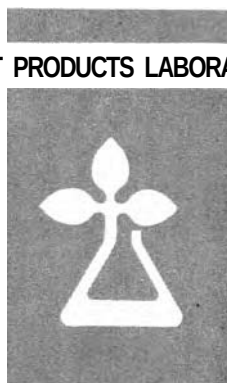


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METHODS FOR EVALUATING TENSILE AND COMPRESSIVE PROPERTIES OF PLASTIC LAMINATES REINFORCED WITH UNWOVEN GLASS FIBERS

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METHODS OF EVALUATING TENSILE AND
COMPRESSIVE PROPERTIES OF PLASTIC LAMINATES
REINFORCED WITH UNWOVEN GLASS FIBERS¹

By

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Abstract

Methods of obtaining strength and elastic properties of plastic laminates reinforced with unwoven glass fibers were evaluated using the criteria of the strength values obtained and the failure characteristics observed. Variables investigated were specimen configuration and the manner of supporting and loading the specimens.

Results of this investigation indicate that satisfactory tensile failures can be obtained by reinforcing the shank portion of the tension specimen with 1/32-inch sheet aluminum. Variation of tensile specimen geometry was inconclusive, with at least partial failures always occurring in the shank portion.

Difficulty was encountered in trying to obtain accurate compressive strength data on the composite material comprising these laminates. Some acceptable compression failures were obtained using a 5-1/8-inch-long specimen clamped at the ends and supported laterally by the standard FTM-406 jig, described in the Federal Test Method Standard No. 406. Failures varied for different laminates, indicating that resin properties may control failure when the material acts as a composite.

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²Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Introduction

The recent demand for high-strength structural plastics to be used as internal and external pressure vessels has resulted in the development of plastic laminates reinforced with unwoven glass fibers. These composite materials develop extremely high tensile and compressive strengths when load is applied parallel to the fibers. Unfortunately, however, test procedures formerly used in evaluating strength properties of plastic laminates are often not adaptable to the new unwoven glass-reinforced plastics. Test procedures presented by the American Society for Testing and Materials and Federal Test Method Standard No. 406 result in failures in the grips for tension specimens and brooming and splitting at the ends for compression specimens. Failures, of course, are also partially dependent upon resin properties and strength of the interlaminar bond.

The difficulties encountered in evaluating tensile strength of materials having exceptionally strong longitudinal fibers are not new. The configuration of wood specimens (ASTM D143), used for obtaining the tensile strength parallel to the fibers, has been the result of several modifications. This configuration has a long radius curvature in the necked-down area and a long shank in the grip area. Compared to wood, plastics reinforced with unidirectional unwoven glass have much higher ratios of tensile to shear strength parallel to the fibers. It is not probable that the previous difficulties can be overcome by extending the shank length or using a gentler fairing radius.

Tension specimens of plastic laminates reinforced with unwoven glass fibers, prepared according to ASTM Method D638, often fail in shear within the shank and parallel to the reinforcement prior to achieving the ultimate tensile load. Various methods have been suggested to prevent this type of failure. Boyd and Moore (2)³ laminated two additional plies of unidirectional unwoven fibers to the grip section of both sides of the specimen to overcome the shear stresses. Reinforcing the grip areas of the specimen with biaxial fabric during the fabrication process was reported by Jaffe, Bandaruk, and Mills (8). McGlone (9) found that the radius of the cut surface comprising the neck-down portion has a considerable effect on the ultimate strength obtainable. Boller (1) reports other tension specimens, cut from flat sheets, were reinforced with aluminum plates glued to the shank area to improve shear strength.

The Naval Ordnance Laboratory NOL ring test (4) was developed to evaluate tensile properties of unwoven, glass-reinforced, filament-wound, plastic specimens. This test has also been used to a considerable extent on parallel windings, but has certain limitations.

³Underlined numbers in parentheses refer to Literature Cited at the end of this report.

Over the years, compression tests have been made on specimens designed as either long or short columns, with and without lateral support. Types of lateral support have varied from thin steel fingers, similar to those used in plywood testing, to flat metal I-shaped supports frequently used in testing metals. Presently, glass-reinforced plastics are often tested with lateral supports, in order to observe compressive strains, or as short columns (7). For short columns, it is generally stipulated that the ratio of length to least radius of gyration shall be in the range of 11 to 15.

In tension testing, the type of resin apparently has little influence on the ultimate strength, but in compression testing, both the compressive strength and failure characteristics appear to be closely related to the amount and kind of resin and to the strength of the interlaminar bond, which depends on fiber-to-resin adhesion. Recent papers (3,5,6) have attempted to analyze and evaluate failure mechanisms under compressive load in unwoven and filament-wound glass-reinforced plastics. Elkins (3) reported that initial failure usually occurs in the end grain if it is not reinforced. When failure does not occur at the ends, it appears to develop as a shear fracture plane at some angle to the load. Elkins believes this is caused by the "spreading apart of the fibers, caused by the column buckling of the fibers and by failure of the resin under shear and tension. Fracture of a shear type points to the dominating role of the resin." Fried (5) presented a paper which developed a method for computing the ultimate strength of a composite specimen. His formula is based upon the theory that failure is initiated when the resin begins yielding and no longer supports the glass fibers, causing them to buckle. Another study of the origin of stress failure in glass-reinforced plastics, by Throckmorton, Hickman, and Browne (10), concluded that "laminates fail primarily by loss of adhesion between the resin and glass filament surface, without fracture of the glass filament."

Higher compressive strengths have been experienced by Fried and Winans on specimens with clamped ends and a radius machined into the thickness of the specimen (6). This type of specimen evolved from a series of tests on specimen configurations and methods of loading. Apparently, much higher compressive stresses are achieved on specimens of this nature, but modulus of elasticity values cannot be obtained on the same specimen. Also, the net area of the specimen used in evaluation is extremely small in size and is undesirable.

The dumbbell-shaped specimen has been used successfully for glass-fabric-reinforced plastic laminates; however, when used for laminates reinforced with unwoven glass, failure did not always occur in the net section.

It is the purpose of this study to evaluate the tensile and compressive strength of flat panels reinforced with unwoven glass fibers and to observe modes of failure obtainable from various test procedures, premised on two basic requirements namely:

- (1) The configuration shall fail in the net section.
- (2) The net section shall be of sufficient length to allow strain measurements

In tension, this investigation studied the effect on ultimate strength and type of failure of: (1) shank length, (2) net section width, and (3) increased shank thickness by use of reinforcement.

In compression, the type of failure and ultimate strength were studied in: (1) the plywood compression jig, (2) fatigue grips with no lateral support, (3) the FTM-406 jig presently used in compression testing of plastics, and (4) a modified FTM-406 setup with clamped specimen ends.

Materials

The evaluations in this study were made of four typical unidirectional laminates, reinforced with unwoven glass fibers. Three of the materials, types A, B, and C, were provided by the Minnesota Mining and Manufacturing Company, St. Paul, Minn., and were made up in 1/8-inch-thick panels with different epoxy resin systems. A fourth material, type D, was a straight fiber epoxy laminate (Novalac)⁴ 1/16 inch in thickness, furnished by the Dow Chemical Company, Midland, Mich. As the purpose of this study was primarily to observe modes of failure obtained from different test procedures and not to obtain comparative strength data of various laminates, physical properties such as specific gravity, resin content, and hardness were not obtained.

Discussion of Procedures and Results

Tension and compression tests were conducted in a mechanical testing machine of 120,000-pound capacity. Load was applied at a head speed of 0.04 to 0.06 inch

⁴Proprietary names are given at the request of the MIL-HDBK-17 Working Group.

per minute for all specimens, except those tension specimens in which the length was varied. For these specimens, the head speed was controlled so that the time rate of unit fiber strain was the same for all lengths. The ends of the compression specimens were machined smooth and perpendicular to the specimen sides.

Compression

Initial tests were conducted using the plywood test apparatus and arrangement shown in figure 1 and described in ASTM D805-52. This method had previously been used successfully at the Forest Products Laboratory on glass-cloth-reinforced plastic laminates (11). Specimens prepared from type D laminate were used in this series. The following are experimental methods and devices used in this study, each of which is illustrated in figure 2.

(1) The first configuration studied was a necked-down rectangular specimen 1 inch wide reduced down to 3/4 inch at the net section, without end reinforcement (fig. 2A). Two specimens were tested and both failed at about 83,000 pounds per square inch by end-brooming, with vertical splits running the length of the specimen.

(2) The next two specimens were of the same configuration, but were end-dipped in an epoxy resin to increase the resistance of the ends to splitting (fig. 2B). However, the resin coating loosened and initiated end failure prior to failure of either specimen.

(3) Another method of reinforcing the ends was the use of 1/4- or 1/2-inch steel clamps on the ends of the specimens (fig. 2C), to increase the resistance to end failure. The 1/4-inch clamps were not strong enough to inhibit the end failure. Difficulty arose with the 1/2-inch clamps because of the 5/8-inch length of specimen left unsupported laterally, which buckled in a manner similar to a fixed-end column loaded at the free end.

(4) The grips shown in figure 2D were the next method used for reinforcing the ends of the specimens. The grips were similar to those required in fatigue testing to load the specimens in both tension and compression. The specimens used were 4-1/2 inches in length and since the ends of the grips were beveled, it was difficult to determine the free column length. If full fixity of the ends could be obtained in the grips, the effective column length would be one-half that of a simply supported column. Three specimens were tested and all failed between 85,000 and 97,000 pounds per square inch compressive loading. The failures were probably caused by instability, although it was difficult to observe accurately the type of failure. However, after failure there was no evidence of end failure having contributed to the total failure.

From the results of these four initial tests it was believed an acceptable compression test could be accomplished if the ends of the specimens were given support comparable to that of the fatigue grips, in combination with sufficient free length to permit measurement of modulus of elasticity. The FTM-406 jig shown in figure 3 facilitates this measurement, but additional modifications were considered desirable. Therefore, a new jig (fig. 4) was designed and built, incorporating the advantages of the fatigue grips and the FTM-406 supporting device. The new jig was then used to investigate the failure characteristics of different specimen configurations. Maximum load was recorded so that stresses of the different configurations at failure could be compared to obtain indications of compressive strength on those specimens that appeared to develop acceptable compressive failures. Tables 1, 2, and 3 present the results of tests on the various configurations and indicate those specimens on which acceptable compression failures (a sliding shear plane at some angle) occurred.

The first tests were conducted using the standard FTM-406 arrangement with the 3-1/8-inch-long specimen (fig. 5A, 6A) for comparison with other arrangements and specimens. The variables investigated on the longer specimens with clamped ends were: (1) different widths of straight-sided specimens, (2) variable net widths on specimens 3/4 inchwide with a 3-inch fairing radius, (3) variable fairing radii on specimens 3/4 inchwide necked-down to 1/2-inch net width, and (4) with and without aluminum reinforcement of shank on specimens 3/4 inch wide, necked-down to 1/2 inch, with a 3-inch fairing radius.

In general, failures in straight-sided specimens tended to be erratic for all widths with strength values, similar to those obtained on the standard specimens used in the FTM-406 jig. Typical failures for the 1/2- and 3/4-inch-wide specimens of types A and B are shown in figures 5B, 5C, 6B, and 6C, respectively. The 1/4-inch-wide specimens buckled out at the sides of the restrainer at relatively low loads.

Using specimens with a 3-inch radius and net widths from 3/8 to 3/4 inch showed that the best failures and highest strengths were obtained on specimens with 1/2-inch net width for both types A and B laminates. Type B, which yielded higher compressive stresses, showed fewer acceptable failure patterns. Type B specimens of 3/8-inch net width failed by buckling at the sides of the restrainer. Typical failures for the 3/8-, 1/2-, and 5/8-inch net width specimens of types A and B are shown in figures 5 (D, E, F) and 6 (D, E, F), respectively. A maximum stress of 128,000 pounds per square inch was obtained on one of the type B specimens and failure occurred as a sliding shear plane.

Variation of the fairing radius from 3 to 10 inches on types A, B, and C laminates proved inconclusive, although type C laminate, apparently the material with

the weakest compressive strength, showed higher average stresses with a 10-inch fairing radius. In the stronger laminates, specimens with the 10-inch radius showed more evidence of end failure, probably resulting from lower shank stability and therefore acted more like straight-sided specimens. In general, the outer shank portions of type B specimens, which had been necked-down, tended to fail in shear at about 80,000 pounds per square inch, and leave essentially a straight-sided specimen. To prevent premature failure of the shank, aluminum reinforcement was glued to the shank of three type B laminate specimens. Although the aluminum reinforcement appeared to stop the end failure of the shank and give added strength to the shank portion, it did not give higher strength values to the few specimens tested.

An indication of the validity of these results may be obtained by calculating the stresses in the glass at failure. Glass stress may be computed using the following formula:

$$\frac{\sigma_g}{\sigma_c} = \frac{(\text{Sp. Gr.})_g}{(\text{Sp. Gr.})_c V_g}$$

<u>Symbol</u>	<u>Description</u>	<u>Type A</u>	<u>Type B</u>
$(\text{Sp. Gr.})_g$	Glass specific gravity	2.57	2.57
$(\text{Sp. Gr.})_c$	Composite specific gravity	1.85	1.84
σ_c	Stress in composite--p.s.i.	100,000	120,000
V_g	Percent glass (by volume) as a decimal	0.666	0.627
σ_g	Stress in glass--p.s.i.	210,000	270,000

The glass stress at failure is not the ultimate strength of the glass, for either type of laminate but the type B specimens had much larger glass stresses at failure. However, it should be noted that the type A specimens consistently failed in sliding shear planes typical of compression failures in many materials, while the failures of type B specimens were much more erratic. This seems to support Fried's theory (5) that the composite compression strength is controlled by the point at which the resin yields.

Tension

The primary problem in evaluating the tensile strength of plastic laminates reinforced with unwoven glass fibers is to strengthen the gripped portion of the tension specimen to insure failure in the net section. Three methods of increasing the shank strength were investigated, namely: (a) increasing the shank length by increasing the specimen length but holding the net section length and fairing radius constant, (b) utilizing net section widths of 1/4 and 1/8 inch, and (c) increasing the shank thickness by the use of aluminum reinforcement on the shank.

(a) Shank length.--Shank length was varied by extending the length of the specimen while holding the net section length constant at 2 inches and the fairing radius constant at 3 inches. Specimen lengths of 9-3/8, 11-3/8, 13-3/8, and 15-3/8 inches were investigated for specimens of 1/4-inch net width, and lengths of 9-3/8, 13-3/8, and 15-3/8 inches for specimens of 1/8-inch net width. Table 4 presents a tabulation of the results of this series of tests; and figures 7 and 8 show typical specimens tested and resultant failures that occurred. It will be noted in figure 8 that shear failures occurred in the shank of all specimens with 1/4-inch net width, and that specimens with 1/8-inch net width appeared to have failed due to a combination of spreading of the outer fibers in the net section and shear failure extending up into the shank. An unexpected phenomenon occurred in the failures of the specimens 15-3/8 inches in length with 1/4-inch net width, when the shank failure did not occur in two shear planes parallel to the fibers but in one diagonal shear plane across the shank, resulting in strength values of only 70,000 pounds per square inch. The strength results given in table 4 show that the highest strength values for both net widths occurred in specimens of 13-3/8-inch length--107,000 pounds per square inch for the 1/4-inch net width specimens and 121,000 pounds per square inch for the 1/8-inch net width specimens.

(b) Net section width.--In the study of shank length, specimens of 1/8- and 1/4-inch net width were used. At each length where different net width specimens were evaluated, the 1/8-inch net width specimens resulted in significantly higher strengths as shown in table 4. This is undoubtedly because the 1/4-inch net width specimens had twice the tensile area but substantially the same shank area in shear as the 1/8-inch net width specimens. Therefore, the 1/4-inch net width specimens failed in the shank due to shear prior to any tensile failure of the net section.

Additional tests were then conducted using four specimens made of different material but of standard 9-3/8-inch length and 1/8-inch net width. Three of the four specimens tested failed in shear parallel to the fibers in the shank.

(c) Shank thickness.--Because partial or complete shear failure in the shank plagued all of the previous tests in which specimen configuration was investigated, it was decided to investigate the effect that reinforcing the shank would have on strength and failure characteristics. A twofold benefit was sought in reinforcing the shank: (1) to provide sufficient shear strength to avoid failure in the shank area rather than in the net width section; (2) to attain more uniform load distribution within the grips to lower stress concentrations in the specimen and yield higher computed strength values. Accordingly, a group of specimens were prepared and tested. The specimen configurations, methods of reinforcement and resultant failures are shown in figure 9, and test data obtained are given in table 4.

The upper three specimens (fig. 9A, B, C) are of standard 9-3/8-inch length and 1/8-inch net width and show failures that occurred, including the one specimen (C) that appeared to fail in the net section. The next two specimens (D and E) are of the same length, but one had a net width section of 1/4 inch. These specimens were reinforced with 1/32-inch sheet aluminum. All specimens tested in this manner appeared to fail in the net section with apparently the same computed strengths for both net widths. The phenomenon of failure in the net section for these specimens appeared again to begin with initial separating of the outer fibers and subsequent net section reduction. The bottom specimen (F) shows an attempt that was made to inhibit the separating of the outer fibers and obtain a more uniform application of load from the grips to the specimen. The only specimen tested was reinforced with aluminum 3/16 inch in thickness, with a gap of only 3/8 inch at the center. While this configuration appeared to restrict the failure entirely to the net section upon uniform application of load, the resulting computed strength was 111,000 pounds per square inch and within the same range experienced on the other specimens. In the initial series of tests to study the effect of shank length on strength, it appeared that the 13-3/8-inch-long specimen was the optimum length. A specimen of this length was then tested after being reinforced in the shank with 1/32-inch sheet aluminum. The results of these tests are given in table 4 and show that an average computed strength of 126,600 pounds per square inch was obtained--the highest of any configuration investigated.

Following the same line of analysis used in reinforcing the necked-down specimens with 3/16-inch aluminum, a series of straight-sided specimens 12-1/8 inches in length were prepared and reinforced with 3/16-inch aluminum, extending for various lengths on the specimen. A 16-inch-long straight-sided specimen with no reinforcement was also included for comparison. Figure 10 shows the various configurations used and test data for this series are given in table 5. The strength of the specimens did not appear to be significantly affected

by the length of the aluminum reinforcement, as all specimens failed in the neighborhood of 95,000 pounds per square inch. The 16-inch-long unreinforced specimen failed at 71,000 pounds per square inch with much evidence of cracking and splintering of the fibers near the grips.

Summary of Findings

Compression

In the compression testing of glass-reinforced plastics, it appears advantageous to support the shank of specimens in a manner simulating the grip used in holding fatigue specimens, and to provide lateral support similar to that afforded by the FTM-406 jig. Modulus of elasticity and strength data may be obtained with this test arrangement. Aluminum reinforcement glued to the shank of the specimen seemed to provide resistance to splitting in the shank. Variation in specimen configuration proved inconclusive and pointed out that more reliability and consistency in types of failure is necessary before the refinements in specimen configuration are considered. For the two principal laminates tested, computation of glass stresses at failure showed large differences. The lowest computed glass stresses resulted from the material that gave the best compression failures. There were a sufficient number of compression type failures occurring on sliding shear planes to indicate that the analysis presented by Fried (5) deserves more experimental investigation concerning its relationship to unwoven laminates. In particular, more data are required concerning the mechanical properties of resins used in these laminates.

Tension

All tension specimens tested without shank reinforcement failed primarily or partially due to shear failures in the shank. Results obtained on specimens reinforced with different thicknesses of aluminum indicated that strength values and failure characteristics were independent of the thickness and size of the aluminum reinforcement. The optimum specimen investigated in this study was a 13-3/8-inch-long specimen with a 1/4-inch net width, a fairing radius of 3 inches, and a shank reinforced with sheet aluminum 1/32 inch in thickness. Failure on this specimen occurred in the net section at a computed average strength of 126,600 pounds per square inch.

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Table 1.--Compressive strength values obtained on plastic laminates reinforced with unwoven glass fibers, showing effect of specimen width

Laminate type	Standard FTM-406 specimen		Straight-sided specimens of various widths ¹	
	Compressive strength	Modulus of elasticity	1/2 inch	3/4 inch
	<u>P.s.i.</u>	<u>1,000,000</u> <u>p.s.i.</u>	<u>P.s.i.</u>	<u>P.s.i.</u>
A	277,200	4.65	80,500	291,700
	297,500	4.92	298,300	294,000
	290,000	5.18		80,800
Av.	288,200	4.92	89,400	88,800
B	103,500	4.74	106,000	89,200
	85,000	4.79	88,500	100,000
	101,000	4.54	87,000	95,000
Av.	99,800	4.69	93,800	94,700

¹1/4-inch-wide specimens buckled.

²Appeared to be valid compression failures.

Table 2.--Compressive strength values obtained on plastic laminates reinforced with unwoven glass fibers, showing the effect of necked-down net width section

Laminate type	Specimens necked-down to various net widths			
	3/8 inch	1/2 inch	5/8 inch	3/4 inch
	<u>P.s.i.</u>	<u>P.s.i.</u>	<u>P.s.i.</u>	<u>P.s.i.</u>
A	¹ 102,000	¹ 98,200	¹ 90,700	¹ 91,700
	¹ 93,300	¹ 103,500	¹ 102,500	¹ 94,000
	¹ 104,000	¹ 111,000	¹ 95,700	80,800
Av.	¹ 99,800	¹ 104,200	¹ 96,300	88,800
B	86,500	¹ 128,500	100,000	89,200
	104,000	115,200	¹ 120,000	100,000
	88,000	113,100	104,000	95,000
Av.	92,800	118,900	108,000	94,700

¹Appeared to be valid compression failures.

Table 3. -- Compressive strength values obtained on plastic-laminates specimens reinforced with unwoven glass fibers and having a 1/2-inch net width section, showing the effect of fairing radius

Laminate type	Specimens with various fairing radius		
	3 inches	6 inches	10 inches
	<u>P.s.i.</u>	<u>P.s.i.</u>	<u>P.s.i.</u>
A	¹ 98,200	¹ 99,800	¹ 113,000
	¹ 103,500	¹ 111,000	¹ 112,000
	¹ 111,000	¹ 107,000	101,000
Av.	¹ 104,200	¹ 105,900	108,700
B	¹ 128,500	101,000	115,200
	115,200	¹ 128,500	108,400
	113,100	¹ 117,100	¹ 120,000
Av.	118,900	115,500	114,500
B	² 120,000		
	² 104,000		
	² 126,000		
Av.	² 116,700		
C	¹ 70,800	¹ 85,000	¹ 97,200
	¹ 86,500	¹ 78,800	¹ 107,100
	¹ 85,900	¹ 93,000	¹ 103,500
	¹ 85,800	¹ 86,600	¹ 107,200
	¹ 84,800	¹ 84,700	¹ 103,800
	¹ 88,900	¹ 89,700	¹ 102,400
Av.	¹ 83,800	¹ 86,300	¹ 103,500

¹Appeared to be valid compression failures.

²Shank reinforced with aluminum.

Table 4.- -Tensile strength values obtained on plastic-laminate specimens reinforced with unwoven glass fibers, showing the effect of shank length, net width section, and shank reinforcement

Specimens of various lengths			
9-3/8 inches	11-3/8 inches	13-3/8 inches	15-3/8 inches
<u>P.s.i.</u>	<u>P.s.i.</u>	<u>P.s.i.</u>	<u>P.s.i.</u>
1/4-INCH NET SECTION WIDTH			
83,700	104,100	105,400	71,500
91,400	96,600	103,400	57,900
92,600	94,800	96,400	81,800
87,800	102,500	109,700	68,500
92,200	95,400	122,000	70,600
Av. 89,500	98,700	107,400	70,100
1,2 ¹ 124,800		1,2 ¹ 125,500	
1,2 ¹ 118,100		1,2 ¹ 123,000	
1,2 ¹ 114,000		1,2 ¹ 125,200	
1,2 ¹ 117,500		1,2 ¹ 132,600	
1,2 ¹ 117,500			
Av. 1,2 ¹ 118,400		1,2 ¹ 126,600	
1/8-INCH NET SECTION WIDTH			
107,000		121,700	121,500
1 ¹ 108,000		120,600	115,500
94,600		118,800	115,400
104,200		128,100	112,000
1 ¹ 105,800		114,500	120,000
Av. 103,900		120,700	116,900
1,2 ¹ 108,000			
1,2 ¹ 114,500			
1,2 ¹ 123,600			
1,2 ¹ 120,500			
Av. 1,2 ¹ 116,700			

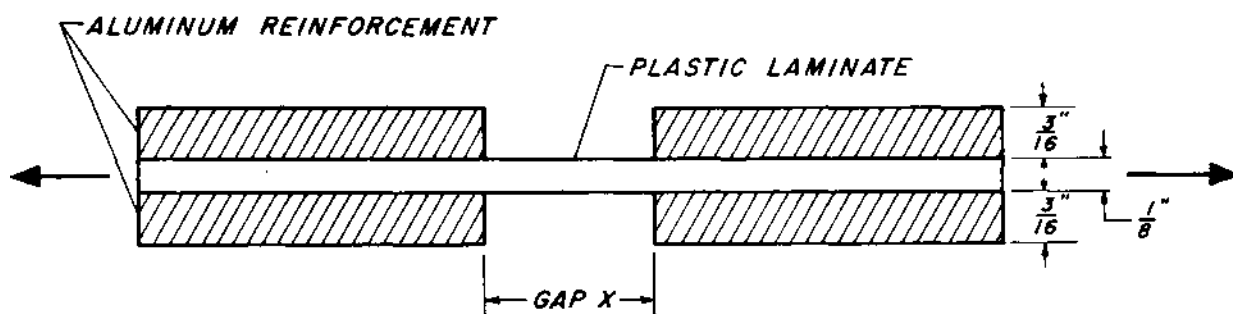
¹Apparent net section failures.

²Shank reinforced with aluminum.

Table 5. - -Tensile strength values of plastic laminates reinforced with unwoven glass fibers, showing the effect of length of aluminum reinforcement

Specimen length	Net section	Length of Gap X at center of specimen	Tensile strength
<u>In.</u>		<u>In.</u>	<u>P.s.i.</u>
9-3/8	:Reduced to 1/8 inch	: 3/8	: 111,100
12-1/8	:Straight --3/4 inch	: 1/8	: 93,000
12-1/8	:Straight --3/4 inch	: 1-1/8	: 93,800
12-1/8	:Straight --3/4 inch	: 2-1/8	: 100,700
12-1/8	:Straight --3/4 inch	: 4-1/8	: 90,600
16	:Straight -- 3/4 inch	: (1)	: 71,100

¹No reinforcement provided.



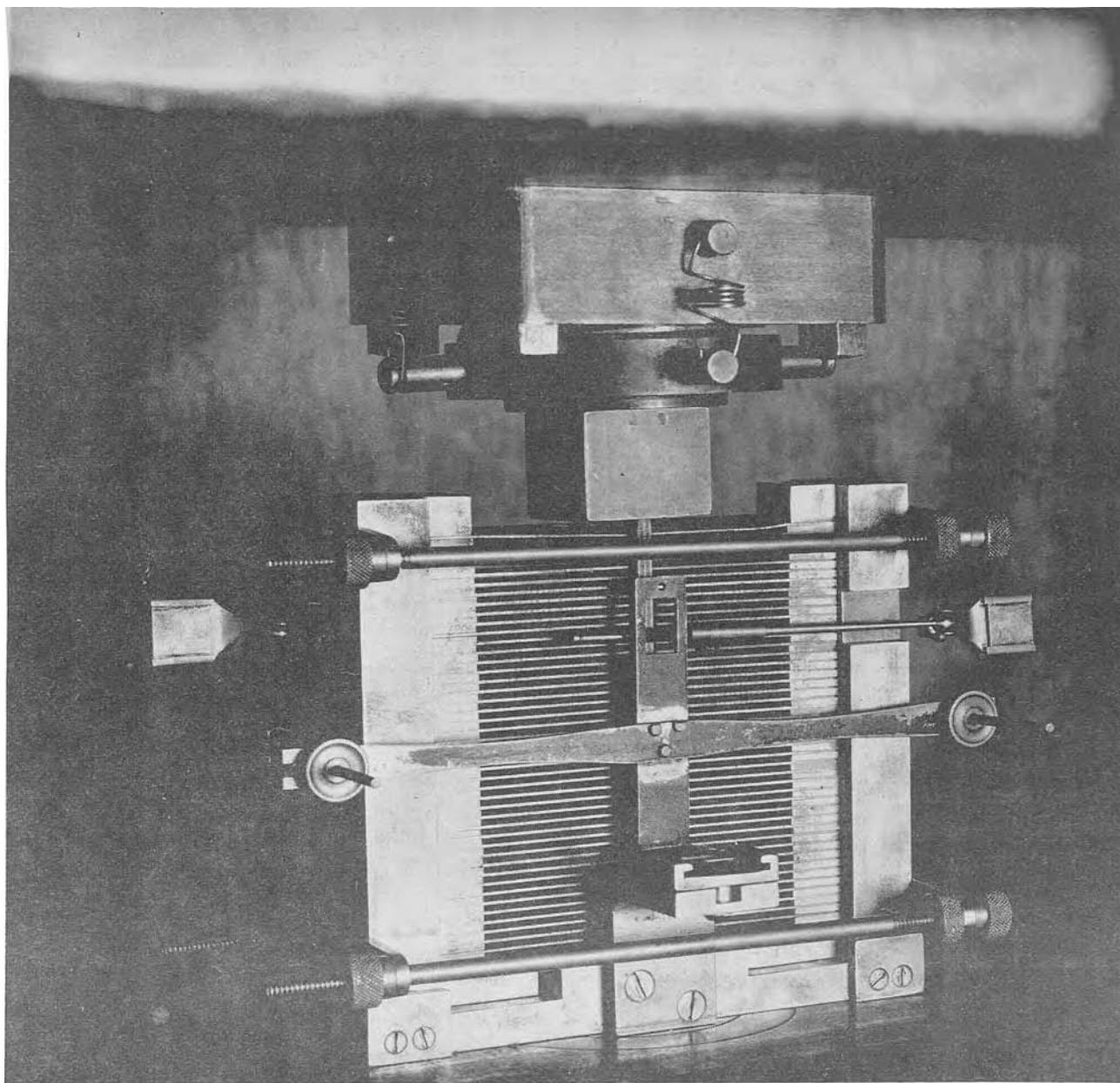
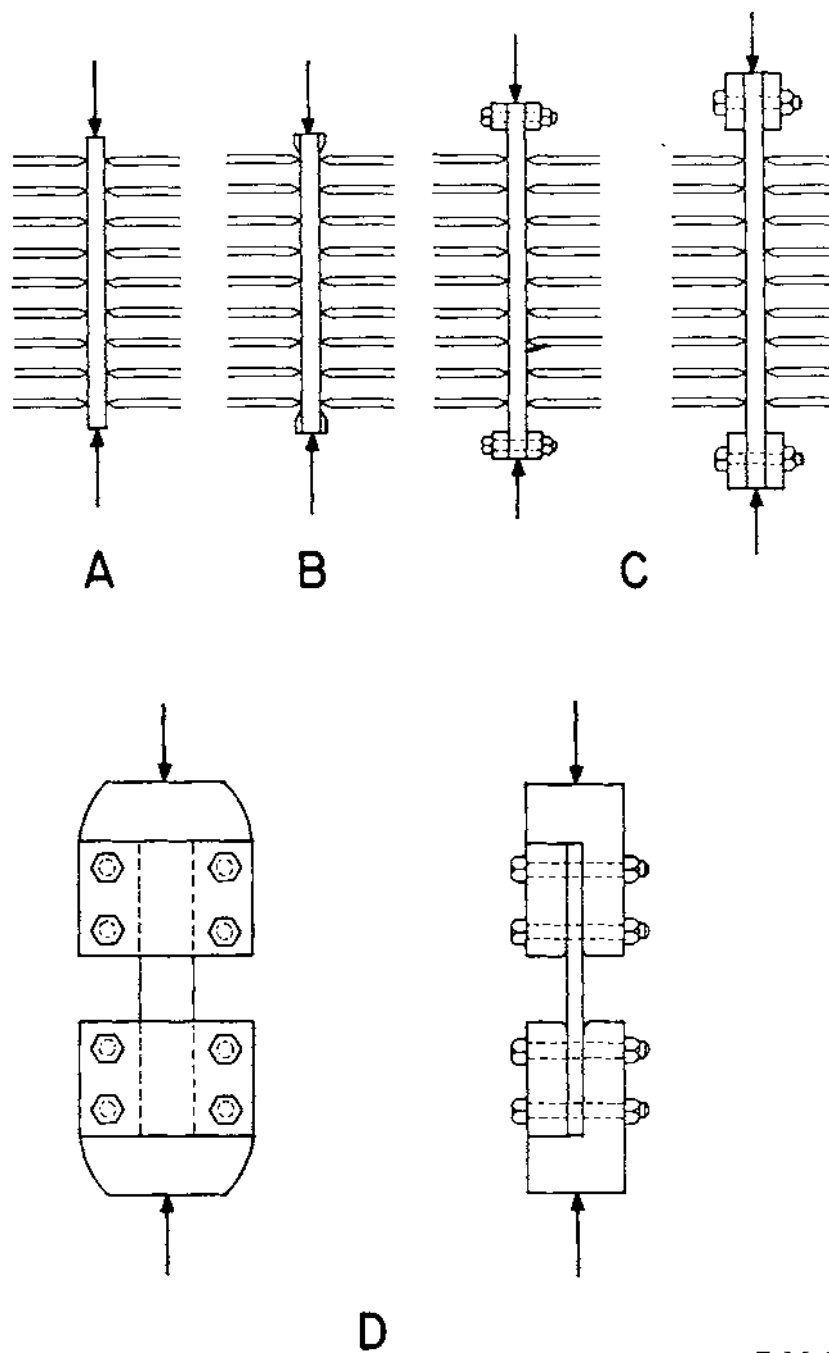


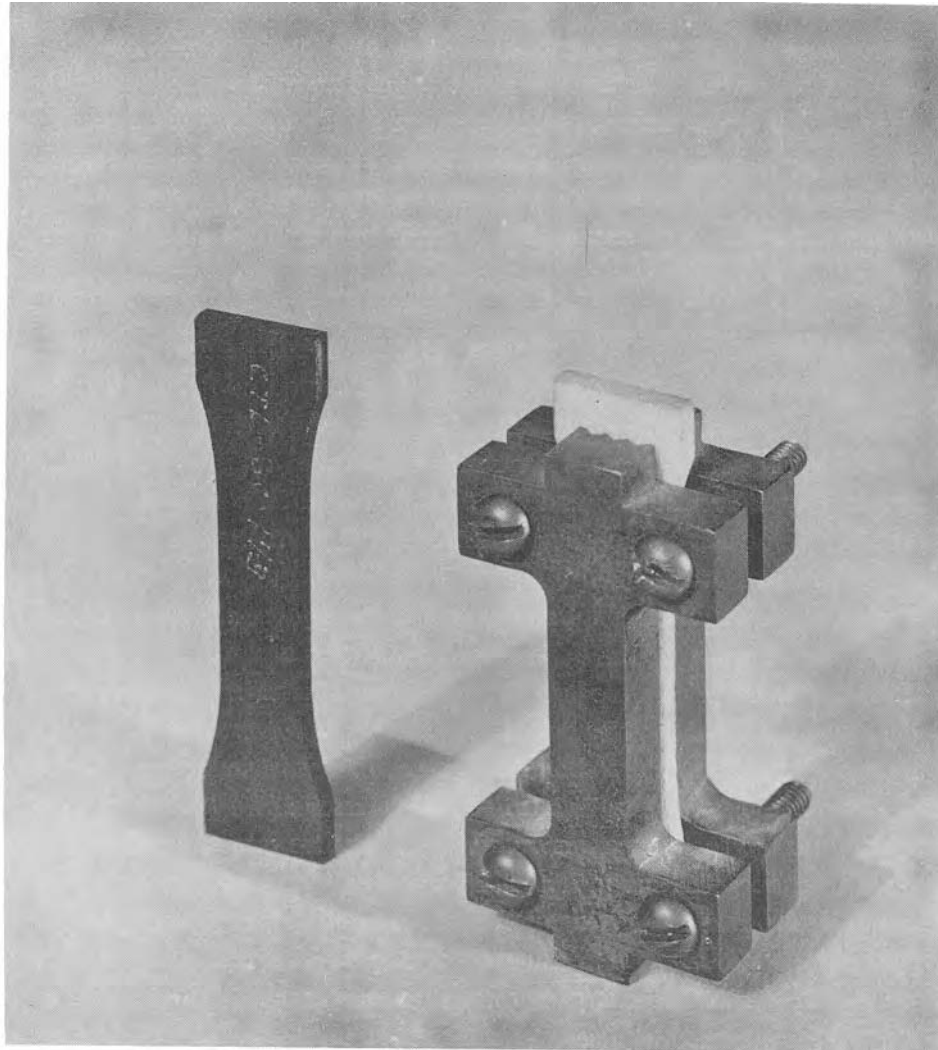
Figure 1.--Compression test apparatus commonly used in testing plywood, and used in this study for testing plastic-laminate specimens reinforced with unwoven glass fibers.

Z M 49602 17



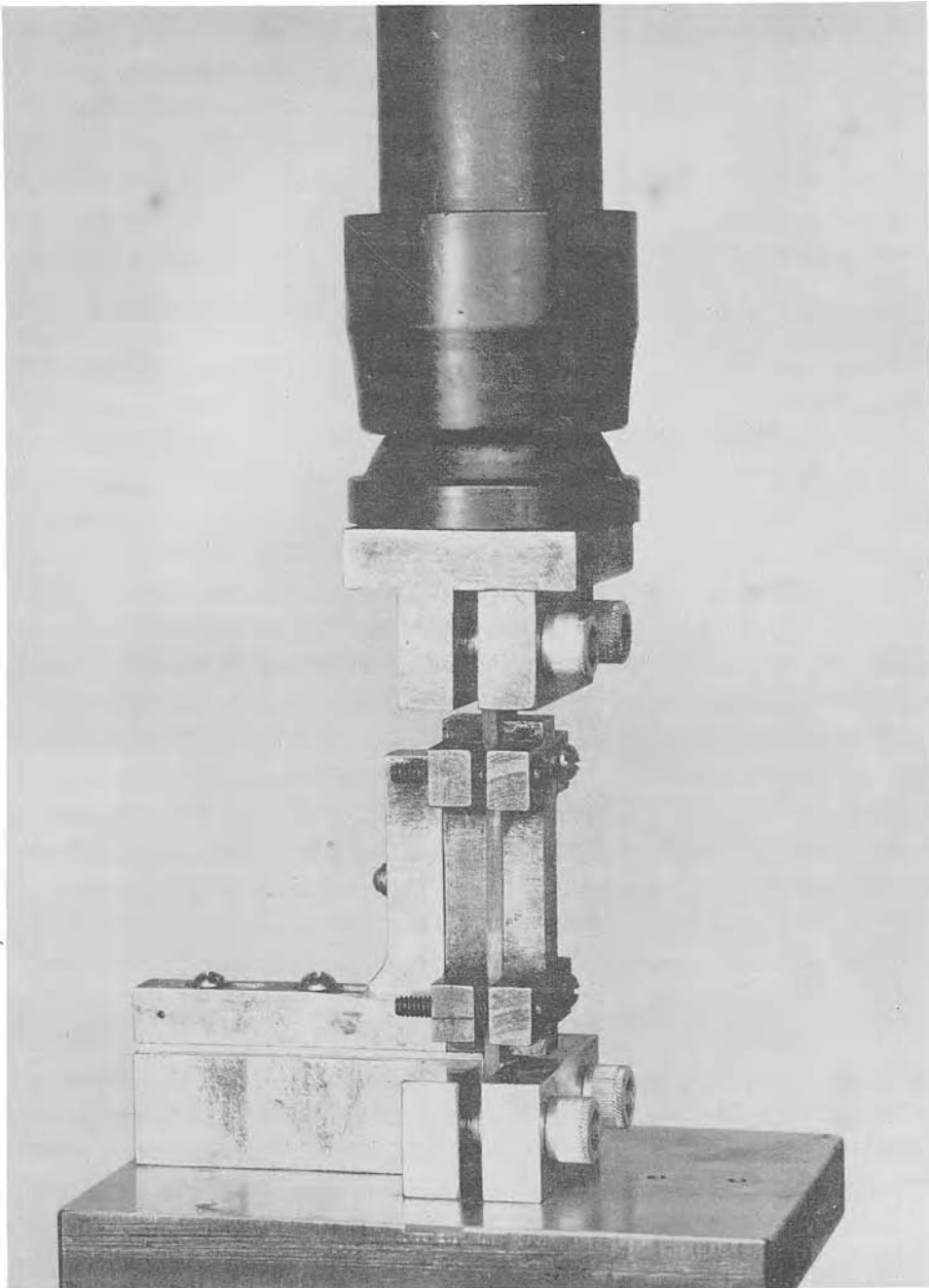
Z M 126 767

Figure 2.--Experimental methods and devices used in the study and evaluation of plastic-laminate specimens reinforced with unwoven glass-fibers: A, no end reinforcement; B, ends dipped in epi-bond; C, 1/4- and 1/2-inch clamps; D, fatigue grips.



Z M 114 364

Figure 3.--Typical necked-down compression specimen and FTM-406 jig used for support during test.



Z M 124 323

Figure 4.--Modified FTM-406 jig with end clamps.

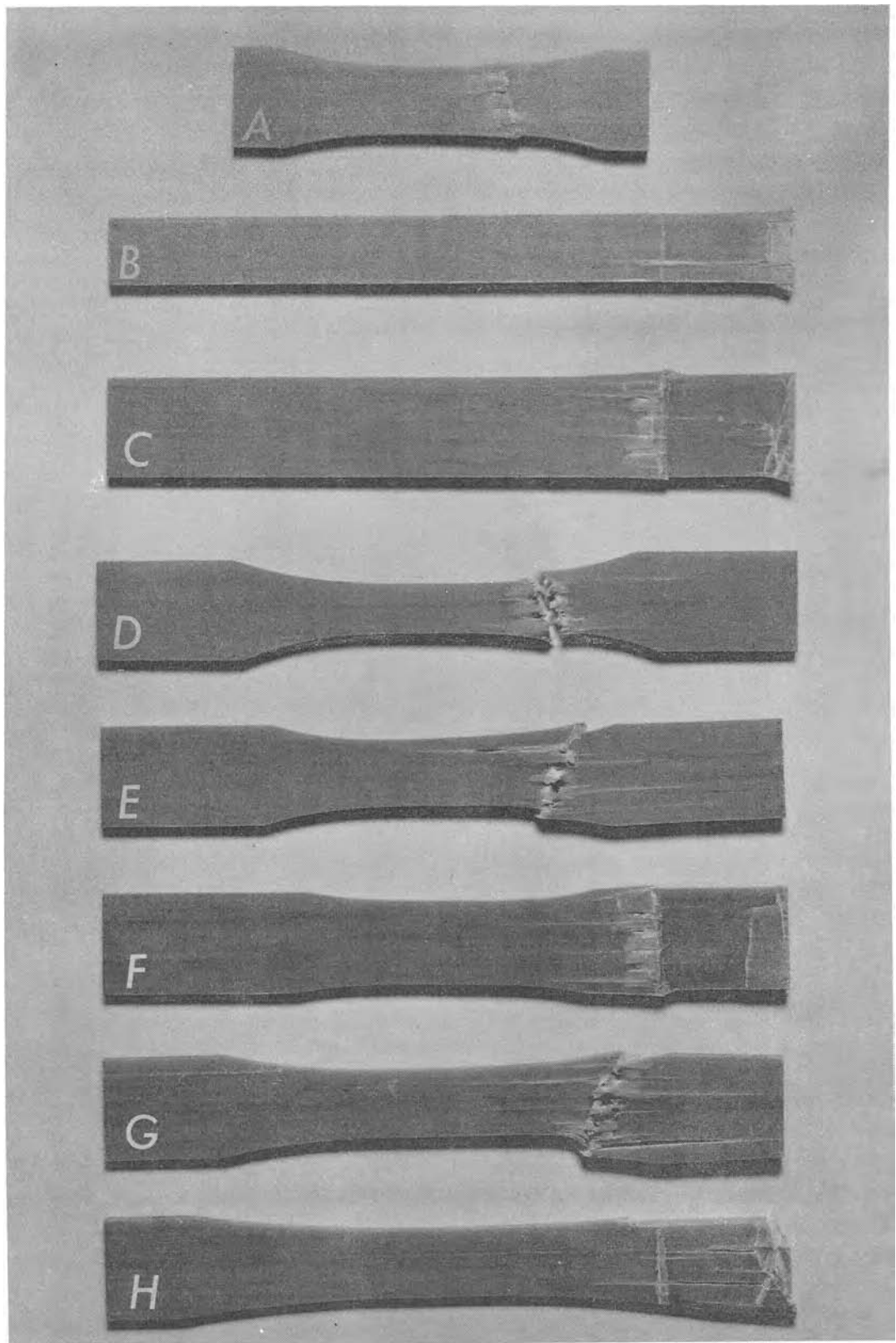
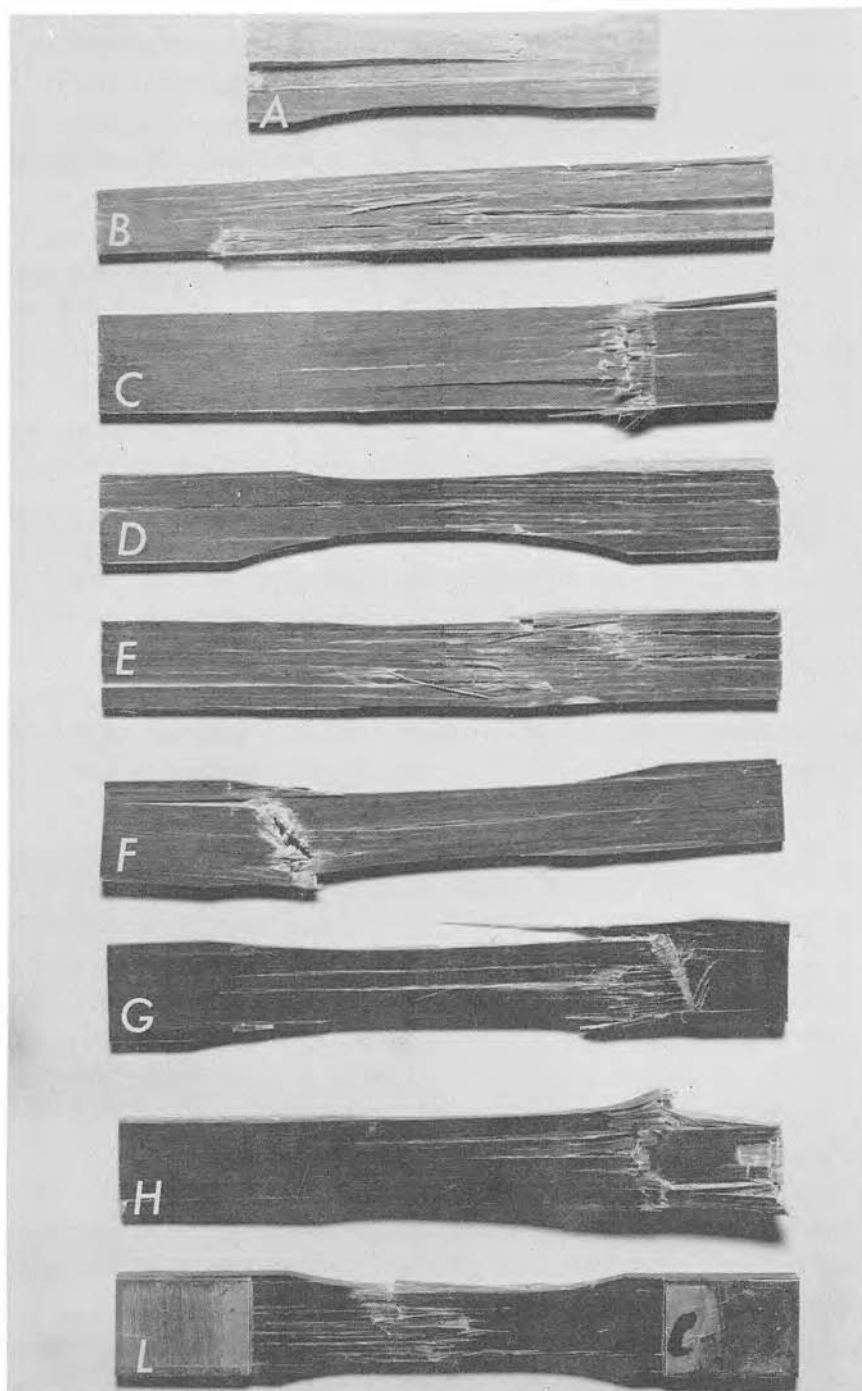
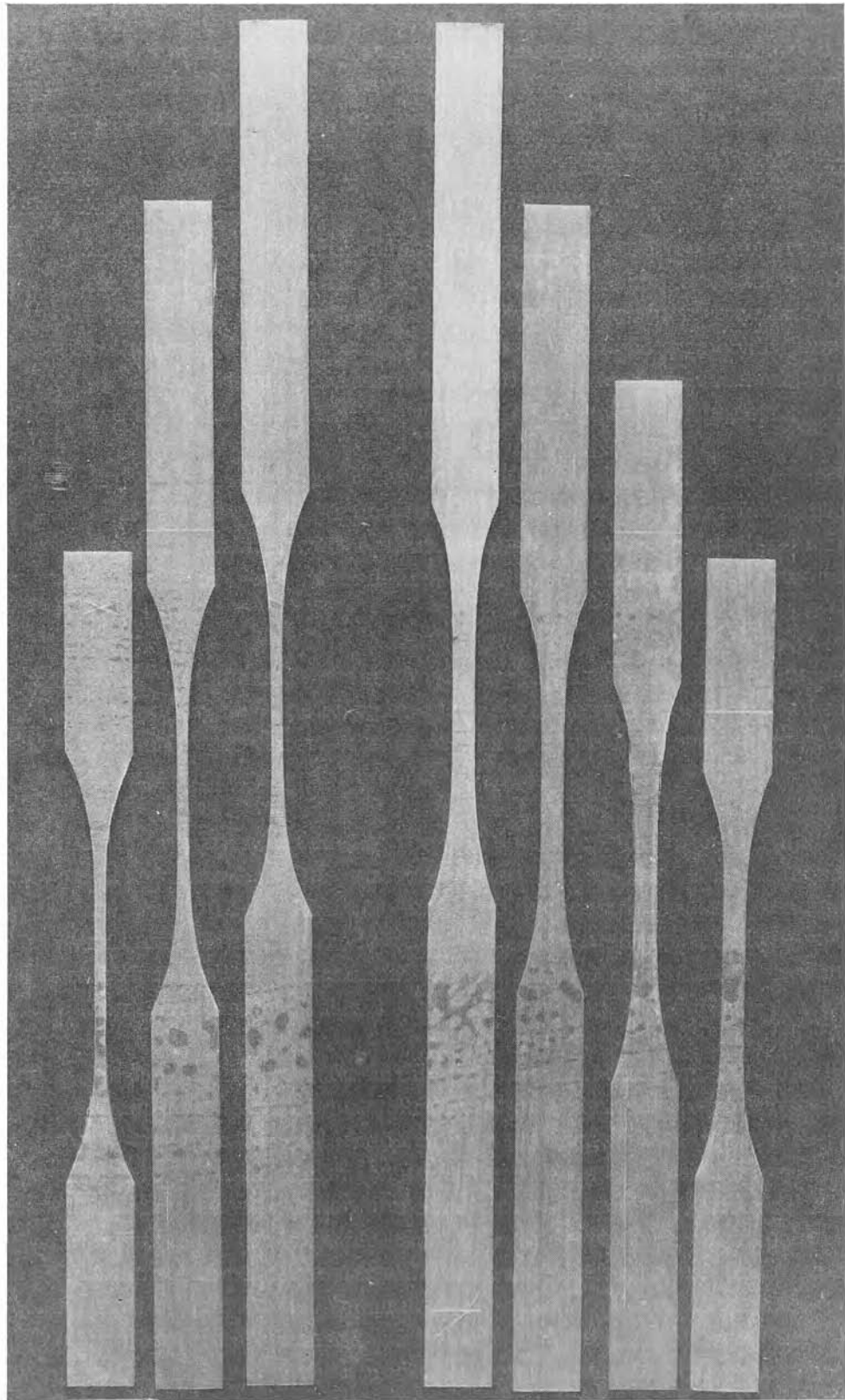


Figure 5.--Typical failures observed on type A plastic-laminate specimens of various width, net-width section, and radius: A, standard FTM-406 specimen; B, C, experimental straight-sided specimens of 1/2- and 3/4-inch-net width, respectively; D, E, F, necked-down specimens of 3/8-, 1/2-, and 5/8-inch-net-width sections; and G, H, necked-down specimens with 6- and 10-inch-fairing radius.



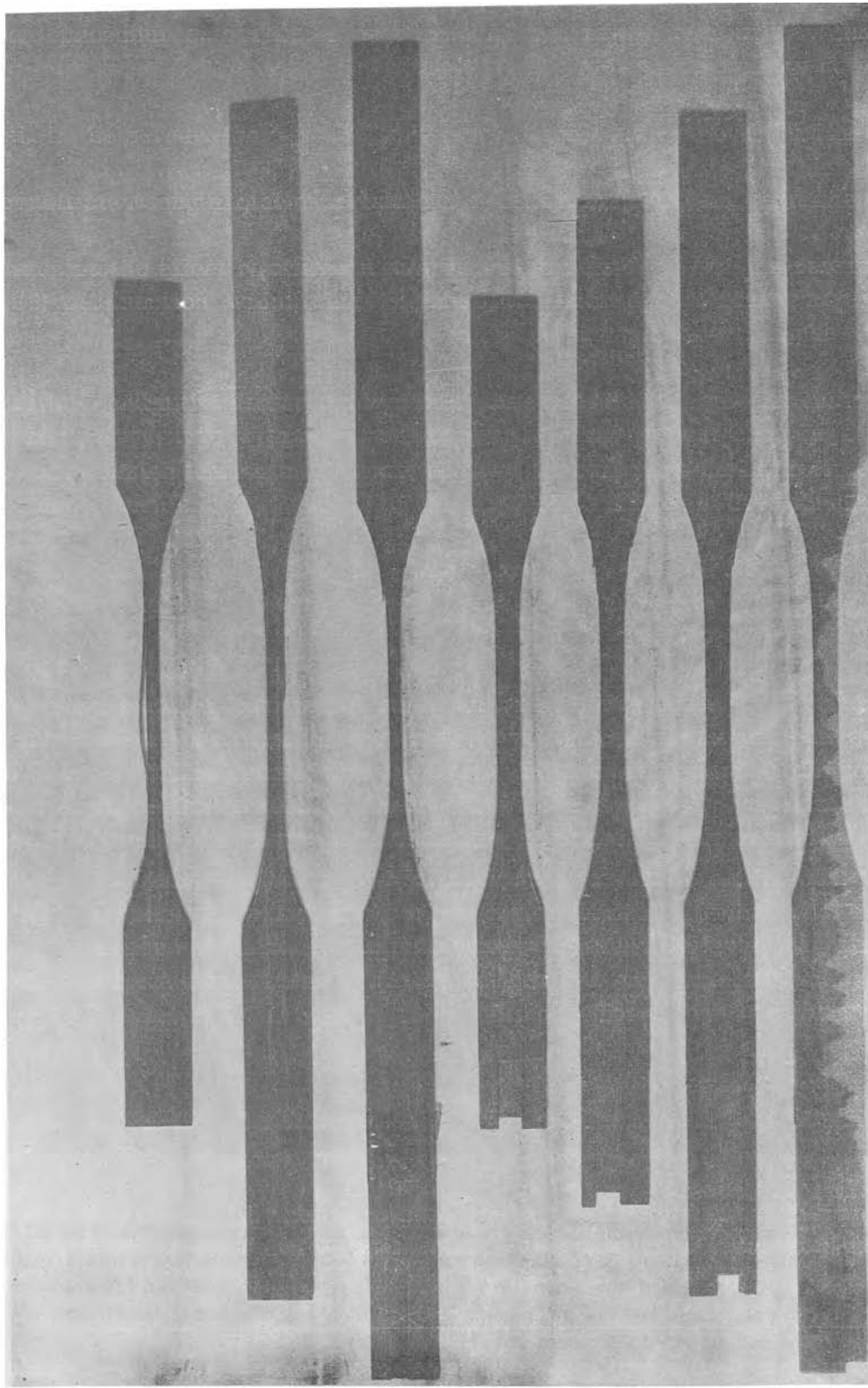
Z M 125 437

Figure 6.--Typical failures observed on type B plastic-laminate specimens of various width, net-width section, and radius: A, standard FTM-406 specimen; B, C, experimental straight-sided specimens of 1/2- and 3/4-width, respectively; D, E, F, necked-down specimens of 3/8-, 1/2-, and 5/8-inch-net-width sections; G, H, necked-down specimens with 6- and 10-inch fairing radius; L, specimen with 1/2-inch net width, 3-inch-fairing radius, and aluminum reinforcement on ends.



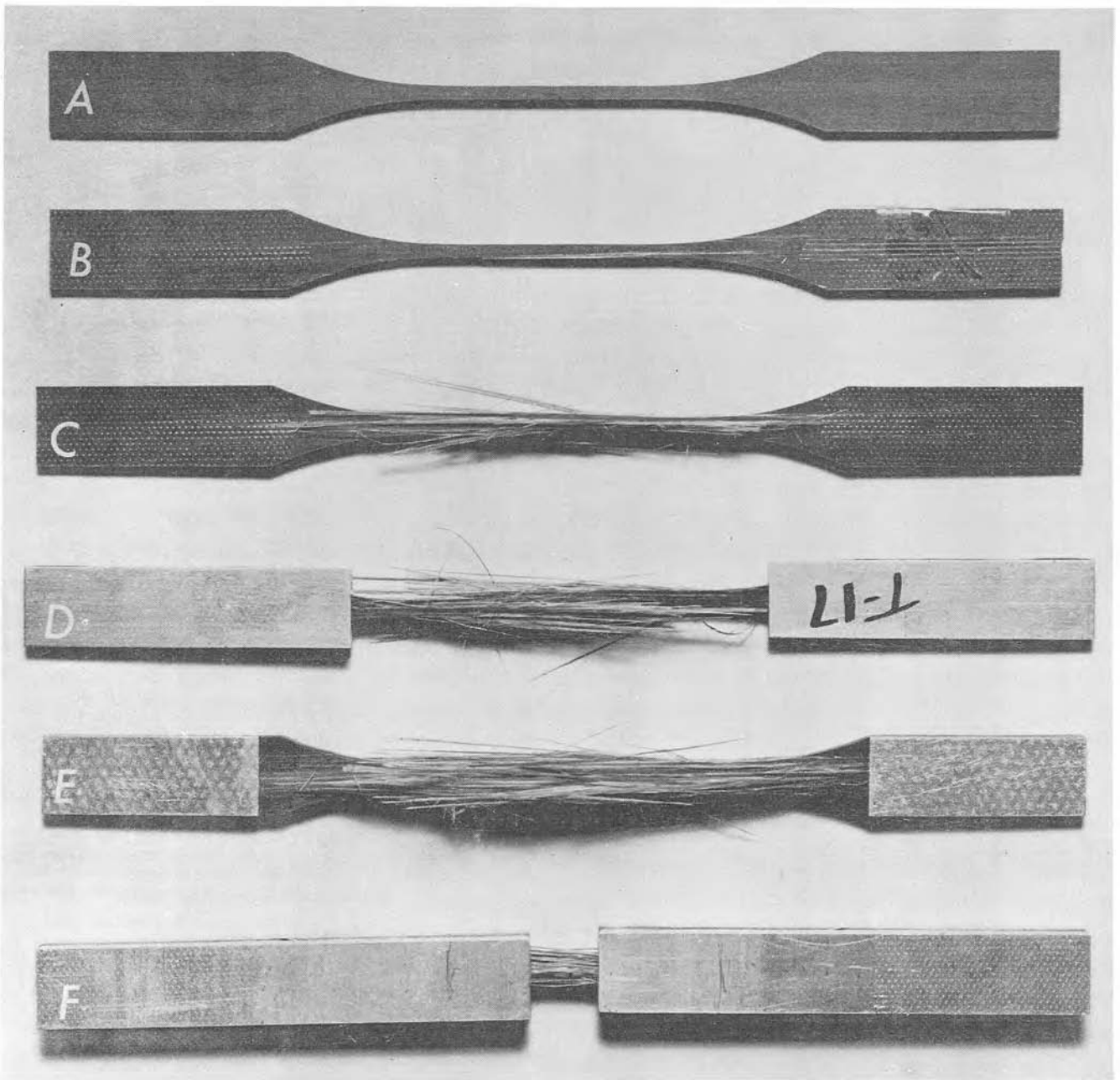
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Figure 7.--Untested specimens of various lengths used in evaluating the effect of shank length on specimens with 1/8- mid 1/4-inch-net width section.



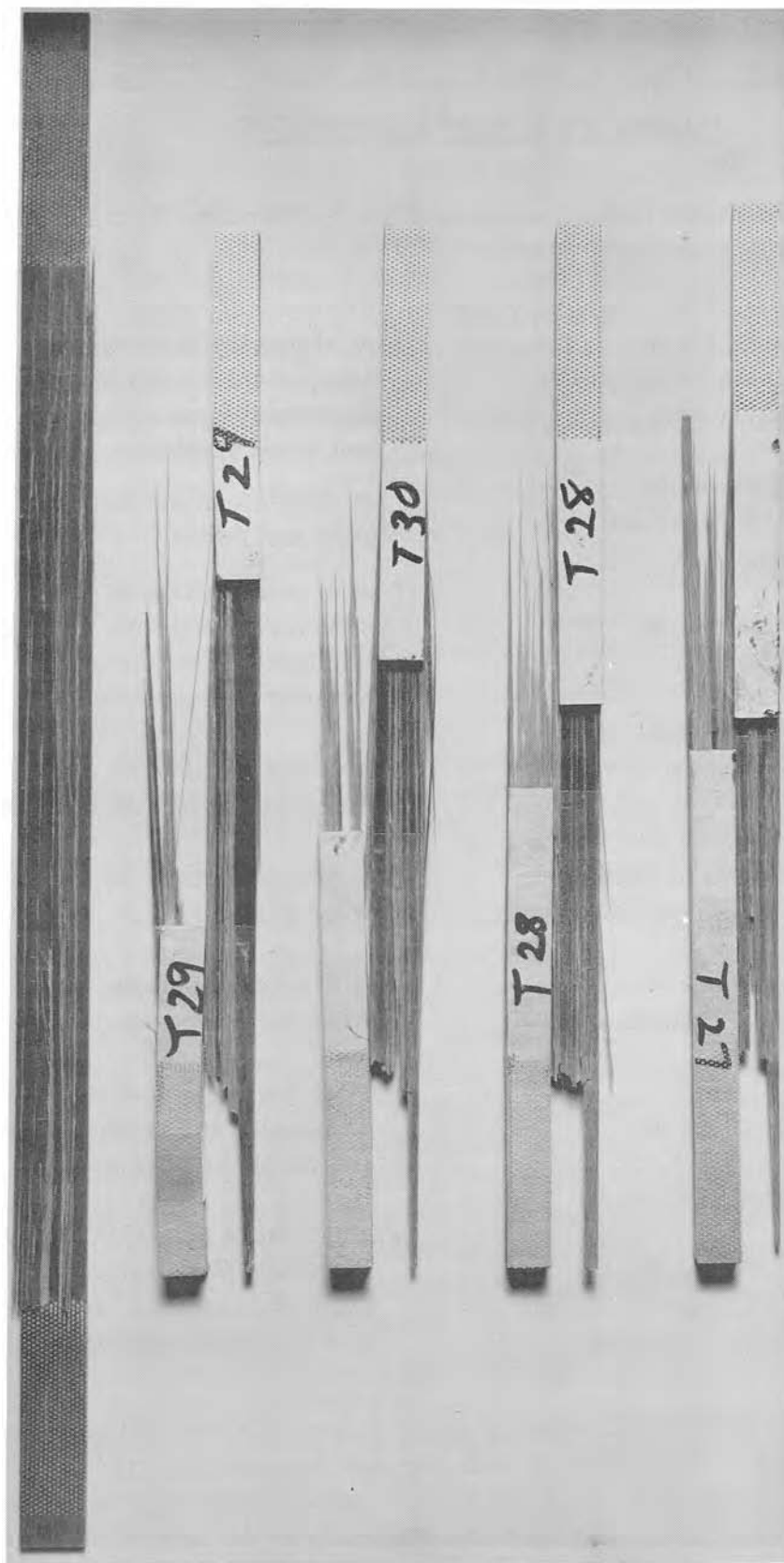
Z M 125 439

Figure 8.--Typical failures observed on various length specimens with 1/8- and 1/4-inch-net width sections.



Z M 125 440

Figure 9.--Methods used in reinforcing shank areas and resultant failures of specimens with 1/8- and 1/4-inch-net width sections: A, B, C, standard specimens 9-3/8 inches in length with 1/8-inch-net width section; D, E, standard specimens 9-3/8 inches in length with 1/8- and 1/4-inch-net width sections, and with aluminum end reinforcement; F, specimen 9-3/8 inches in length with 1/4-inch-net-width section and extended aluminum end reinforcement.



Z M 125 438

Figure 10.--Straight-sided specimens with various lengths of 3/16-inch-aluminum reinforcement, showing failures observed.

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