RESEARCH REPORT NO. 39

DEVELOPMENT OF NEW BUILDING AND PIPE MATERIALS FROM COALINGA FIBER

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ABSTRACT

As a result of a program to develop new products for the building industry, high strength materials have been produced by reacting Coalinga asbestos with phosphoric acid and with phenolic resin. Pipe and sheet are formed easily by extrusion and calender rolling at room temperatures. The process combines a low ingredient cost and a low fabrication cost making the resultant materials attractive as competitors to commercial cement-asbestos products.

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SUMMARY

This report covers the initial phase of a development program to find new uses for Coalinga Fiber in the building materials industry. Several products comprising sheet and pipe have given encouraging results and appear to have considerable market potential in competition with cement-asbestos products.

These new products offer a low basic raw material cost combined with a low-cost fabrication technique which is unique in the industry. The significant product and process advances are as follows:

1. The reaction mixture of Coalinga fiber and phosphoric acid (P-38) has been found to be a soft putty-like inorganic plastic which yields itself to forming by extrusion into pipe and sheet. The unit flexural strength of this material after curing is higher than that of similar cement-asbestos products.

2. The P-38 is compatible with and may be combined with other materials such as water soluble resins, resin latices, and inorganic fibers which lend flexibility and toughness to the finished material.

3. Coalinga fiber has been found to combine with water-soluble phenolic resin to form a strong and tough material. This product offers chemical and water resistant features which make it desirable for pipe and duct uses. It is produced from a water-wet mix of phenolic resin and asbestos that forms readily into sheet and pipe by cold extrusion.

4. Manufacturing processes now proposed are as follows:

   a. Sheet: Extrusion of the wet mix into slab form followed by rolling to obtain final sheet dimensions. Tests indicate that modular wall panels (e.g. 4' x 8') might be produced by laminating rolled sheets and re-rolling to form a large sheet.

   b. Pipe: The wet mixes (both P-38 and the phenolic resin-asbestos) may be directly extruded into pipe to any desired length.

   c. Curing: Both sheet and pipe products require a 150°C temperature for curing to develop maximum strength.

5. The extrudability and moldability both of the P-38 and the phenolic asbestos mixes are due to the unique physical characteristics of Coalinga fiber.

Canadian asbestos does not lend itself to these operations without the inclusion of a water-retaining organic compound such as hydroxy-ethyl cellulose or gum tragacanth.

6. The current market for the uses under consideration is estimated as follows:

Cement-Asbestos Shingles	460,000,000 sq.ft/yr.
Cement-Asbestos Siding and Wallboard	106,000,000 sq.ft/yr.
Cement-Asbestos Pipe, Conduit and Ducts	327,210 tons/yr.

(These figures are taken from Manufacturers-Industry Statistics for 1958).

Small sample sheet and pipe have been produced and are being tested for strength and resistance to environmental factors in our Laboratory and at MIT. Since the results are encouraging, it is recommended that consideration be given to the construction of a semi-commercial pilot plant for production of pipe and sheet products. These materials could then be offered for test usage throughout the country to permit evaluation of the product and the development of a suitable market.

INTRODUCTION

The Union Carbide Nuclear Company's asbestos deposit in Coalinga, California will produce a fiber that is of uniform grade corresponding to the approximate range of No. 7 size (short) Canadian chrysotile asbestos. In uses where grade 7 asbestos finds acceptance, such as the floor tile industry Coalinga fiber was successfully demonstrated as a replacement during the initial development program (last three quarters of 1960). Development effort was then directed toward finding other applications and new asbestos-based products for the building materials industry.

In the course of the 1961 program it was found that Coalinga fiber was a chemically active material which combined readily with acids (e.g. phosphoric) and with some organic resins (e.g. water-soluble phenolics). These reaction products exhibited sufficient plasticity to permit forming by extrusion and molding techniques. This property was found to be unique for Coalinga asbestos and offered a means of low-cost fabrication of sheet and pipe products. The strength of the optimum compositions of these materials was found to be above that of commercial cement-asbestos products.

DISCUSSION

I. Properties of Coalinga Fiber

Coalinga fiber belongs to the chrysotile family of asbestos minerals. It is of uniform short length with a fiber diameter of 20-30 millimicrons and an L/D ratio of roughly 100/1.

Its chemical formula may be expressed as:

$$Mg_6 (OH)_8 \cdot Si_4 O_{10}$$

It reacts as a base having a pH of 9-10 in water. This indicates the presence of labile hydroxyl groups.

Thermal decomposition occurs at approximately 600°C with the loss of water. The crystalline structure is destroyed and the fiber loses it fiber geometry.

The physical properties of Coalinga fiber are compared with a Canadian chrysotile in Table I.

It is the difference in the physical structure of the materials that gives Coalinga fiber its unique properties.

Reacted with phosphoric acid, Coalinga fiber forms a soft putty-like plastic substance (Code designation is P-38) which responds well to extrusion and molding operations. It dries to a strong, concrete-like material. The nature of the reaction was first observed when the chemicals were mixed to prepare a fertilizer. The same reaction product prepared from Canadian asbestos was found to have limited extrudability and moldability. The mixture tends to ooze water as the extrusion pressure is increased and it becomes more resistant to flow. Figure I illustrates this behavior. It is seen that the extrusion rates of the two types of Canadian asbestos were not constant. Thus, a product of non-uniform density and quality is made. The P-38 made from Coalinga fiber extruded at a constant rate and pressure and yielded a uniform product.

Further investigation of the phosphoric acid-Coalinga fiber reaction product (P-38) proved it could be easily extruded and compression molded into various shapes, such as pipe, sheet, rods, and filaments. These shapes maintained their integrity upon curing (maximum temperature 150°C is required). Sheets formed by extrusion were then found to be amenable to calender rolling to any desired thickness. These forming techniques offered a low-cost fabrication process which combined with low-cost ingredients made P-38 look attractive as a competitive building material to commercial cement-asbestos products.

II. Process and Processing Conditions

The following procedure was established for the preparation

(see Flowsheet on page 9a)

TABLE I

PHYSICAL PROPERTIES OF COALINGA FIBER AND CANADIAN CHRYSOTILE

Material	Specific Surface sq. meters/gm.	Water Retention gms/20 gms fiber	Oil Adsorption, gms/10 gms fiber
Coalinga fiber	48 - 58	42	8
Canadian 7-R	17 - 20	32 - 34	4 - 5

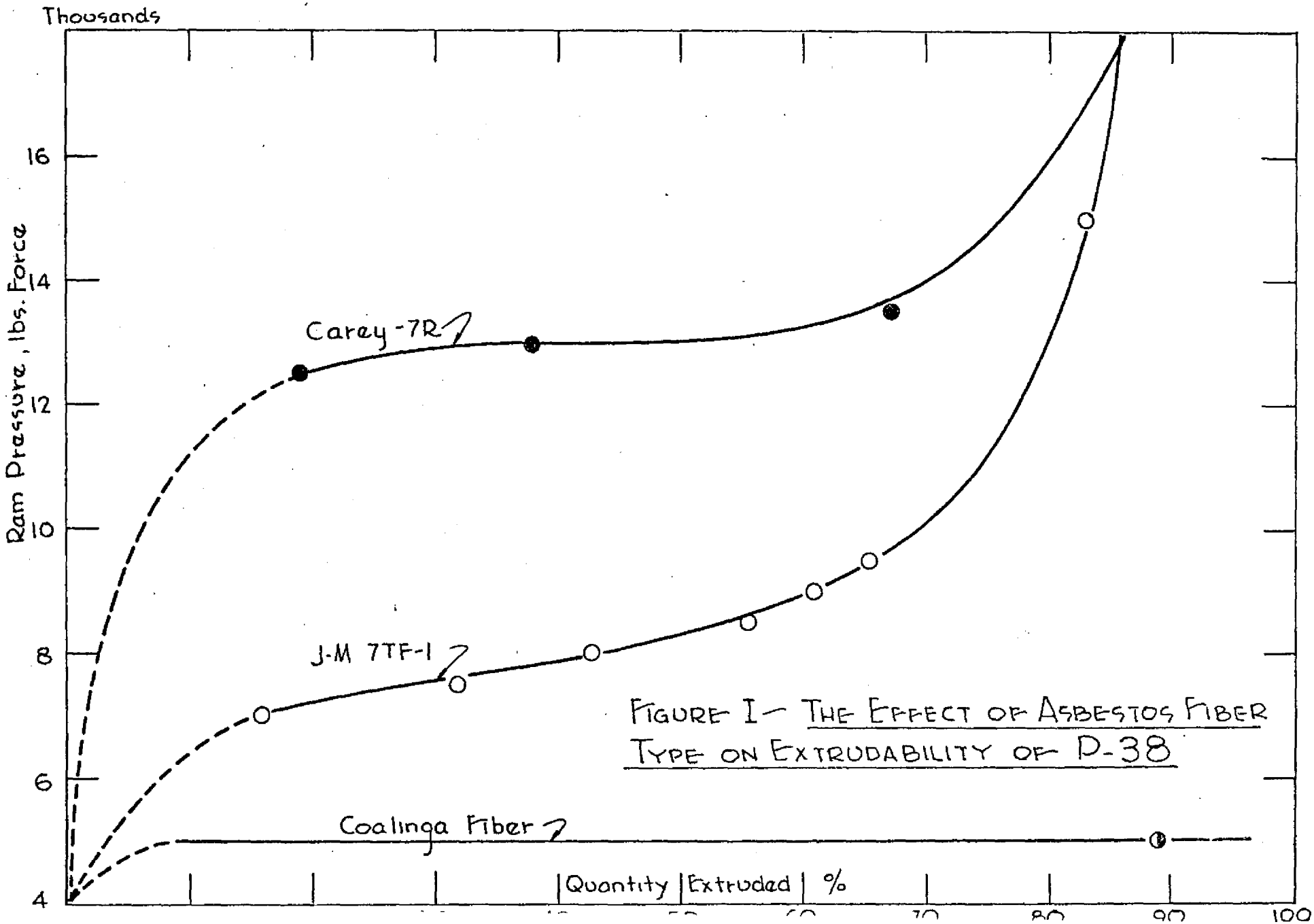


FIGURE I — THE EFFECT OF ASBESTOS FIBER TYPE ON EXTRUDABILITY OF D-38

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of Coalinga fiber-phosphoric acid (P-38) mixes and consolidation into sheet.

A. Mixing: A P-38 mix is prepared by reacting asbestos fiber with phosphoric acid with enough water to insure thorough wetting.

The fiber is charged to a Simpson Mix-Muller (24-inch diameter unit with a capacity of 3/4 cubic foot) and a known amount of water-acid mixture is added slowly while blending. There is a considerable evolution of heat as the reaction proceeds which should be controlled to a maximum mix temperature of 40°C to prevent the loss of water. The normal reaction cycle is fifteen minutes.

When the reaction is complete, as evidenced by cooling, other ingredients may be added to the mix such as glass fibers, asbestos fibers, water-soluble resins, and organic latices. These materials serve to modify the physical properties of the P-38 and therefore must be compatible and homogeneously distributed by further mixing.

B. Extrusion

1. Continuous Auger Extrusion

Initial sheet extrusions were done with a continuous auger extruder. The prepared P-38 mix was charged to a hopper and screw extruded through a 3-inch x 1/4-inch slit die.

The low discharge pressure developed by the auger extruder restricted the use to those mixes that had a limited viscosity range. Continuous extrusion is preferable and a properly designed extruder for P-38 mixes is being investigated.

2. Batch Ram Extrusion

The P-38 mix is loaded into the extruder barrel. The ram is moved forward to seal the end of the loaded barrel. The barrel is then evacuated (-28 in. Hg) for five minutes. The P-38 is extruded at a constant rate (9 ft/min) under a variable pressure. Normal pressure is about 1000 psi. The extruded material is re-cycled a minimum of three

times to develop higher green strength and to improve the uniformity of the extruded shape.

Since the ram extruder develops pressures as high as 6,250 psi at the die, the P-38 mix compositions could be altered to cover a wide range of variables without encountering extrusion difficulties. Limitations are those typical of any batch process, although it appears possible to interrupt the extrusion for reloading of the barrel without seriously damaging the extruded piece. Batch capacity is approximately 5 kgs. of mix.

C. Calendering

The extruded sheet (3-inches wide x 1/4-inch thick) is cut into 12-inch lengths and each section is calender-rolled transverse to the extrusion direction to the desired thickness (0.150-inch). Size reduction is made in two passes (.050-inch each) of the sheet at each roll setting.

To prevent adherence to the rolls it is necessary to sandwich the panels between wax paper sheets. Highly polished rolls or rolls coated with a release agent such as teflon might eliminate this problem.

P-38 responds well to size reduction by calendering; some .050-inch thick sheets have been made from panels as thick as .250-inch. By a process of laminating calandered sheets, large panels can be fabricated. This method is being further investigated as a means of producing modular wall panels from minimum width extruded sheets.

D. Curing

The calendered panels must be supported during the curing cycle to prevent warpage. Presently, they are sandwiched between expanded metal sheets in a vertical position. This allows uniform drying on both sides.

The curing cycle for standard P-38 is 24 hours at room temperature (25° C) followed by four hours at 150° C. For P-38 mixes containing heat-sensitive organic additives such as polyvinyl acetate, phenolic resins, etc., the maximum oven temperature must be lowered or the time exposure reduced. The oven cure has not been optimized for

several of these additives. A room temperature cure, however, for up to 24 hours appears necessary for mixes involving the asbestos-phosphoric acid reaction.

III. Properties and Applications in Building Materials

A. P-38 Test Program

In order to evaluate P-38 for use in the building materials industry, an evaluation program was inaugurated in conjunction with Professor A. Dietz of the Building Materials Department at the Massachusetts Institute of Technology. Initial testing was limited to the determination of flexural strength and elasticity since these two values provide a measurement of the toughness of the material. Comparative test data were established on standard commercially available cement-asbestos boards, specifically Johns-Manville Flexboard and Asbestocite.

Test panels (6-inch x 12-inch x 1/8-inch) were fabricated at the Tuxedo Laboratory by extruding a 3-inch x 12-inch x 1/4-inch strip and calender-rolling to size. Ten test specimens were cut from each sheet (five in each direction - transverse and parallel to the original extrusion direction). These samples were then tested in flexure and the strength and the elastic modulus were determined in psi referenced to the cross sectional area of the samples. Similar tests were later carried out at the Tuxedo Laboratory to expedite results.

A summary of the compositions of all P-38 panels tested to date are presented in Table II. Flexural strength test results are given in Table III and graphically illustrated in Figure II.

The P-38 compositions which have exhibited flexural strengths equal to or higher than that of cement-asbestos board are listed in Table IV.

These four compositions have average flexural strengths 20-35% higher than that of standard J-M Flexboard. In the case of mix TL-250-02 containing phenolic resin the high strength is accompanied by a low elastic modulus indicating flexibility equivalent to that of Flexboard.

B. Variables Affecting Physical Properties

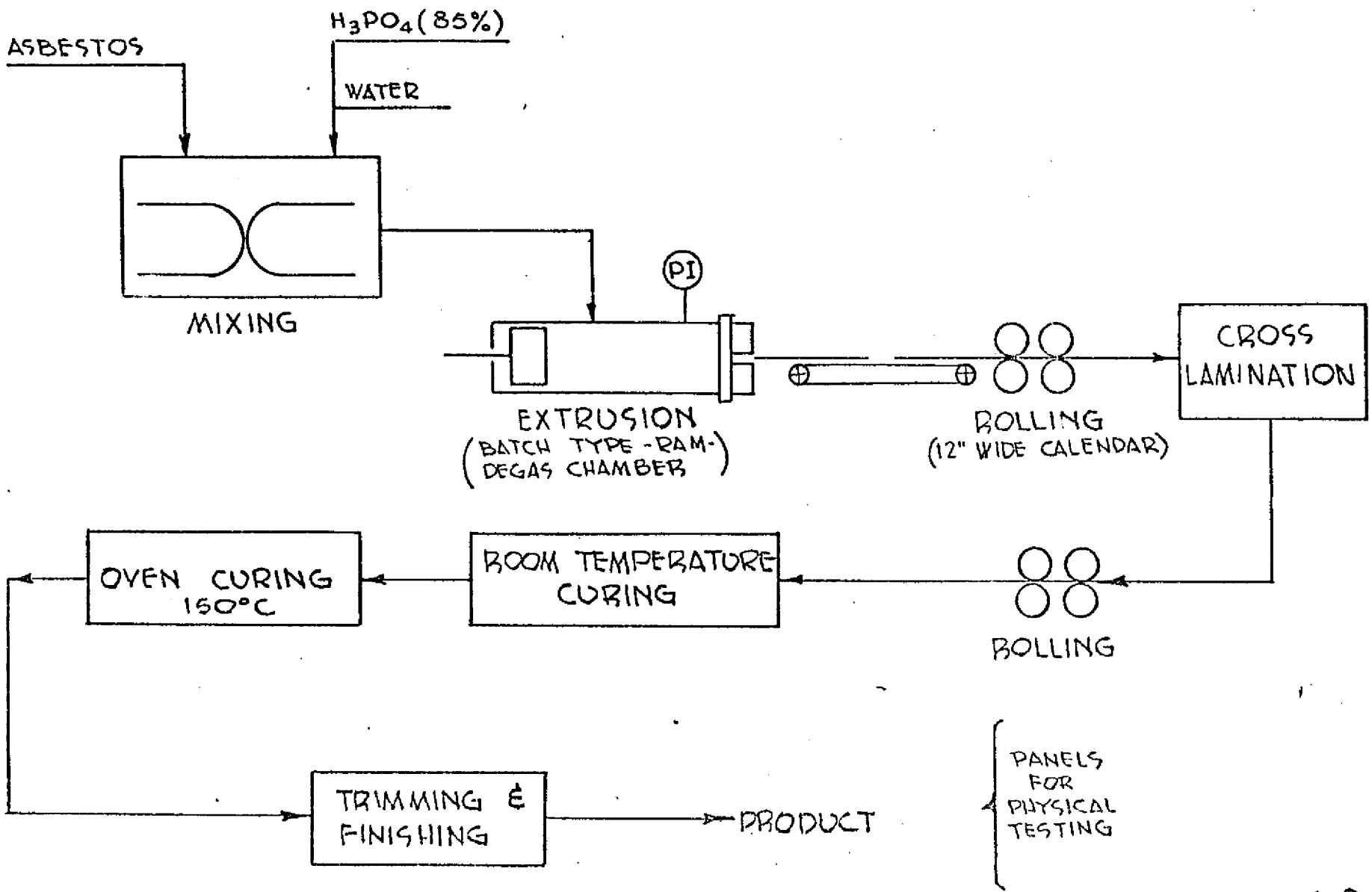
On the basis of test results to date, it is possible to delineate those factors which affect flexural strength and elastic modulus of the P-38.

Those factors significant in obtaining increased flexural strength are:

1. Acid-Fiber Ratio and Acid Concentration

If we assume in the standard chrysotile

P-38 BUILDING MATERIALS FLOW SHEET



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TABLE II - TABULATION OF P-38 PANEL EXPERIMENTS

Exp't No.	Batch No.	Sample No.	Type UCNC Fiber	UCNC Fiber (parts)	85% H_3PO_4 (parts)	Total Water (parts)	Type Fill	Fill (parts)	% Fill UCNC Fiber Basis
TL-001	01	01-05	Opened Whole Ore	80	20	35	0	0	0
TL-001	02	01-04	" " "	80	20	35	0	0	0
TL-001	03	01-04	" " "	80	20	35	0	0	0
TL-002	01	01-05	" " "	80	20	35	Quebec 6D-20	10	12.5
TL-002	02	01-06	" " "	80	20	35	" "	10	12.5
TL-002	03	01-06	" " "	80	20	35	" "	10	12.5
TL-003	01	01-04	" " "	80	20	32.2	Polyethylene latex	5	6.25
TL-301	01	01-04	" " "	85	15	32.2	" "	5	5.89
TL-320	01	01-04	" " "	80	20	33.6	Polyvinyl acetate latex	5	6.25
TL-321	01	01-04	" " "	85	15	33.6	" " "	5	5.89
TL-322	01	01-03	" " "	70	15	20)	Polyvinyl acetate and	12	21.4
TL-323	01	01-05	" " "	80	20	30)	Plasticizer	8	10.0
TL-340	01	01-04	" " "	80	20	30	Phenolic BRL-1100	5	6.25
TL-341	01	01-04	" " "	85	15	30	" "	5	5.89
TL-342	01	01-03	" " "	80	20	34.6	Phenolic BKSA 4615	5	6.25
TL-100	01	01-04	2 LB-1L1	80	20	35	0	0	0
TL-100	02	01-04	" "	80	20	35	0	0	0
TL-100	03	01-04	" "	80	20	35	0	0	0
TL-110	02	01-03	2 LB-1L1 Armstrong No. 1	70	30	30	0	0	0
TL-110	03	01-06	"	70	30	35	0	0	0
TL-110	04[1]	01-05	"	70	30	20	0	0	0
TL-110	06[1]	01-07	"	70	30	30	0	0	0
TL-110	07[1]	01-07	"	70	30	25	0	0	0
TL-110	08[1]	01-08	"	70	30	25	0	0	0
TL-115	01[1]	01-11	"	70	30	30	Fiberglass 1/4-inch	3	4.3
TL-115	02[1]	01-08	"	70	30	30	Fiberglass 1-inch	2	2.85
TL-120	01	01-04	"	75	25	35	0	0	0
TL-125	01	01-05	"	75	25	35	Fiberglass	3	4.0
TL-126	01	01-05	"	75	25	35	Fiberglass	1	1.33
TL-140	01	01-05	"	75	25	35	Quebec 5K-04	3	4.0
TL-140	02	01-05	"	75	25	35	" "	5	6.7
TL-150	01	01-04	"	75	25	35	Chopped SS Fiber	2	2.7
TL-160	01	01-04	"	75	25	35	Ground P-38 Recycle	10	14.0
TL-170	01[1]	01-07	"	65	35	20	0	0	0

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TABLE II - TABULATION OF P-38 PANEL EXPERIMENTS (Continued)

Exp't No.	Batch No.	Sample No.	Type UCNC Fiber	UCNC Fiber (parts)	85% H_3PO_4 (parts)	Total Water (parts)	Type Fill	Fill (parts)	% Fill UCNC Fiber Basis
TL-200	02	01-05	Armstrong No. 1 2 LB-1L1	80	20	42.2	Polyethylene latex	5	6.25
TL-205	01	01-06	"	75	25	42	" "	5	6.7
TL-210	02	01-09	"	70	30	27.5	" "	5	7.15
TL-220	01	01-06	"	80	20	38.6	Polyvinyl acetate latex	5	6.25
TL-225	01_2	01-04	"	75	25	38.6	" " "	5	6.7
TL-226	01^2	01-05	"	75	25	38.6	Polyvinyl acetate	5	1.3
							fiberglass	1	
TL-226	02^3	01-05	"	75	25	38.6	Polyvinyl acetate	5	6.7
							Plasticizer	1/2	0.67
							Fiberglass	1	1.3
TL-230	03^1	01-07	"	70	30	28.6	Polyvinyl acetate	5	7.15
TL-240	02	01-03	"	80	20	37.7	Phenolic BRL-1100	5	6.25
TL-245	02_4	01-05	"	75	25	37.7	" "	5	6.7
TL-246	01^4	01-05	"	75	25	37.7	" "	5	6.7
TL-250	01_1	01-02	"	70	30	36.8	" "	3.25	4.6
TL-250	02_1	01-07	"	70	30	28	" "	5	7.15
TL-251	01^1	01-11	"	70	30	25	" "	15	21.5
						)	Phenolic BRL-1100	5	7.15
TL-255	01	01-09	"	70	30	28)	Fiberglass 1-inch	2	2.85
TL-260	01	01-05	"	75	25	35	Crushed Solid Phenolic BRR-5239	5	6.7
TL-400	01_1	01-04	Dispersed Fiber	80	20	35	0	0	0
TL-410	01^1	01-02	" "	70	30	30	0	0	0
TL-500	01	01-04	L-1 Coarse 4-0, 4-4	80	20	35	0	0	0
TL-505	01^1	01-07	L-1 (4-0, 4-4)	70	30	25	0	0	0
TL-510	01	01-03	L-1 Fully Opened 046-1P	80	20	35	0	0	0
TL-511	01	01-04	L-1 Fully Opened 046-1P	75	25	35	0	0	0

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TABLE II - TABULATION OF P-38 PANEL EXPERIMENTS (Continued)

Exp't No.	Batch No.	Sample No.	Type UCNC Fiber	UCNC Fiber (parts)	85% H_3PO_4 (parts)	Total Water (parts)	Type Fill	Fill (parts)	% Fill UCNC Fiber Basis
TL-512	01	01-04	L-1 Coarse Opened 4-0, 4-4	60	20	35	0	0	0
			Tails	20					
TL-513	01	01-04	L-1 (046-1P)	60	20	35	0	0	0
			Tails	20					
TL-515	01	01-05	L-1 (4-0, 4-4)	65	25	35	0	0	0
			P-38 (ground)	10					
TL-520	01	01-04	Jig Flakes APP-8	80	20	35	0	0	0
TL-540	01	01-04	1L1-3LB	75	25	35	0	0	0
TL-580	01	01-04	Armstrong No. 1	37.5	25	35	0	0	0
			Tails	37.5					
TL-585	01	01-04	2 LB-1L1	25	25	35	0	0	0
			Tails	50					
TL-600	01	01-06	Armstrong No. 1	75	25	35	Quebec No. 5K-04	5	6.7
							Polyvinyl acetate	5	6.7
TL-610	01	01-06	Armstrong No. 1	70	30	35	Quebec No. 5K-04	5	7.0
			Whole Ore (0468)	10			Fiberglass	1	1.4
							Polyvinyl acetate	3	4.3
							Plasticizer	.25	0.35
TL-800	02[1]	01-10	Armstrong No. 1	70	30	32	Polyox (A-3250)	1	1.4
							Phenolic (BRL-1100)	4	5.7
TL-850	01[1]	01-07	2 LB-1L1 Armstrong No. 1	70	15	22.5	Phenolic BRL-1100	10	14.2
TL-851	01[1]	01-06	"	75	15	25	Phenolic BRL-1100	10	12.5

[1] Extruded with hydraulic ram.

[2] Cured 24 hrs. at Room Temperature-4 hrs. at 110°C-1 hr. at 150° C.

[3] No Room Temperature Cure-4 hrs. at 110°C-3 hrs. at 150° C.

[4] No Room Temperature Cure-4 hrs. at 110°C 3 hrs. at 150° C.

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TABLE III - AVERAGE PHYSICAL TEST DATA - P-38 PANELS

Exp't No. and Batch No.	MIT TEST RESULTS				TUXEDO LABORATORY TEST RESULTS			
	Flexural Strength psi x 10^3		Elastic Modulus psi x 10^6		Flexural Strength psi x 10^3		Elastic Modulus psi x 10^6	
	Parallel	Transverse	Parallel	Transverse	Parallel	Transverse	Parallel	Transverse
TL-001-01	5.69	5.53	2.94	2.73				
TL-001-02	5.07	4.97	2.83	2.48				
TL-001-03	5.26	5.21	2.91	2.57				
TL-002-01	4.46	4.29	2.91	2.42				
TL-002-02	4.32	3.93	2.83	2.49				
TL-002-03	4.50	4.42	2.82	2.58				
TL-300-01	6.44	6.51	2.59	2.27				
TL-301-01	3.22	3.32	2.05	1.72				
TL-320-01	6.82	6.80	3.16	2.71				
TL-321-01	3.25	3.14	2.03	1.74				
TL-322-01	3.48	2.63	1.21	1.21				
TL-323-01	2.73	2.77	1.52	1.36				
TL-340-01	7.01	7.37	3.05	2.57				
TL-341-01	4.15	3.82	2.33	1.80				
TL-342-01	3.0							
TL-100-01	3.64	2.84	2.05	1.58				
TL-100-02	4.35	3.89	2.28	1.90				
TL-100-03	4.19	3.77	2.35	1.86				
TL-110-02	7.73	7.38	3.52	3.25				
TL-110-03	7.22	6.44	3.59	3.01	6.95	6.32	3.72	2.29
TL-110-04	Panel	Cracked						
TL-110-06	7.94	6.32	3.61	3.00	7.29	5.31	3.17	2.71
TL-110-07	9.42	7.26	3.87	3.23	8.84	6.05	3.75	2.92
TL-110-08					8.68	6.26	3.83	3.03
TL-115-01					7.29	5.98	3.08	2.02
TL-115-02					7.82	5.41	3.37	2.62
TL-120-01	5.36	5.19	3.13	2.70				
TL-125-01	5.92	5.38	2.84	2.51				
TL-126-01	5.03	4.71	2.73	2.34				
TL-140-01	6.16	6.03	3.12	2.91	6.13	5.85	2.91	2.55
TL-140-02	5.67	5.47	3.23	2.95	5.22	4.73	2.93	2.63
TL-150-01	6.53	5.91	3.43	3.00				
TL-160-01					4.43	4.25	2.42	2.10
TL-170-01					6.69	4.99	3.51	2.57

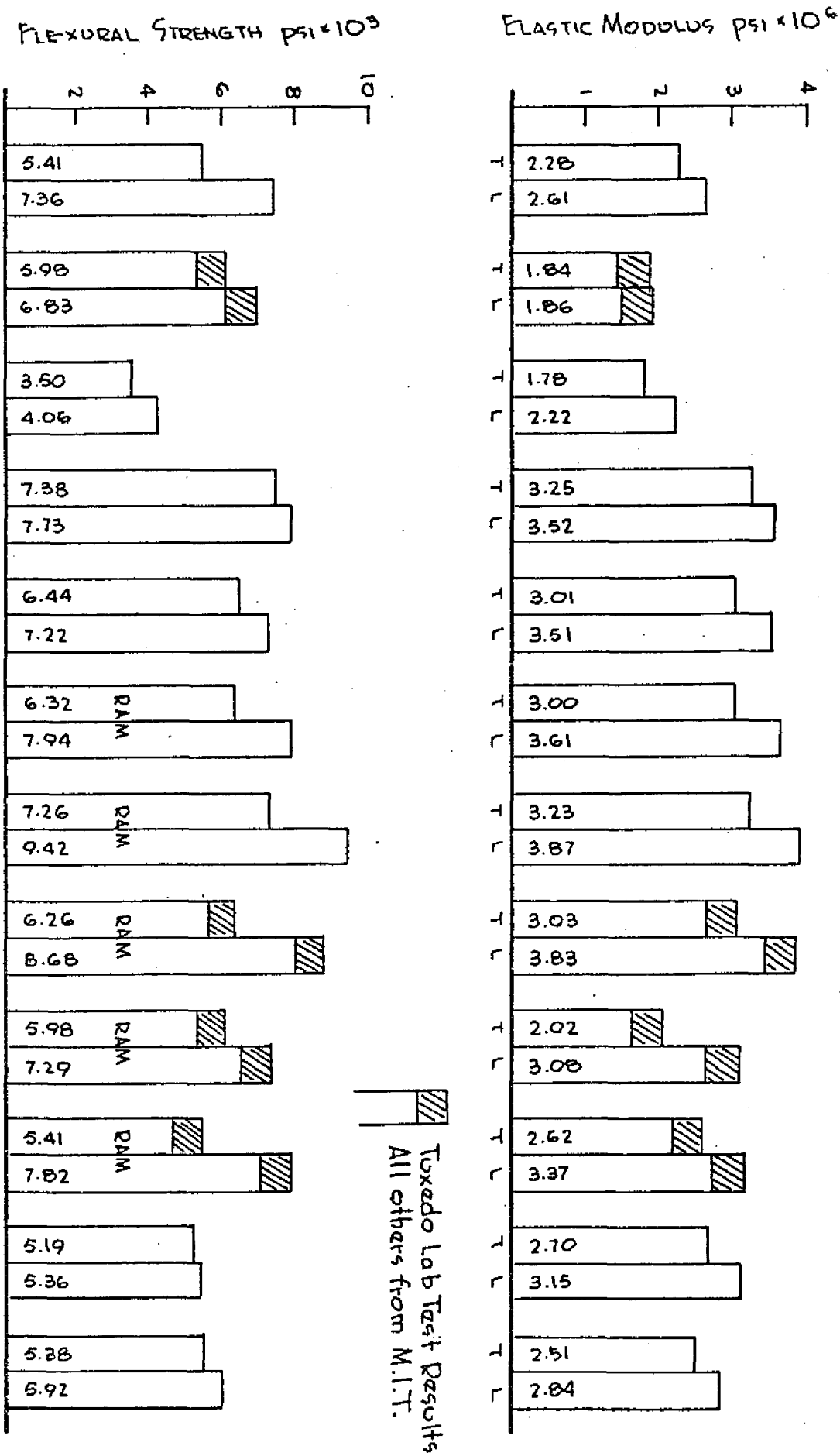
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TABLE III - AVERAGE PHYSICAL TEST DATA - P-38 PANELS
(Continued)

Exp't No. and Batch No.	MIT TEST RESULTS				TUXEDO LABORATORY TEST RESULTS			
	Flexural Strength psi x 10^3		Elastic Modulus psi x 10^6		Flexural Strength psi x 10^3		Elastic Modulus psi x 10^6	
	Parallel	Transverse	Parallel	Transverse	Parallel	Transverse	Parallel	Transverse
TL-200-02	3.49	3.39	2.09	1.87				
TL-205-01	4.12	3.57	2.24	1.81				
TL-210-02					6.79	5.07	3.10	2.26
TL-220-01	4.38	4.16	2.26	2.06				
TL-225-01	4.75	4.24	2.60	2.30				
TL-226-01					5.37	4.37	2.89	2.70
TL-226-02								
TL-227-01					5.40	4.88	2.77	2.48
TL-230-03	9.05	6.40	3.79	3.04	8.66	5.90	3.70	2.82
TL-240-02	3.18	2.27	1.55	1.28				
TL-245-02	5.06	4.20	1.94	1.67				
TL-246-01	3.33	3.26	1.94	1.72	2.99	2.98	1.50	1.43
TL-250-02					8.22	6.17	2.57	2.02
TL-251-01					6.57	4.83	1.85	1.29
TL-255-01					7.71	5.40	2.59	1.83
TL-260-01								
TL-400-01	4.95	4.58	2.55	2.28				
TL-500-01	4.08	4.15	2.13	1.85				
TL-505-01					9.92	7.28	3.49	2.72
TL-510-01	3.87	3.18	1.97	1.77				
TL-511-01	7.70	6.98	3.34	2.84	6.96	6.88	2.76	2.67
TL-512-01					5.02	4.54	2.18	1.98
TL-513-01								
TL-515-01	7.90	7.84	2.96	2.85				
TL-520-01	3.14	2.94	1.90	1.58				
TL-540-01					6.59	5.88	3.24	2.95
TL-580-01								
TL-585-01	2.38	2.82	1.64	0.96				
TL-600-01	5.06	4.62	2.77	2.38	4.93	4.55	2.73	2.46
TL-610-01					4.82	4.29	2.83	2.47
TL-800-02					7.44	4.98	3.16	2.54
TL-850-01					5.54	2.87	1.68	1.02
TL-851-01					4.42	3.30	2.12	1.44

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FIGURE II – FLEXURAL STRENGTH & ELASTIC MODULUS DATA



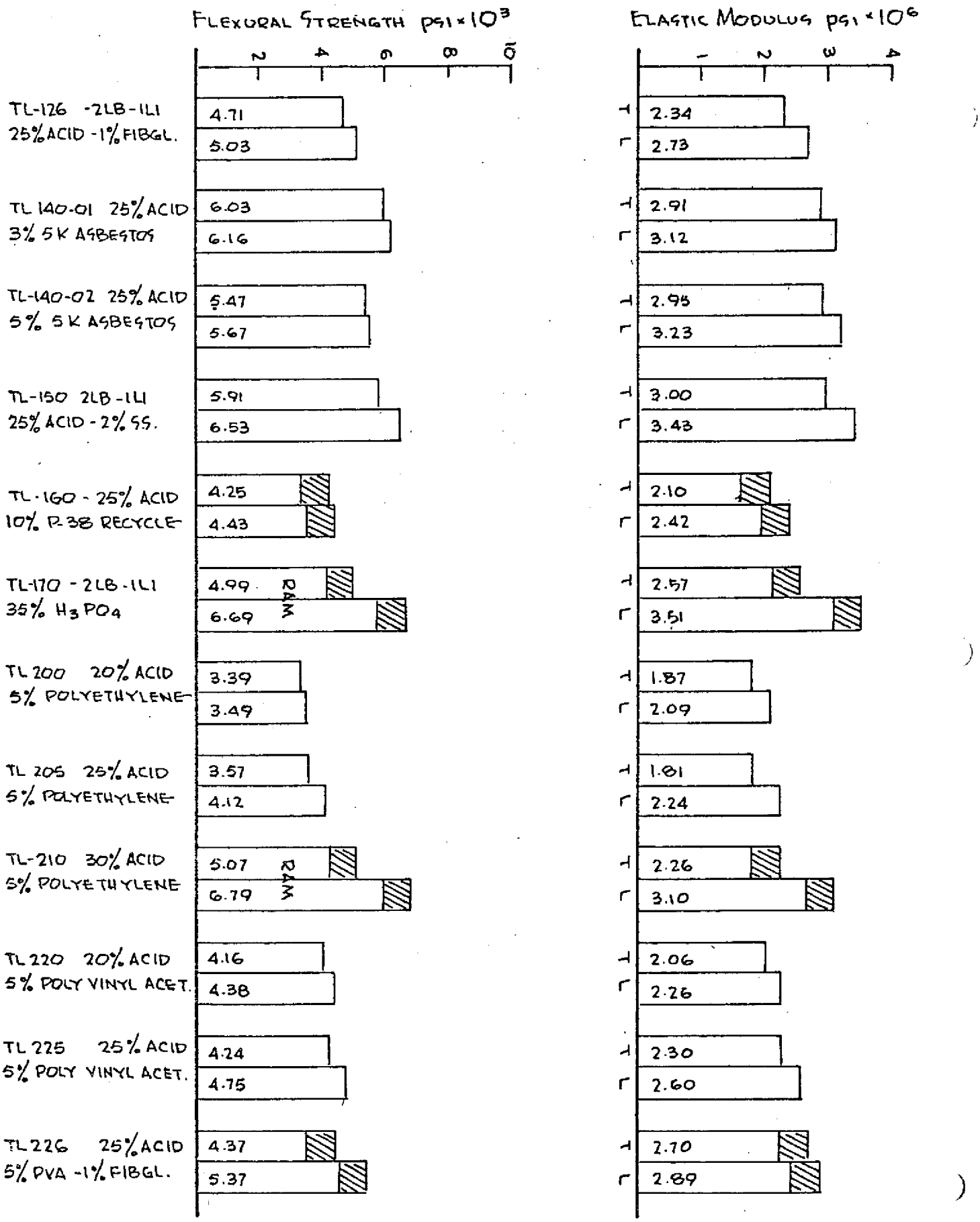


FIGURE II (CON'T)

2 OF 4

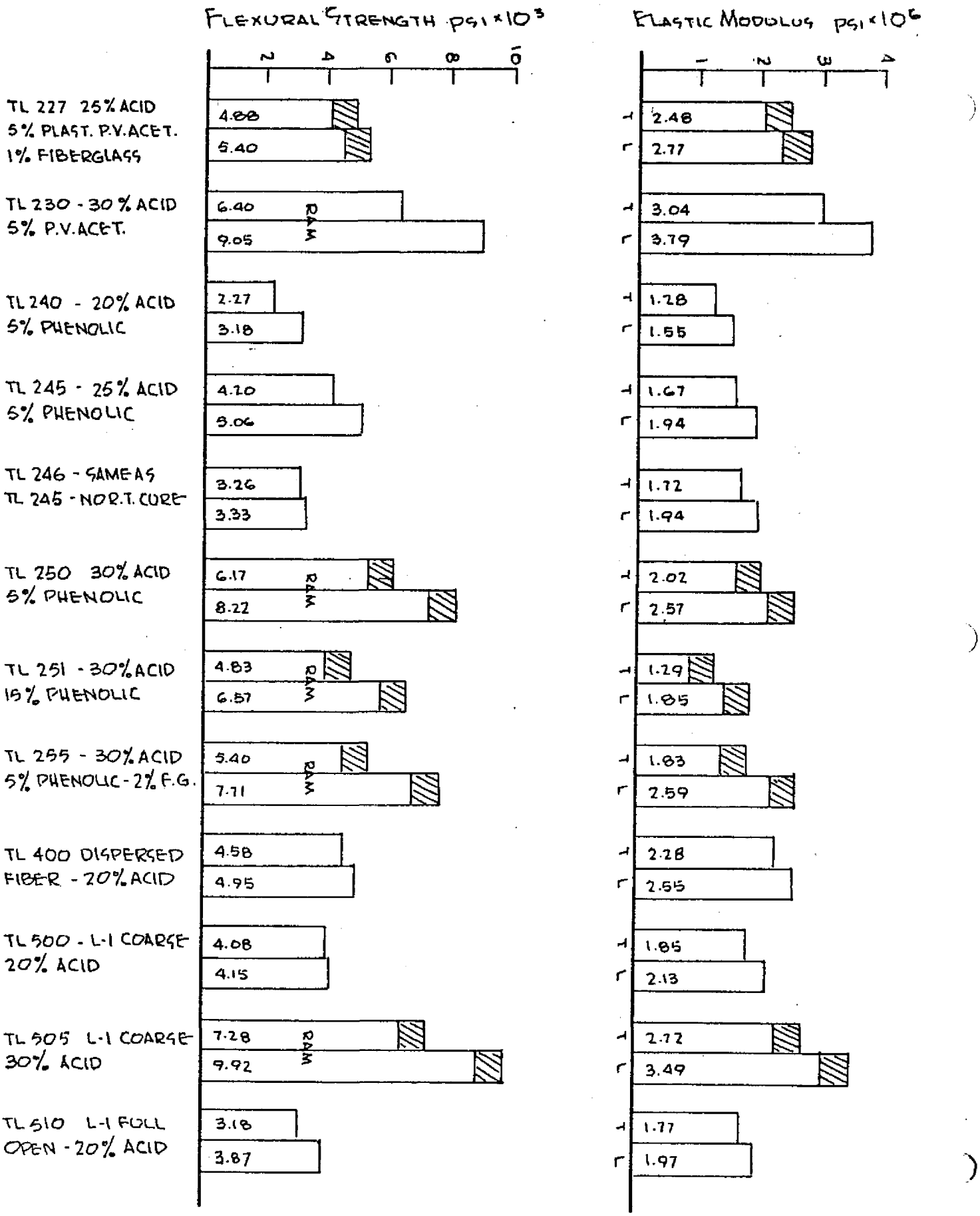


FIGURE II (CONT.)

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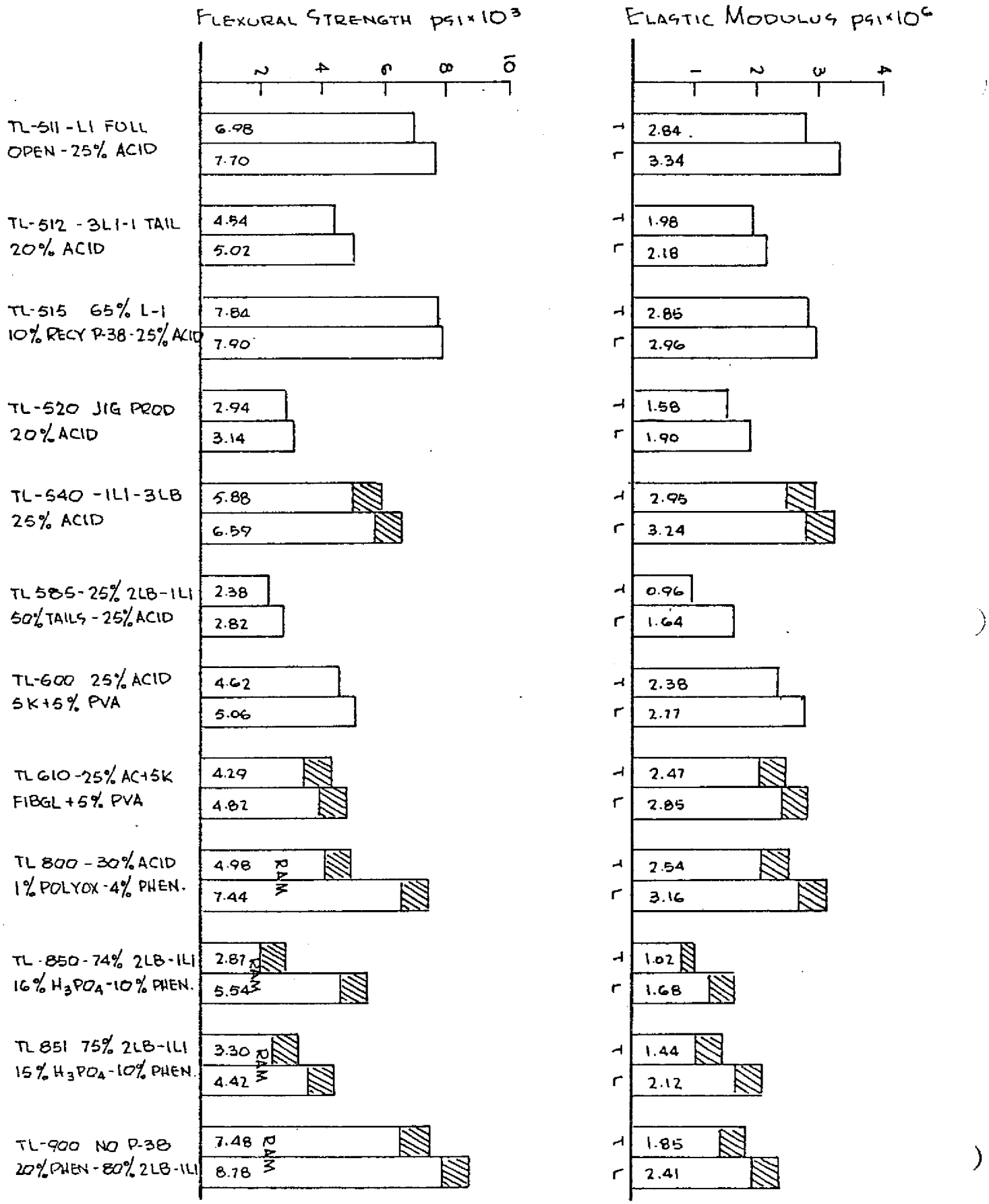


FIGURE II (CON'T.)

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TABLE IV

STRENGTH COMPARISONS OF P-38 AND FLEXBOARD

Material	Flexural Strength psi		Elastic Modulus psi x 10^6	
	Parallel	Transverse	Parallel	Transverse
J-M Flexboard	6832	5982	1.86	1.84
TL-110-07 70 parts fiber 30 parts H_3PO_4 (85%) 25 parts water	9400	7260	3.87	3.23
TL-230-03 70 parts fiber 30 parts H_3PO_4 (85%) 28.6 parts water 5 parts polyvinyl acetate	9050	6400	3.79	3.04
TL-250-02 70 parts fiber 30 parts H_3PO_4 (85%) 28 parts water 5 parts phenolic resin	8220	6210	2.57	2.02
TL-505-01 70 parts L-1 fiber 30 parts H_3PO_4 (85%) 25 parts water	9920	7280	3.49	2.72

formula, $Mg_6(OH)_8 \cdot Si_4O_{10}$, that all the hydroxyl groups are active, then the stoichiometric ratio for reaction with phosphoric acid is 2 parts chrysotile to 1 part H_3PO_4. If the strength of P-38 is derived from the replacement of available hydroxyl bonds with phosphate bonds, a relationship should exist between the ultimate strength of the material and the acid-fiber ratio. This relationship has been found and is illustrated in Figure III. The effect, however, depends not only on the fiber/acid ratio but also on the acid concentration (acid/water ratio). All three quantities are used to determine the overall acid content of the mix.

It is also apparent in Figure III that the maximum realizable strength has been approached in mix TL-110-07 at a fiber/acid ratio of 2.74/1. The difference between this ratio and the stoichiometric quantity is due to impurities in the fiber and will vary probably from grade to grade of fiber.

2. Type of Fiber

P-38 panels made from L-1 fiber fraction appear to have higher flexural strength than the standard 2 LB-1L1 mixture at equivalent acid concentration. The difference does not warrant exclusive use of the L-1 fraction only.

Other fiber grades such as 3 LB-1L1 and dispersed fibers have been processed and have yielded satisfactory strength.

3. Curing

For high strength a room temperature (25°C) cure up to 24 hours is essential. A subsequent oven cure for four hours at 150°C has been satisfactory for all straight P-38 compositions. For materials containing organic additives lower oven temperatur and shorter exposure times have been used. A room temperature cure has proven essential regardless of composition.

The factors most affecting elastic modulus are as follows:

a. Additives: Organic resins and inorganic fiber additives have had the most significant effect on the flexibility of the high strength P-38 -- primarily phenolics and to a lesser extent glass fibers and long fiber asbestos.

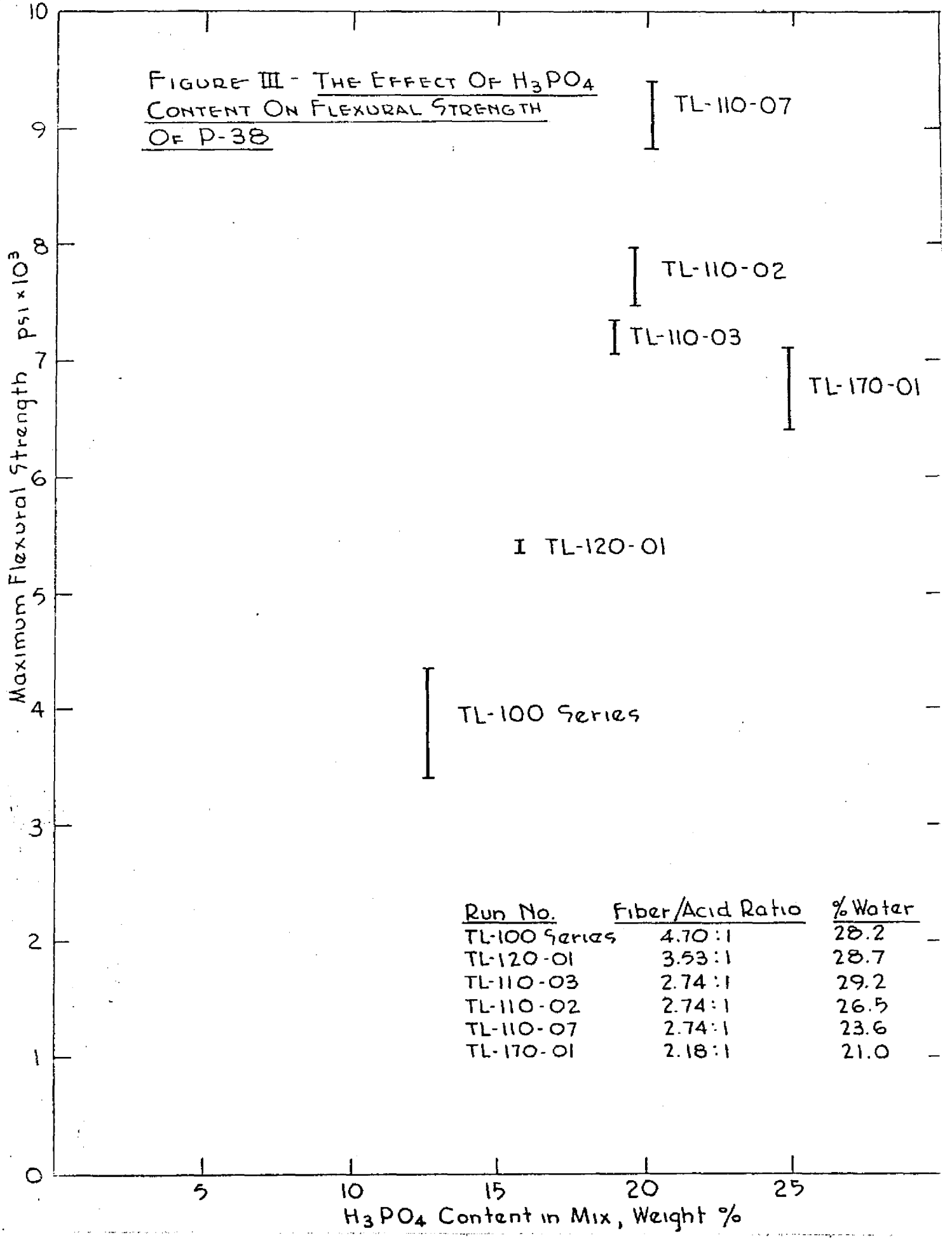


FIGURE III - THE EFFECT OF H_3PO_4 CONTENT ON FLEXURAL STRENGTH OF P-38

Run No.	Fiber/Acid Ratio	% Water
TL-100 Series	4.70 : 1	28.2
TL-120-01	3.53 : 1	28.7
TL-110-03	2.74 : 1	29.2
TL-110-02	2.74 : 1	26.5
TL-110-07	2.74 : 1	23.6
TL-170-01	2.18 : 1	21.0

Though optimum quantities of fill have not been determined, concentrations of phenolics at 5% and of glass fibers and long fiber asbestos at 3% have been most effective.

In the case of phenolics there is strong indication that bonding of the materials involves a chemical reaction between the acidic phenolic groups and any unreacted hydroxyl groups in the P-38. Where the phosphoric acid has incompletely reacted the asbestos, the phenolic-asbestos reaction may supply additional strength as well as flexibility to the final product. In compositions where the reaction between the phosphoric acid and asbestos is complete, or nearly complete, the inclusion of phenolic resin creates a second phase in the material that gives it more flexibility at a lower strength. It would appear that the amount of phenolic required to induce the desired flexibility in a high strength P-38 might be minimized by providing the proper proportion of phosphoric acid.

C. Cost and Market Data

It is believed that P-38 has considerable potential as a building material in applications where cement-asbestos board now finds use namely, shingles, exterior siding, and interior wall paneling. For these uses 77,000 tons (Manufacturers-Industry Statistics 1958) of asbestos were directed during calendar 1958. The proportion of this market that is ultimately attainable willdepend on the relative cost of P-38 products. The fabrication cost, if based on the proposed extrusion forming and rolling of sheet, should be reasonable. Higher strength may also permit use of thinner sheet than now required for cement-asbestos board.

On the contained asbestos basis in P-38 (67%) equivalent tonnage use figures for 1958 would be 260,000 tons of asbestos.

Material costs were considered during the development program and are outlined in Table V for the most attractive compositions.

IV. Pipe and Conduit

A. P-38

Commercial Transite (cement-asbestos) is also produced in pipe and conduit form for industrial water service, telephone cable, sewer and duct uses. For these applications 65,000 tons of asbestos was sold in 1958 (Manufacturers-Industry Statistics 1958). Due to inherent process limitations maximum Transite pipe lengths are 13-feet and grades such as telephone ducts are normally produced in 10-foot sections.

A pipe operation based on extrusion would not be length limited and would also offer a relatively low cost operation. A one-inch I. D. pipe die was designed and standard P-38 compositions have been successfully ram extruded in lengths up to 15-feet.

The pipe has shown acceptable dimensional integrity during cure and satifactory strength (1200 lb/lineal foot - 3/16-inch wall). In static tests some compositions were found to be permeable to water, but this has been considerably reduced by (1) the additions of minor percentages of

TABLE V

ESTIMATED RAW MATERIAL COST OF P-38 COMPOSITIONS

Composition	Density lbs/ft³	Material Cost c/lb.
70 parts Coalinga Fiber (2LB-1L1)	110	0.70
30 parts H_3PO_4 (85%)		1.80
Total		2.50
70 parts Coalinga Fiber (2LB-1L1)	102	0.67
30 parts H_3PO_4 (85%)		1.71
5 parts Phenolic Resin (BRL-1100)		0.95
Total		3.33
70 parts Coalinga Fiber (L-1)		1.40
30 parts H_3PO_4 (85%)		1.80
Total		3.20
70 parts Coalinga Fiber (2LB-1L1)		0.67
30 parts H_3PO_4 (85%)		1.71
5 parts Polyvinyl Acetate Latex		1.43
Total		3.81

The following unit prices were used in determining the estimated unit costs:

a. Coalinga Fiber 2 LB-1L1 at $0.01/lb.

b. Coalinga Fiber L-1 at $0.02/lb.

c. H_3PO_4 at $0.06/lb.

d. Polyvinyl Acetate Latex at $0.30/lb. based on solids content

e. Phenolic Resin (BRL-1100) at $0.20/lb. based on solids content

silicone to the prepared mix or (2) lining the finished pipe with a resin film.

The most promising application under consideration is as a replacement for Transite in underground telephone conduit (15,000,000 lbs. Transite Pipe - 1960). Testing facilities at Bound Brook have been made available and meetings with Bell Telephone Laboratories have been arranged to obtain precise specifications. For conduit testing a 3-1/2-inch I. D. pipe die is being fabricated.

If the total pipe and conduit market in 1959 is converted in terms of asbestos in P-38 rather than asbestos in Transite, the potential is 155,000 tons asbestos per year.

B. Phenolic Resin-Asbestos

A new material has been produced which appears to have promising application as a chemically-resistant pipe and/or conduit and as a special application building or duct material.

It is a unique plastic material in that it is highly filled (80%), is prepared in a water-wet mix, and is cold extruded (room temperature).

A water soluble phenolic resin (UCPC, BRL-1100) is intimately mixed with Coalinga fiber in a ratio of 1 to 4 with sufficient water to extend the phenolic for thorough wetting. This mix may then be extruded at less than 1000 psi into pipe or sheet form.

Curing involves an extended period at room temperature (16-24 hours) followed by slowly increasing the oven temperature to a maximum 150°C to affect polymerization and hardening.

Strength tests have been made on both pipe and panels which are listed in Table VI for comparison with P-38.

The phenolic asbestos material has a higher strength and more flexibility than standard P-38 compositions. Overnight exposure to bot water and 10% sulfuric acid indicated essentially no attack.

It is believed that the strength of the material is due to the three-dimensional interaction of the thermosetting phenolic and the asbestos in a case analogous to the acid-fiber reaction. Maximum strength may be obtained similarly by optimizing the mix quantities. Methods of determining acid equivalence of asbestos, phenolics etc. are under study.

It might be pointed out that many commercial products have been developed that are based on asbestos-phenolic resin (e.g. Haveg).

V. Future Work

Further development effort is planned along three major lines for both the pipe and building materials program. These are process

TABLE VI

PHYSICAL PROPERTIES OF PHENOLIC ASBESTOS AND P-38 PIPE

Material	Flexural Strength, psi		Elastic Modulus psi x 10^6		Crushing Strength, lb/lin.ft. 1-inch I.D.	Density gms/cc.
	Parallel	Trans.	Parallel	Trans.		
Phenolic-Asbestos Panel (1:4)	8870	7270	2.36	1.78	-	1.76
Phenolic-Asbestos Pipe	-	-	-	-	1644	1.81
P-38 Pipe 30% H_3PO_4 0.4% Silicone	-	-	-	-	1560	1.71
P-38 Pipe 30% H_3PO_4 5% Phenolic	-	-	-	-	1332	1.64

improvement, product improvement, and expanded testing. Some of the problems in each of these areas are listed below:

A. Process Improvement

1. (a) Optimum acid-fiber ratio.

   (b) Optimum phenolic-fiber ratio.

2. Mixing - A better method of combining the ingredients is needed to maintain a high acid concentration for the fiber-acid reaction.

3. Curing - (a) Optimum time-temperature cycles for all compositions.

   (b) Improved support for both pipe and panels during cure.

4. The effect of calendering on strength.

5. Calender roll release agent to eliminate the use of a wax paper sandwich.

6. Modular sheet production by lamination and calendering.

7. The suitability of wet milled fiber to P-38 manufacture.

8. The effect of extrusion recycling on strength.

9. The elimination of directional strength differences in ram extruded product.

B. Product Improvement

1. Additives - Further additives should be studied for strength and flexibility effects (e.g. other phenolics, asphalt, rubber latex, epoxies, etc).

2. Weather and water resistance of pipe and sheet.

   Possible approaches are:

   a. addition to the mix of a water-resistant material, such as silicone, asphalt or resins.

   b. external application to the product.

c. impregnation of the finished product.

d. glazing or similar surface treatment.

C. Expanded Testing

Complete evaluation of the various P-38 compositions for structural use is necessary and will be undertaken with the assistance of the Building Materials Department at the Massachusetts Institute of Technology. This expanded testing program is expected to get under way shortly. It will serve to specify further the advantages and disadvantages of the material and to provide a more accurate picture of the overall market potential.