, psi	Flexural Modulus, psi × 10 ⁶
<u>Bakelite Phenoxy unfilled</u>	6,140	0.27
direct mix + 16.6% asbestos	11,500	0.66
" " + 40% "	15,400	1.25
solution mix + 16.6% "	14,920	0.96
" " + 40% "	19,000	1.7
<u>SAN unfilled</u>	9,700	0.45
direct mix + 16.6% "	10,000	0.80
" " + 28.8% "	12,000	0.98
solution mix + 16.6% "	11,500	0.79
" " + 28.8% "	15,900	1.17
<u>GP Styrene unfilled</u>	5,800	0.49
direct mix + 16.6% "	7,300	0.89
" " + 28.8% "	7,900	1.30
solution mix + 16.6% "	10,300	0.99
" " + 28.8% "	11,000	1.30

TABLE 6

Effect of Mixing Time on the Properties of
C & GOB Asbestos-Filled Toughened Polystyrene

Mixing Time, minutes	Polymer and Filler			
	Toughened Polystyrene T3 + 16.6% Grade 2 Asbestos		Toughened Polystyrene T3 + 16.6% Grade 4 Asbestos	
	Tensile Strength, psi	Flexural Modulus, psi × 10 ⁶	Tensile Strength, psi	Flexural Modulus, psi × 10 ⁶
2½	7,200	0.75	6,800	0.72
5	6,600	0.66	7,100	0.74
10	6,000	0.72	5,900	0.68

/TABLE 7

TABLE 7

Properties of Filled Polymers V.
Grade of C & GOB Asbestos Used as Filler

Polymer	Grade of Asbestos	Tensile Strength, psi	Flexural Modulus, psi $\times 10^6$
Polypropylene + 16.6% asbestos	Grade 1	5,920	0.52
	" 2	6,050	0.52
	" 3	6,180	0.49
	" 4	6,100	0.50
	" (1 - 4)	6,000	0.50
	Ungraded	5,630	0.37
Nylon 66 + 16.6% asbestos	Grade 1	19,100	0.88
	" 3	18,000	0.88
	" 4	16,700	0.88
	" 5	17,400	0.78
	Ungraded	16,500	0.64
ABS 28% loading	Grade 1	17,100	0.96
	" 2	17,400	0.90
	" 3	17,200	0.93
	" 4	17,400	0.89
	" 5	16,500	0.88

TABLE 8

TABLE 8

Properties of Selected Thermoplastics
Reinforced with Different Asbestos Fibres

Plastic	Asbestos	Type	ERDE Grade	% Loading, w/w	% Loading, v/v	Tensile Strength, psi × 10 ³	Flexural Modulus, psi × 10 ⁶	
Polypropylene	Chrysotile	C & GOB	(1 - 4)	28	11.1	7.45	0.74	
	"	KB 7D	Ungraded	28	11.1	5.85	0.51	
	"	N 562 5R	(1 - 4)	28	11.1	6.06	0.54	
	"	N 562 5R	1	28	11.1	5.95	0.58	
	"	N 562 5R	4	28	11.1	5.69	0.47	
	"	CT	Ungraded	28	11.1	6.10	0.42	
	"	CT	(1 - 4)	28	11.1	5.93	0.39	
	"	5R (S.A.)	4	28	11.1	5.2	0.45	
	"	Amosite	RK	Ungraded	28	9.5	5.65	0.51
	"	"		(1 - 4)	16	4.9	5.36	0.45
	"	"		(1 - 4)	28	9.5	6.14	0.57
"	"		(1 - 4)	40	15.3	6.26	0.71	
"	"	S/33/65	Ungraded	28	9.5	5.35	0.47	
Toughened polystyrene	Chrysotile	C & GOB	4	28	13.7	7.28	1.17	
	"	N 562 5R	(1 - 4)	28	13.7	5.63	0.73	
	"	N 562 5R	4	28	13.7	6.36	0.42	
	Amosite	RK	Ungraded	28	10.6	5.58	0.68	
	"		(1 - 4)	16	5.5	4.85	0.49	
	"		(1 - 4)	28	10.6	5.17	0.65	
	"		(1 - 4)	40	17.0	5.92	0.75	
"		S/33/65 Caldria 144	Ungraded	28	10.6	4.75	0.60	
ABS	Chrysotile	C & GOB	(1 - 4)	28	13.7	9.72	1.31	
	"	C & GOB	(1 - 4)	40	21.4	8.84	1.87	
	"	N 562 5R	(1 - 4)	28	13.7	7.65	0.53	
	"	N 562 5R	4	28	13.7	6.20	1.03	
	"	CT	(1 - 4)	28	13.7	11.56	0.92	
	"	6D (S.A.)	4	28	13.7	7.4	0.89	
	"	5R (S.A.)	4	28	13.7	7.7	0.79	
	Amosite	RK	Ungraded	28	10.6	8.5	0.68	
	"		(1 - 4)	16	5.5	8.5	0.55	
	"		(1 - 4)	28	10.6	9.5	0.74	
"		(1 - 4)	40	17.0	10.2	0.84		
Nylon 6	Chrysotile	C & GOB	4	28	13.7	18.2	1.32	
	Amosite		4	28	10.6	16.4	1.25	

/TABLE 9

TABLE 9

Tensile Strength and Flexural Modulus of Various
Plastics Reinforced with Chrysotile C & GOB

Material	Percentage Loading, w/w	ERDE Grade	Tensile Strength, psi	Flexural Modulus, psi x 10 ⁶	Flexural Strength, psi
Nylon 66*	0	-	11,400	0.3	-
	9	4	18,400	0.8	-
	28.8	4	21,000	1.25	32,000
	40	4	18,000	1.65	35,600
	58	4	17,400	1.67	36,800
Nylon 6	0	-	9,700	0.28	-
	16.6	Ungraded	14,000	0.53	-
	16.6	4	15,100	0.70	21,000
	28.8	4	18,200	1.00	24,000
ABS	0	-	5,200	0.38	-
	16.6	Ungraded	8,350	0.67	-
	16.6	(1 - 4)	10,300	0.84	18,700
	28.8	(1 - 4)	9,700	1.31	18,400
	40	(1 - 4)	8,800	1.87	17,200
	16.6	4	11,000	0.87	17,800
	28.8	4	12,400	0.89	17,700
40	4	12,400	1.6	17,700	
Polypropylene	0	-	4,200	0.21	-
	16.6	Ungraded	5,600	0.37	-
	16.6	(1 - 4)	5,860	0.59	-
	28.8	(1 - 4)	7,450	0.74	-
	40	(1 - 4)	8,590	0.86	11,000
Toughened polystyrene	0	-	4,600	0.34	-
	16.6	Ungraded	5,700	0.51	-
	16.6	(1 - 4)	5,150	0.87	12,200
	28.8	(1 - 4)	6,500	0.99	12,500
	40	(1 - 4)	7,000	1.50	14,000
GP polystyrene	0	-	5,800	0.49	9,700
	16.6	(1 - 4)	7,300	0.89	10,700
	28.8	(1 - 4)	7,900	1.3	14,000
	40	(1 - 4)	7,000	1.4	11,500
			9,000	0.46	12,300

A

Toughened polystyrene	0	-	4,600	0.34	12,200
	16.6	Ungraded	5,700	0.51	12,500
	16.6	(1 - 4)	5,150	0.87	14,000
	28.8	(1 - 4)	6,500	0.99	9,700
	40	(1 - 4)	7,000	1.50	10,700
GP polystyrene	0	-	5,800	0.49	14,000
	16.6	(1 - 4)	7,500	0.89	11,500
	28.8	(1 - 4)	7,900	1.3	12,300
	40	(1 - 4)	7,000	1.4	18,000
PMMA	0	-	9,000	0.46	-
	16.6	(1 - 4)	11,800	0.92	-
	30	(1 - 4)	16,700	1.29	17,700
	40	(1 - 4)	15,000	1.70	13,000
SAN	0	-	9,700	0.45	15,000
	16.6	(1 - 4)	10,000	0.80	8,900
	28.8	(1 - 4)	12,000	0.98	10,500
TPX	0	-	3,360	0.21	-
	16.6	-	5,500	0.36	-
	28.8	-	5,770	0.54	-
	40	-	6,400	0.68	-
EVA	0	-	2,760	0.004	-
	16.6	-	2,050	0.01	-
	28.8	-	2,160	0.054	-
	40	-	2,000	0.13	-
Surlyn A	0	(1 - 4)	2,180	0.38	-
	16.6	-	4,640	0.54	-
	28.8	-	5,530	0.76	-
	40	-	6,770	0.36	16,300
Bakelite phenoxy	0	4	11,500	0.66	20,600
	16.6	4	15,400	1.25	-
	40	4	4,700	0.20	-
CAB	0	4	9,100	1.08	-
	28	4	10,000	1.28	-
	40	4	-	-	-

*Solution mixed

/TABLE 10

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TABLE 10

Tensile Strength and Flexural
Properties of Glass-Filled Plastics

Material and Fibre Content by Weight	Tensile Strength, psi	Flexural Strength, psi	Flexural Modulus, psi x 10 ⁶
Polypropylene 20% glass	6,000	8,000	0.40
Nylon 6 30% glass	19,000	30,000	0.85
Nylon 66 30% glass	22,000	28,000	1.10
ABS 30% glass	10,000	12,100	0.94
SAN 30% glass	17,000	22,000	1.42

TABLE

TABLE

Conversion of psi to Equivalent SI Units (MN/m²)

psi	0	10	20	30	40	50	60	70	80	90	psi	MN/m ²
0	.00	.07	.14	.21	.28	.34	.41	.48	.55	.62	1	.01
100	.69	.76	.83	.90	.97	1.03	1.10	1.17	1.24	1.31	2	.01
200	1.38	1.45	1.52	1.59	1.65	1.72	1.79	1.86	1.93	2.00	3	.02
300	2.07	2.14	2.21	2.28	2.34	2.41	2.48	2.55	2.62	2.69	4	.03
400	2.76	2.83	2.90	2.96	3.03	3.10	3.17	3.24	3.31	3.38	5	.03
500	3.45	3.52	3.59	3.65	3.72	3.79	3.86	3.93	4.00	4.07	6	.04
600	4.14	4.21	4.27	4.34	4.41	4.48	4.55	4.62	4.69	4.76	7	.05
700	4.83	4.90	4.96	5.03	5.10	5.17	5.24	5.31	5.38	5.45	8	.06
800	5.52	5.58	5.65	5.72	5.79	5.86	5.93	6.00	6.07	6.14	9	.06
900	6.21	6.27	6.34	6.41	6.48	6.55	6.62	6.69	6.76	6.83	10	.07
1000	6.90											

ERDE TR 2



PLATE 1 UNGRADED CHRYSTILE (C & GOB). Magnification x 12

ERDE TR 2

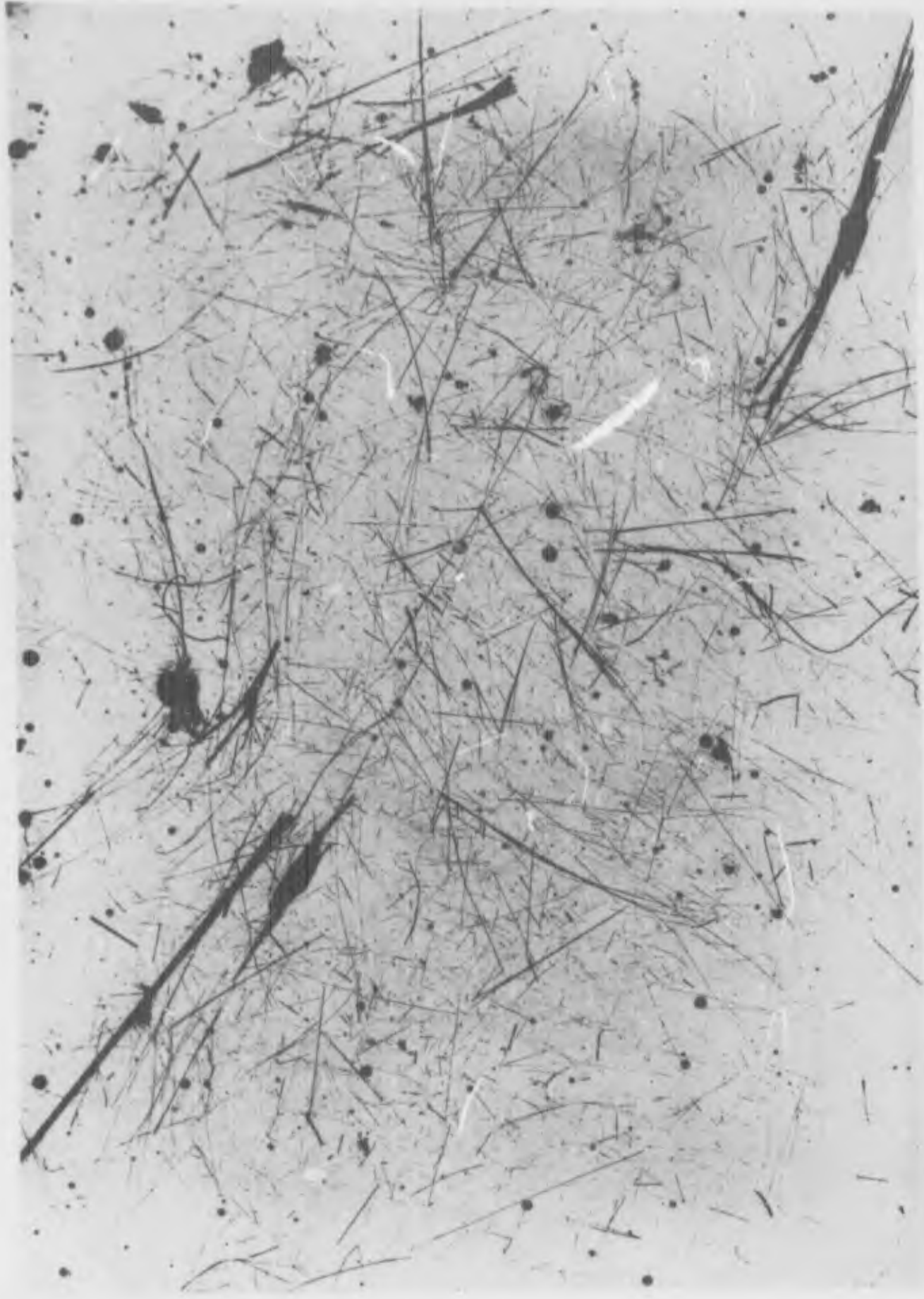


PLATE 2 UNGRADED CROCIDOLITE. Magnification x 12

ERDE TR 2

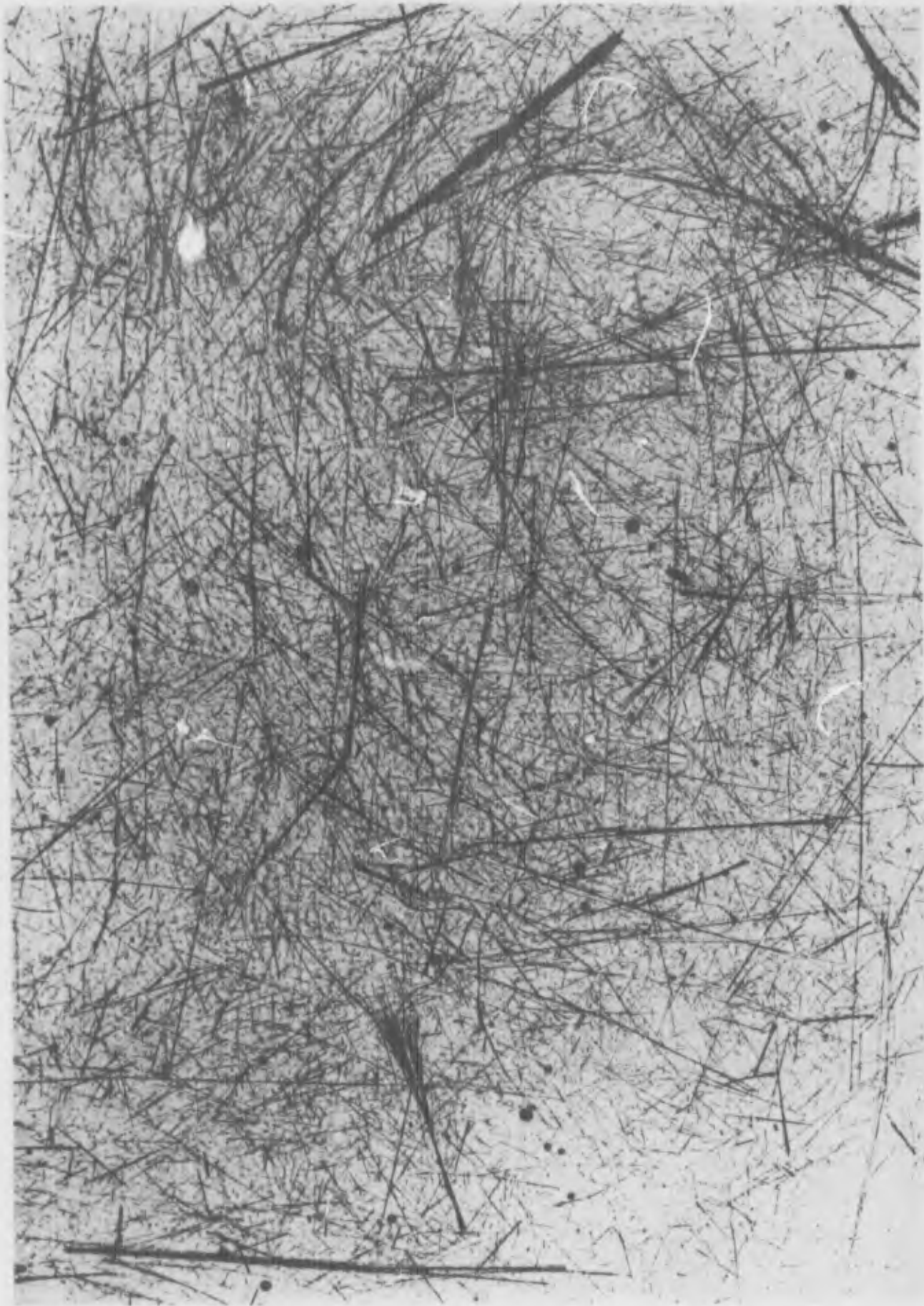


PLATE 3 UNGRADED AMOSITE Magnification x 12

ERDE TR 2

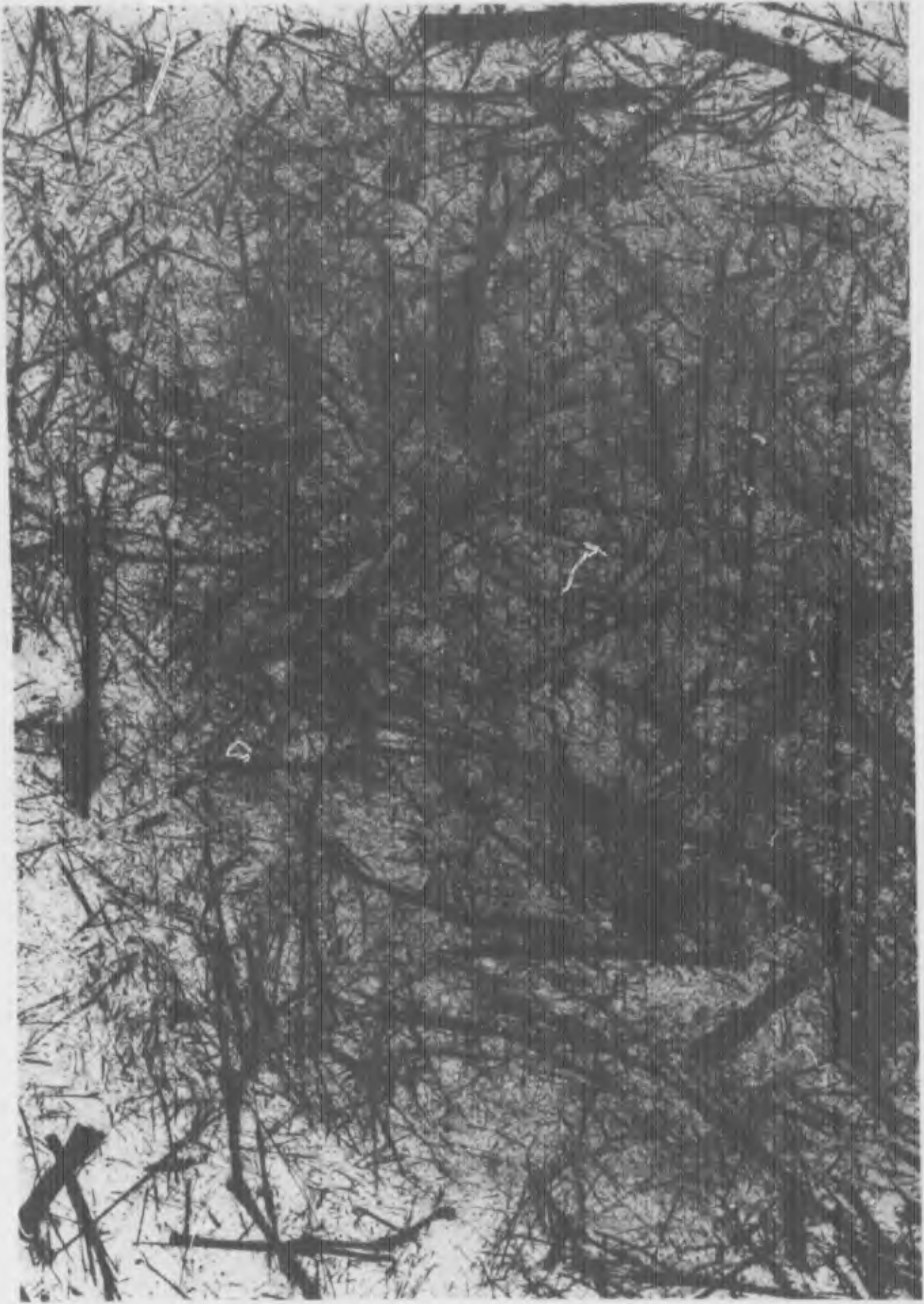


PLATE 4 UNGRADED ANTHOPHYLLITE. Magnification x 12



PLATE 5 GRADE 2 CHRYSOTILE (C & GOB). Magnification x 12

ERDE TR 2



PLATE 6 GRADE (1-4) AMOSITE . Magnification x 12



PLATE 7 GRADE (1-4) CHRYSOTILE (CT). UNTREATED. Magnification x 12



PLATE 6 GRADE 4 CHRYSOTILE (N 562 5R) Magnification x 12



PLATE 9 RECOVERED CHRYSOTILE (C & GOB), 16% GRADE 1
IN POLYPROPYLENE. Magnification x 20

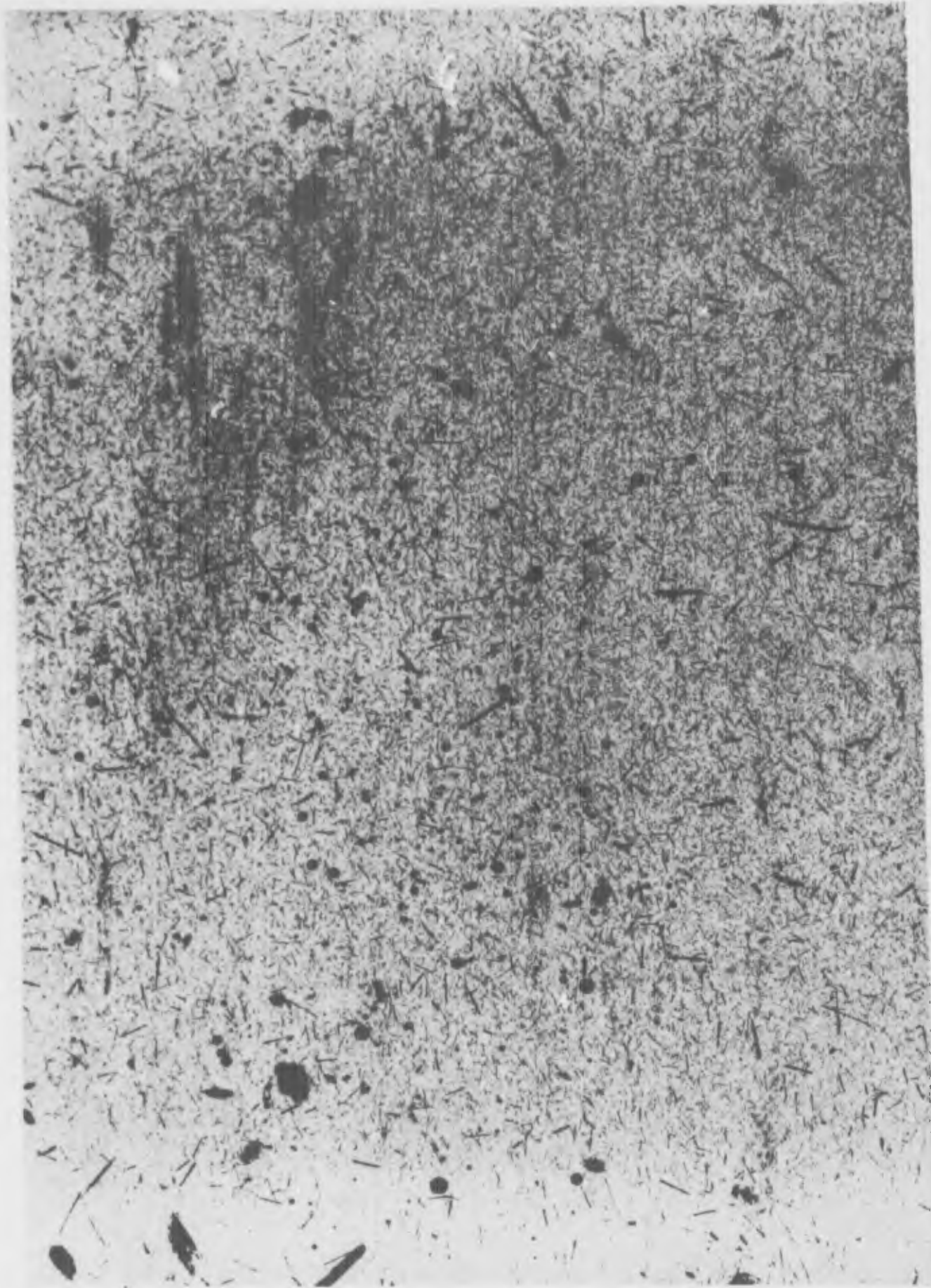


PLATE 10 RECOVERED AMOSITE. 28% GRADE (1-4) IN POLYPROPYLENE.
Magnification x 20

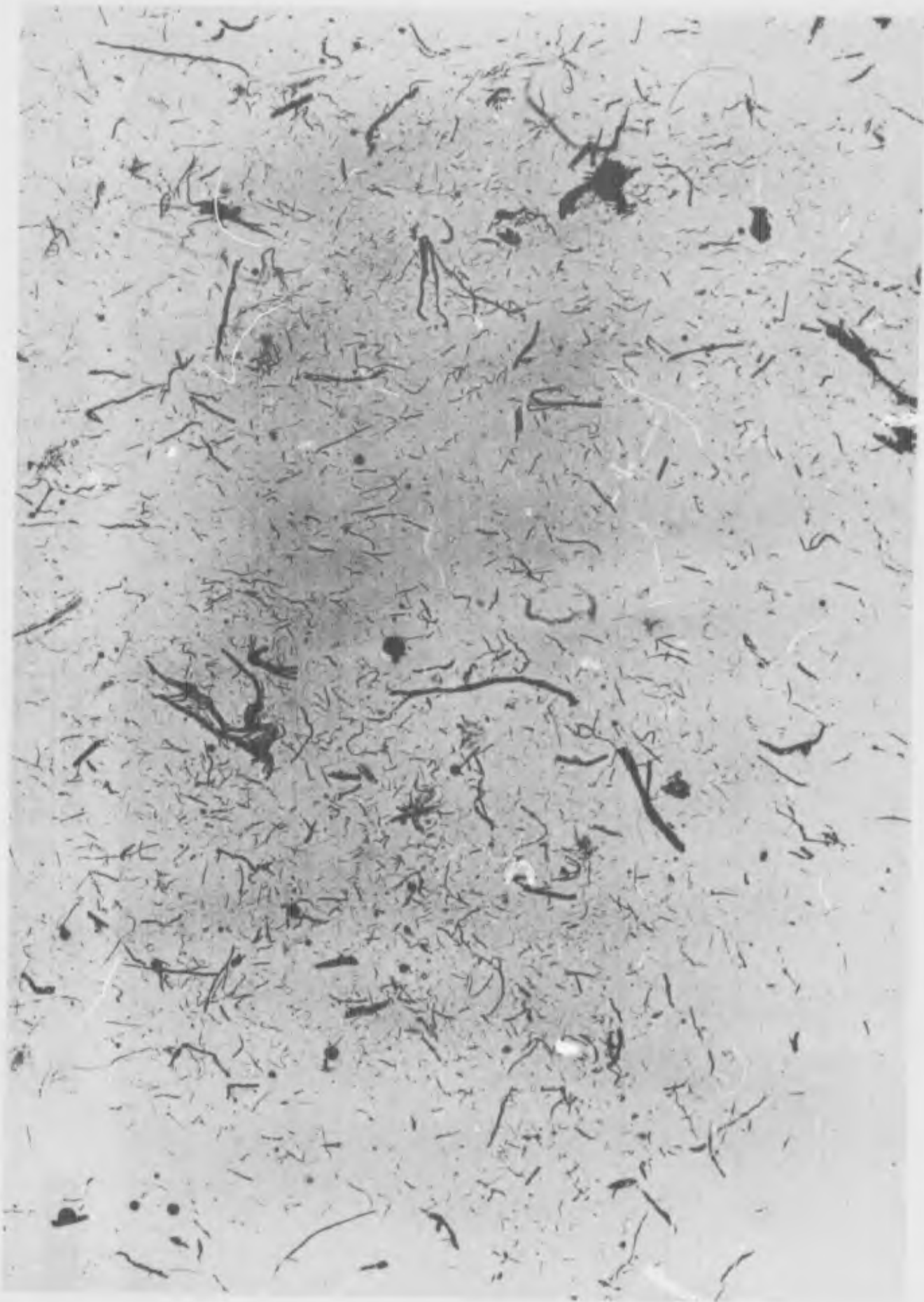


PLATE 11 RECOVERED CHRYSOTILE (CT) . 16% GRADE (1-4) IN POLYPROPYLENE.
Magnification x 20



PLATE 12 RECOVERED CHRYSOTILE (N 562 5R) 28% GRADE (1-4)
IN POLYPROPYLENE. Magnification x 20

ERDE TR 2

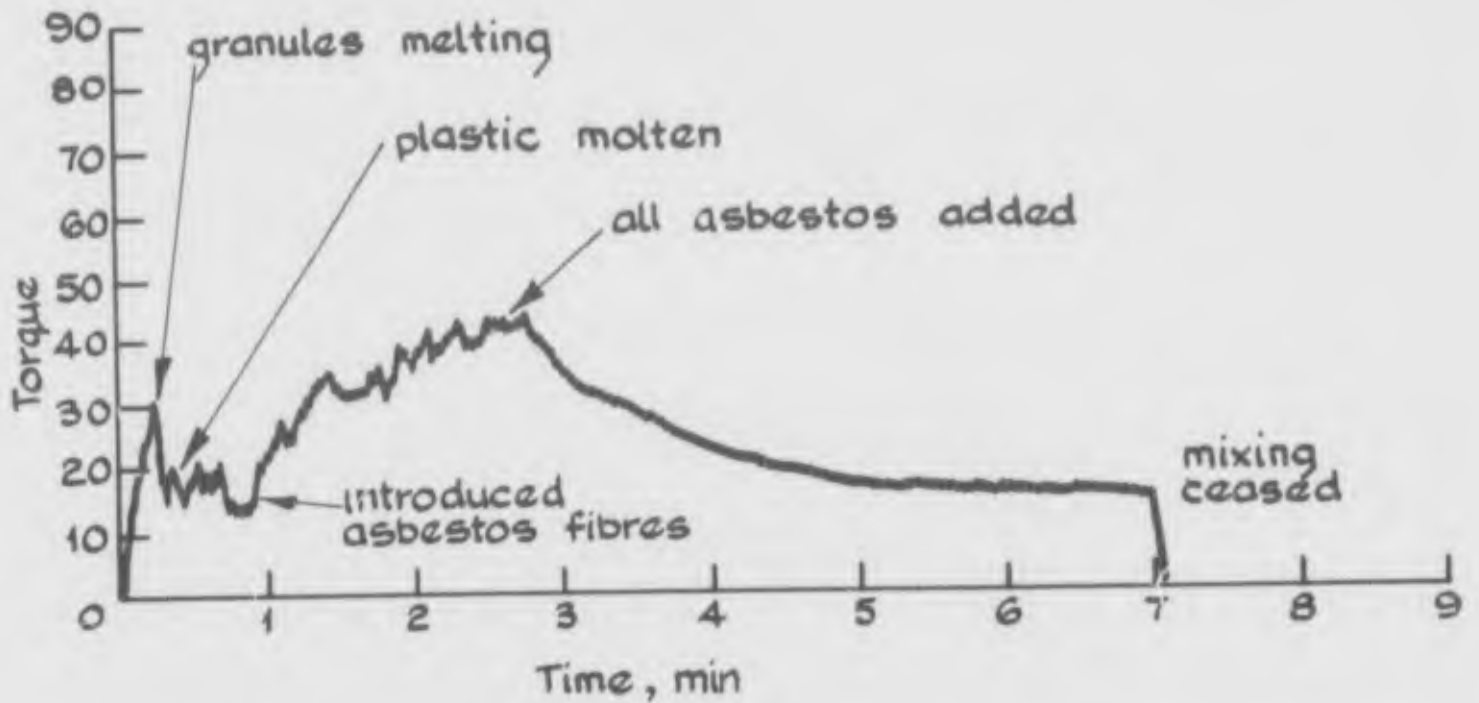


FIG. 1 TORQUE VS TIME CURVE ON MIXING AMOSITE
(OR C & GOB) 50% LOADING IN XL750
TOUGHENED POLYSTYRENE.

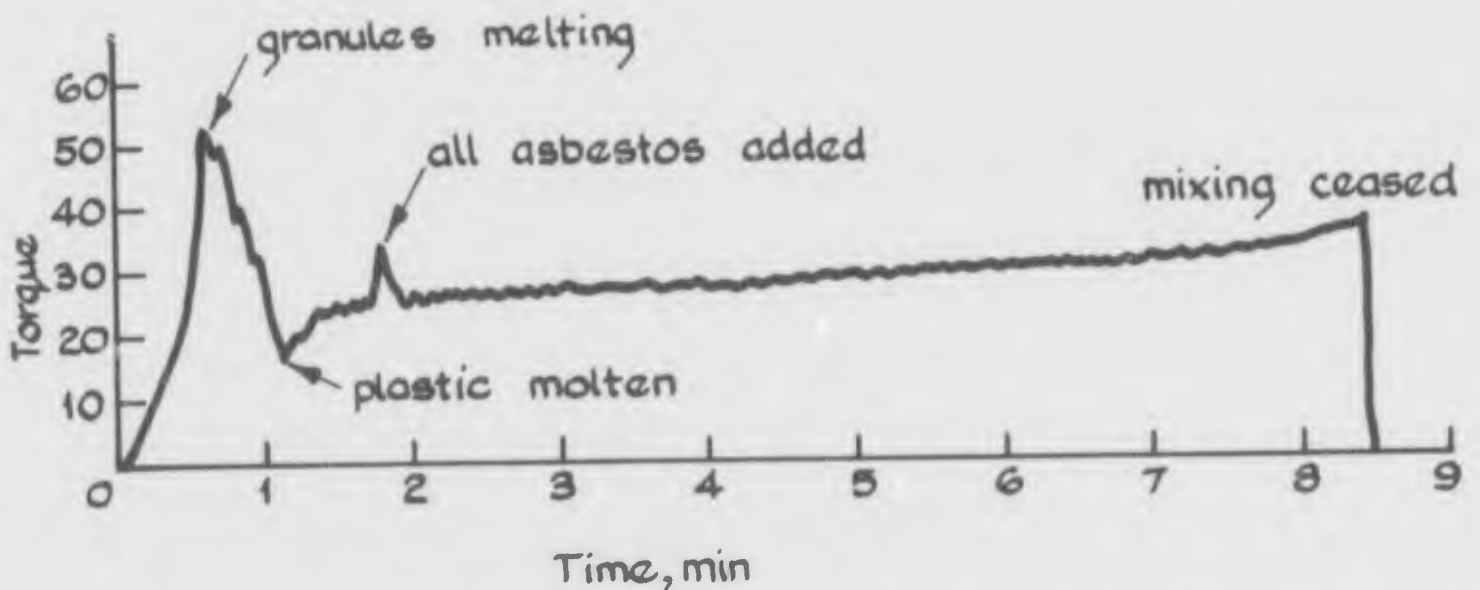


FIG. 2 TORQUE VS TIME CURVE ON MIXING CANADIAN
THETFORD CHRYSOTILE. 28% LOADING IN
POLYPROPYLENE.

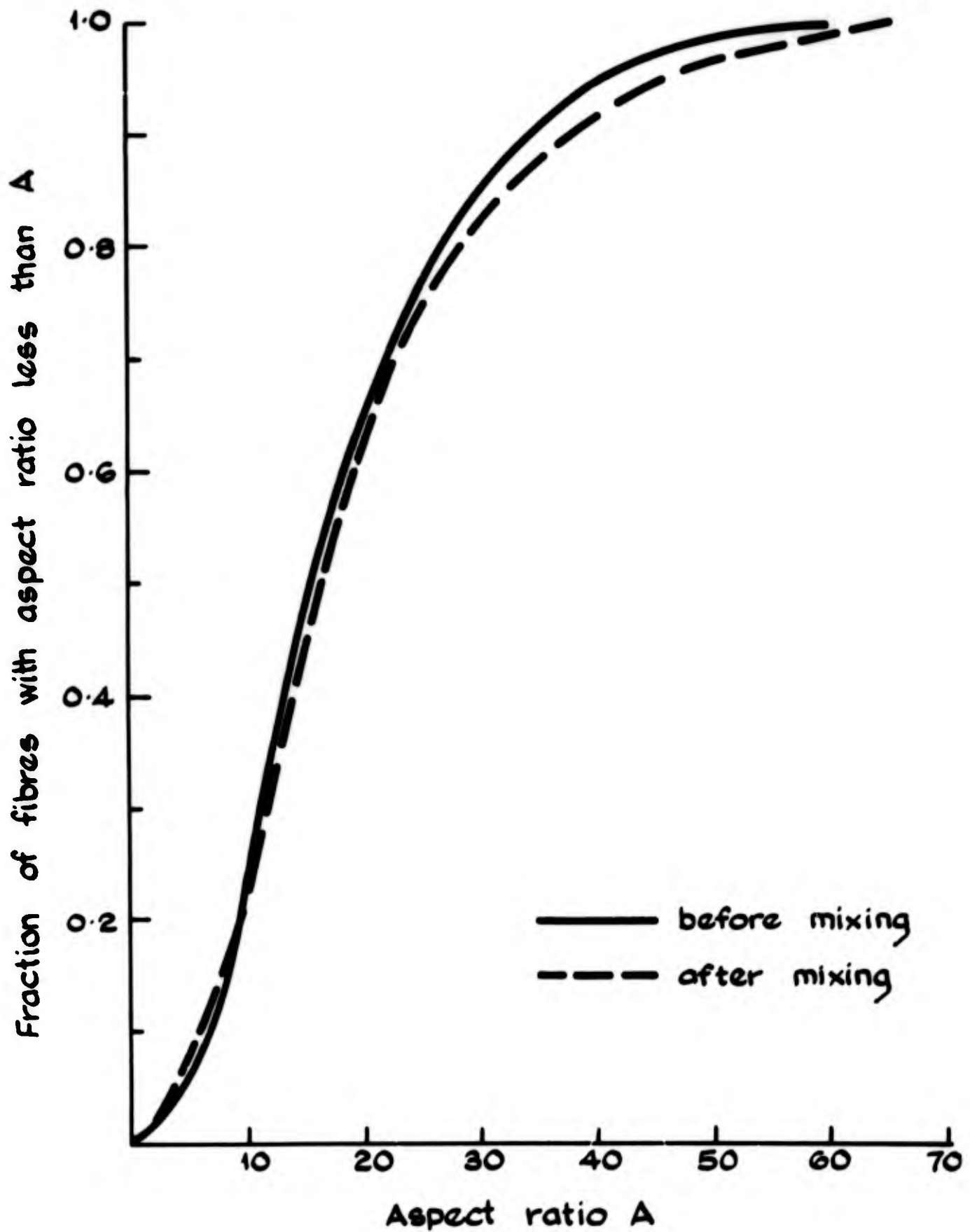


FIG. 3 ASPECT RATIO AND FIBRE LENGTH
DISTRIBUTION BEFORE AND AFTER MIXING.
C & GOB GRADE 4.

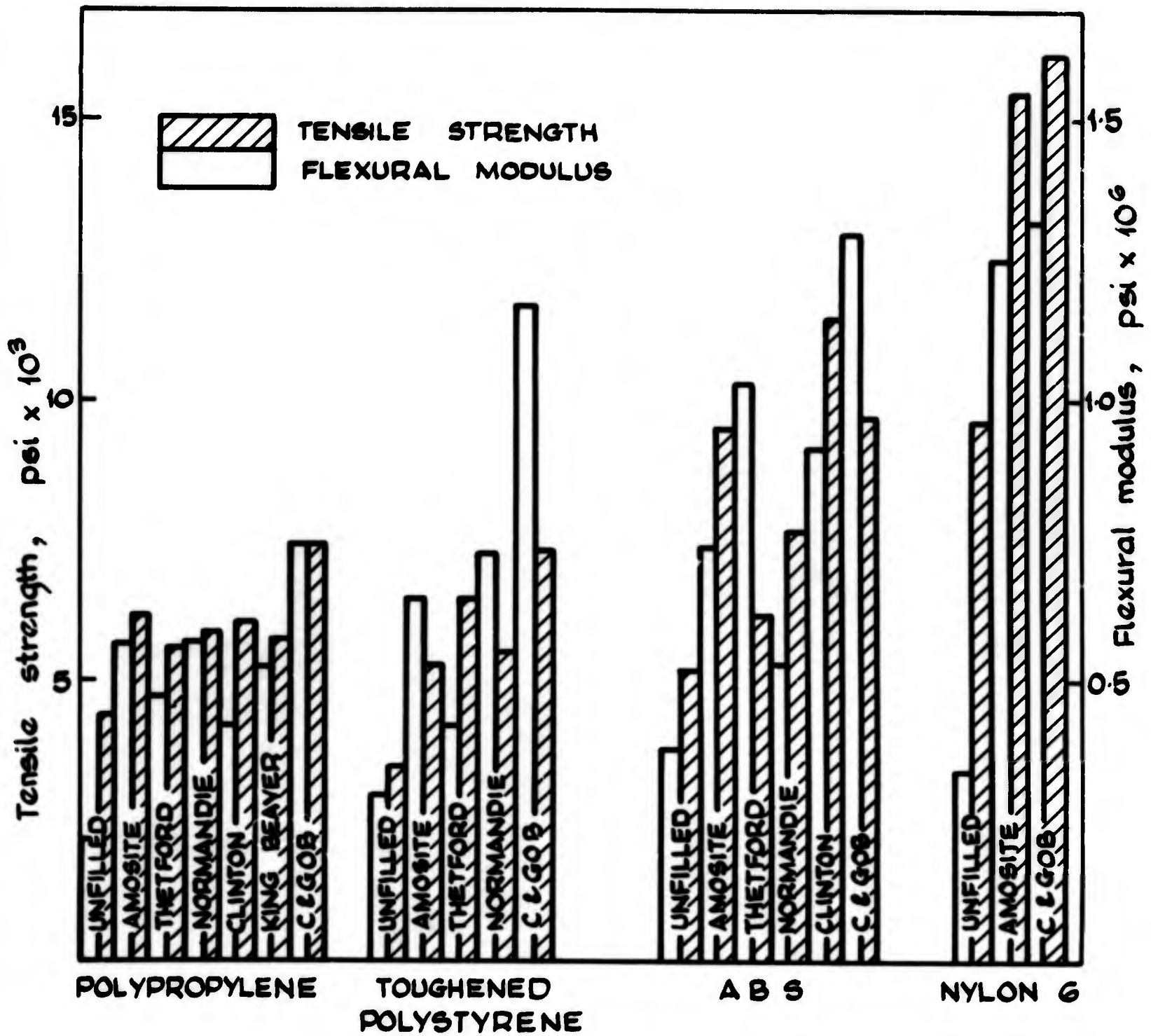


FIG. 4 TENSILE STRENGTHS AND FLEXURAL MODULI OF POLYPROPYLENE, TOUGHENED POLYSTYRENE, ABS AND NYLON 6 WITH DIFFERENT ASBESTOS (28% LOADING).

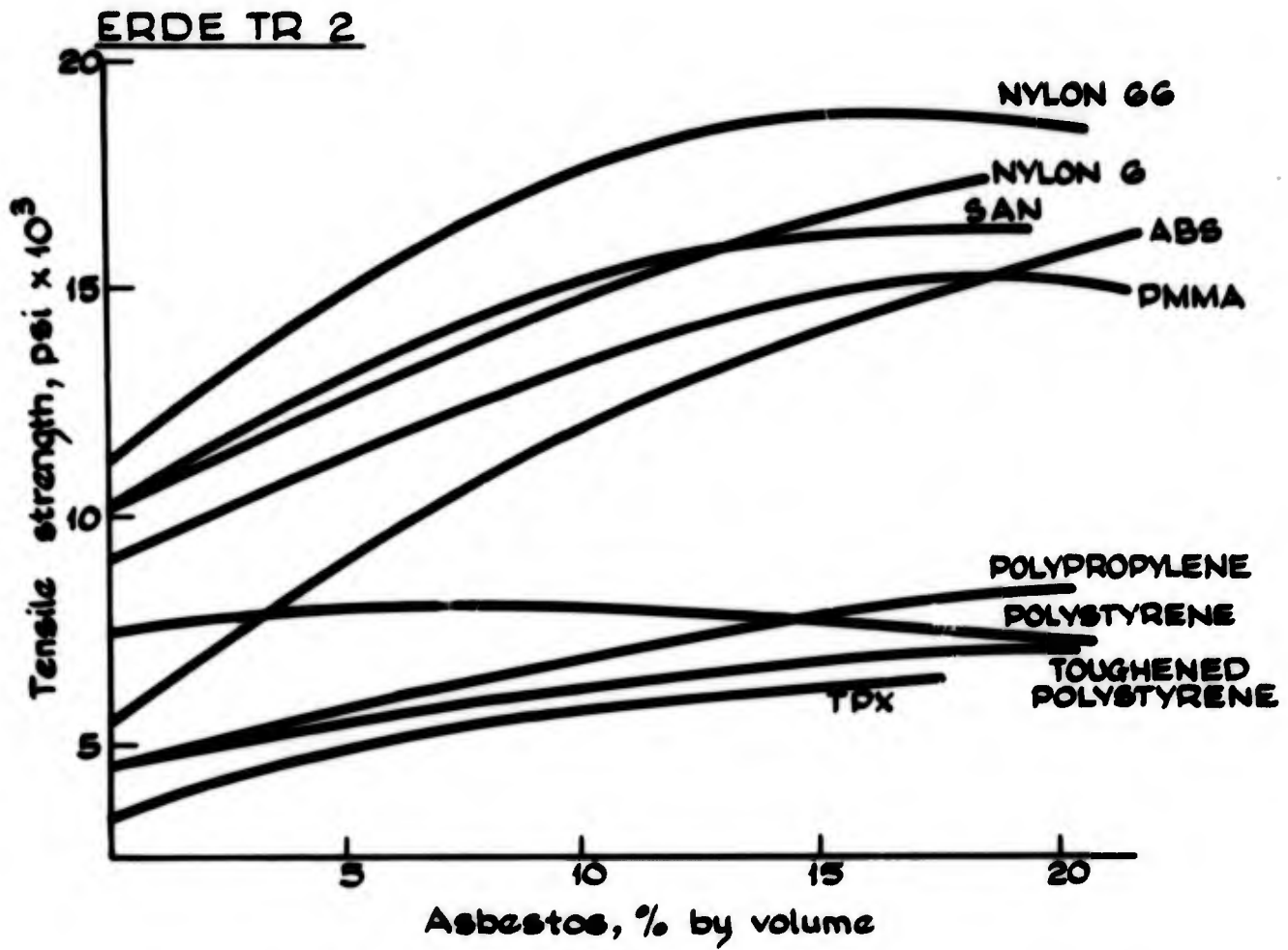


FIG. 5

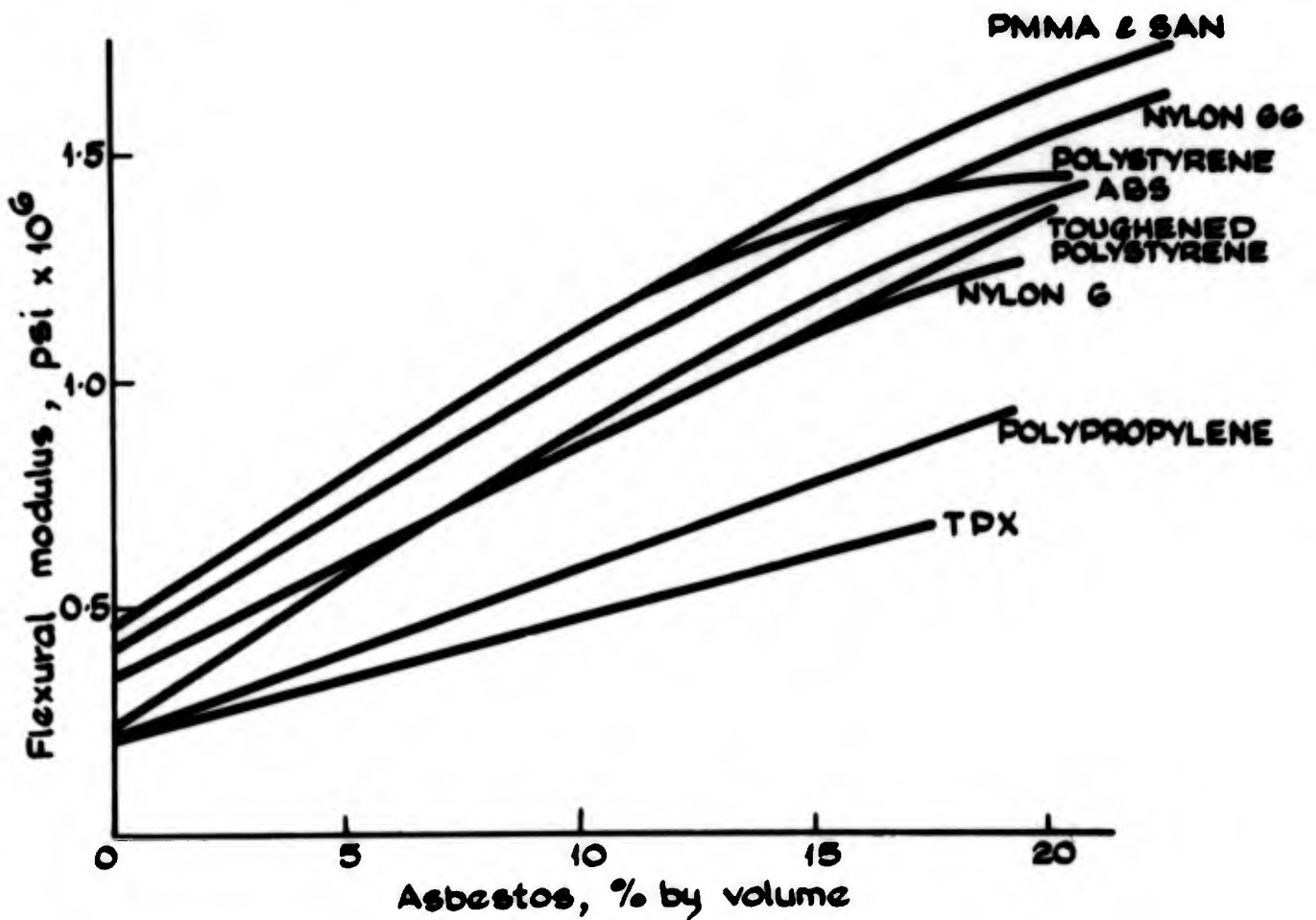


FIG. 6

**REINFORCEMENT OF THERMOPLASTICS WITH
C & GOB ASBESTOS.**