CREEP TESTS OF SANDWICH CONSTRUCTIONS SUBJECTED TO SHEAR AT NORMAL TEMPERATURES

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In Cooperation with the University of Wisconsin

CREEP TESTS OF SANDWICH CONSTRUCTIONS SUBJECTED TO SHEAR AT NORMAL TEMPERATURES[1]

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Summary

Curves showing the stress level plotted against the duration of constant shear stress (figs. 1, 2, and 3) were obtained from tests of sandwich constructions using seven-ply glass-cloth faces and cores of cellular cellulose acetate, honeycomb glass fabric, and paper honeycomb. Inconclusive data from tests of the construction using cellular-hard-rubber core are given in figure 4. The duration of stress was limited to about 200 hours.

The relationship between the total strain and the duration of stress for each test is shown by the curves in figures 5 through 27.

Introduction

The U. S. Forest Products Laboratory, in cooperation with the Engineering Division, Air Materiel Command, undertook this study of creep in sandwich constructions subjected to constant shear at normal temperatures to attain two major objectives, namely:

1. The determination of the rate of relative motion between the faces of sandwich constructions subjected to constant shear; and
2. The determination of the time elapsed from the application of a constant shear load to the failure of the material.

The study includes tests for the creep in each material when subjected to constant shear stress, the strength and the modulus of rigidity in shear, the

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strength in tension normal to the facings, and the strength in edgewise compression. The sandwich materials were limited to four constructions, each using facings of glass-cloth laminate and a core of either cellular cellulose acetate, glass-fabric-base honeycomb, paper honeycomb, or cellular hard rubber. All specimens were brought to equilibrium conditions and tested at a temperature of 75° F. and a relative humidity of 64 percent.

Materials

Four sandwich panels were fabricated at the Forest Products Laboratory using the techniques described in Forest Products Laboratory Report No. 1574, "Fabrication of Lightweight Sandwich Panels of the Aircraft Type," June 1947. The facings of the panels were each made of seven plies of glass cloth 112-14. The plies filled with a polyester laminating resin were built up on the cores, and the assemblies were then cured under pressure for 1 hour at 225° F. to produce the sandwich panels. Additional details in the construction of each panel are as follows:

Panel 1.--The core of panel 1 was made of cellular cellulose acetate with a density of 6.66 pounds per cubic foot. The material was purchased in the form of extruded strips about 5 inches wide. The surface crusts were removed from the strips as the material was trimmed and cut on a band saw to a thickness of 0.465 inch. These strips were then edge-glued with an intermediate-temperature-setting phenol resin to make a core slab 30 inches square.

The sandwich was formed between wood-blanket cauls in a hot press that maintained a pressure of 15 pounds per square inch throughout the curing period. The final resin content of the faces was 55 percent by weight and the over-all density of the sandwich was 16 pounds per cubic foot.

Panel 2.--The core of panel 2 was made of glass-fabric-base honeycomb with nominal 1/4-inch cells and a density of 5.85 pounds per cubic foot. This material was purchased in the form of a block approximately 3 inches thick and 18 inches wide. Sections 0.475 inch thick were cut perpendicular to the length of the cells. As these sections were subsequently laid up on one facing of the panel, 117 grams (20 percent of the original weight of the core) of a polyester laminating resin were added to the core to improve the bond between core and facings. The second facing of the panel was immediately built up to complete the assembly.

This assembly was then cured between wool-blanket cauls in a hot press at 15 pounds per square inch for 1 hour. When the panel was completed, the resin content of the glass-cloth facings was 53 percent by weight and the over-all density of the sandwich was 16 pounds per cubic foot.

Panel 3.--The core of panel 3 was paper honeycomb made at the Forest Products Laboratory from 4.5-mil kraft paper as described in the above-mentioned Forest Products Laboratory Report No. 1574. It was cut to a thickness of 0.465 inch. At the time the elements of the sandwich were assembled, 127 grams (17 percent of the weight of the core) of a polyester laminating resin were added to the core to improve the bond between core and facings.

The assembly was pressed at 15 pounds per square inch between wall-blanket cauls in a hot press. When the panel was completed, the resin content of the facings was 54 percent by weight and the density of the sandwich was 17 pounds per cubic foot.

Panel 4.--The core of panel 4 was cellular hard rubber weighing 7.93 pounds per cubic foot. This material was purchased in the form of cast slabs. Strips from which the surface skin had been removed were edge-glued to make a core 0.460 inch thick by 30 inches square. Both faces of the core were given a brush coating with a solution of benzoyl peroxide, water, and alcohol and allowed to dry. The core and the glass-cloth facings, saturated with a polyester laminating resin, were then assembled.

This assembly was cured by the bag-molding method, using a vacuum of 25 inches of mercury. When the panel was completed, the resin content of the facings was 50 percent by weight and the density of the sandwich was 18.0 pounds per cubic foot.

Each of the four completed panels was cooled with both faces exposed to air at room temperature for 24 hours or more before it was marked and cut into specimens.

Marking and Matching

The system of marking specimens was similar for all four sandwich panels (fig. 28). Columns 2 inches wide by the dimension of the panel were laid out parallel to one edge of the panel and assigned consecutive numbers. Specimen blanks 2 inches wide by 6 inches long within each column were numbered in rows across the columns. Thus the column number and the row number were sufficient to identify each blank in a panel. Specimen blanks for the shear-creep test were marked with a T, specimens for the shear-strength test were lettered M, compression-test specimens were marked with a c, and specimens for the tension test were marked with a t. For example, a specimen for a compression test from column 3, the fourth row, was marked 3c4. The panel identification was added, i.e., the identification symbol became 3c4-Pl2 if the specimen was from the second panel. Alternate specimens were selected for the shear-creep test and the shear-strength test so that the material in these specimens would be closely matched. Also, defective material was avoided by choosing the location of the specimens as follows:

Panel 1.--Streaks of granular material and of cavernous material parallel to the direction of extrusion of the cellular-cellulose acetate material were quite obvious in the core of panel 1, where the granular streaks appeared dark.

Columns were marked parallel to these streaks to obtain material as uniform as possible throughout the lengths of the columns. Blanks within each column were then alternated between strength-test specimens and creep-test specimens (fig. 28 and table 1, cols. 2 and 5). The average strength of the shear-test specimens within a column was assumed to apply to the shear-creep specimens taken from the same column.

Panel 2.--The layout of the various specimens was slightly irregular to avoid nonuniform material, which was made apparent by transmission of light through the sandwich to show the location of joints and of various irregularities in the core. The 2- by 6-inch blanks were cut down to 1 by 6 inches to make the specimens to be loaded in shear, and the irregularities apparent in certain blanks were not included in the material tested. The average of all the values of shear strength obtained was assumed to apply to the creep specimens cut from the panel (table 1, cols. 2 and 5).

Panel 3.--The core material of this panel appeared quite uniform, and the only irregularities noted and avoided were the joints in the core. However, the glue spread appeared not to be uniform, and, therefore, the average strength of the three or four shear-test specimens adjacent to a creep-test specimen was assumed to apply to the creep-test specimen (table 1, cols. 2 and 5).

Panel 4.--The layout of specimens and the location of joints in this core were similar to those of panel 1, illustrated in figure 28. The average of all the values obtained from the shear-strength tests was assumed to apply to the shear-creep specimens, as in panel 2 (table 1, cols. 2 and 5).

Methods of Test

Figure 29 is a sketch of the type of specimen used for both the shear-strength tests and the shear-creep tests. The facings were cut with the projections shown. The deformation apparatus was attached to these projections as subsequently described. The specimens were glued to steel bars as shown in figure 30. The 5/8-inch holes near the opposite ends of the bars were reamed with a taper from both ends to 1/32 inch from the center to produce a bearing surface at the center 1/16 inch wide. Bolts 1/2 inch in diameter were inserted in these holes and used with a yoke to apply tensile loads. The holes were located so that the line of the force applied passed diagonally across the core of the specimen, as shown in figure 30.

The method of measuring strain is illustrated in figures 31 and 32. At the center of each side of the specimen two projections of the facings were sprung slightly to hold a small plate, sharpened at its edges, which supported a mirror. Relative motion between the facings rotated each plate and mirror. To make it possible to compensate for movement of the system as load was applied, for movement of the light source, for movement of the scale, or for other similar disturbances, a third mirror, mounted on the loading bar, was used as a reference. The three simultaneous images of a cross hair in the projector were read on the scales less than 20 seconds after load was applied and periodically thereafter. The distances between the image from the reference mirror and those from the rotating mirrors were measures of the relative displacements of the two facings. The shear strains were computed by dividing these displacements by the thickness of the core.

The apparatus for maintaining constant load in the shear-creep test is shown with a specimen under test in figure 31 (specimen is circled). By proper relationship between the radius of the bolts (A) bearing on the loading strap (B) and the radius of the block (C) bearing on the weighted strap (D), a constant load was obtained on the specimen independent of the position of the lever (E). Load was applied as follows: With the lever (E) supported on a hydraulic jack the dead weight (F) was hung on the strap. The turnbuckle (G) was then tightened to take up the slack in the loading strap. The hydraulic jack was lowered and the lever became suspended on the loading strap in about 10 seconds. This constant load was maintained until failure occurred. Beneath the lever (E) and independent of the frame are "catchers" (H) equipped with push-button switches that stop electric clocks (J) when failure occurs. The a.m. or p.m. time and the day were indicated by the distance between the two small lead shot (K) mounted on a thread hung over the shaft for the hour hand of the clock in use.

In the shear-strength test a four-screw mechanical testing machine was used to apply tension with the head moving at a rate of 0.01 inch per minute.

Compression-edgewise specimens were tested with lateral support at the ends provided by pairs of 3/8-inch-square bars bolted to a snug fit across the faces. A Marten's mirror apparatus was used to measure strain.

Tension tests for maximum load were made by gluing 1-inch aluminum cubes to the faces and loading through self-alining pins.

Both the tension and the compression tests were made in accordance with the methods described in Forest Products Laboratory Report No. 1556, "Tentative Methods for Conducting Mechanical Tests of Sandwich Constructions," December 1946.

Results and Analysis

The results of this study are presented in the form of a summary in table 1, in the form of curves showing stress level plotted against time to failure (figs. 1 through 4), and in the form of curves for each test showing shear strain plotted against duration of stress (figs. 5 through 27).

Table 1.--Results of compression tests, tension tests, shear-strength tests, and pertinent data from creep tests are tabulated for each sandwich construction in table 1. These strengths are briefly compared on the basis of the core materials as follows:

Core material	Average strength in p.s.i.		
	Edgewise compression	Normal tension	Shear
Cellular cellulose acetate	21,500	120	95
Glass honeycomb	21,600	360	260
Paper honeycomb	17,900	385	325
Cellular hard rubber	21,500	225	125

The edgewise compressive strength tabulated in column 10 of table 1 was computed by dividing the maximum load by the cross-sectional area of the facings. Similarly, in computing the modulus of elasticity in compression (col. 11) by the formula $E = \frac{P}{A\epsilon}$, the area (A) is the cross-sectional area of the facings.

P is a load and ϵ is the corresponding strain from the straight portion of the curve. Tensile strength normal to the plane of the panel (col. 13) was computed by dividing the maximum load by the gross cross-sectional area of the core material.

The tensile strengths of specimens and the variations in tensile strength within a given panel are indications of the quality and of the uniformity of the core material. For example, in panel 1 (cellular-cellulose-acetate core) the tensile strengths given in column 13 vary from 87 pounds per square inch to 166 pounds per square inch, and thus indicate a nonuniform core material. In panel 2 (glass honeycomb core) the variation is from 337 pounds per square inch to 390 pounds per square inch and indicates a fairly uniform material. Panel 3 (paper honeycomb core) has one value of 308 pounds per square inch, and the other four vary from 395 to 422 pounds per square inch. The cellular-hard-rubber core in panel 4 varied in tensile strength from 171 to 278 pounds per square inch, and the failures in this material occurred generally in a plane parallel to the faces and less than one-eighth inch from the surface. Within a given panel the variations in tensile strength were similar to those in shear strength.

Values of shear strength and modulus of rigidity also indicate the quality and the uniformity of the core material. The nonuniformity indicated by the tensile strengths of panel 1 is also indicated by the shear strengths obtained from that panel. They varied from 80 to 113 pounds per square inch, as shown in column 7. The shear strengths for panel 2 were quite uniform. Panel 3 gave an occasional specimen having a shear strength about 20 percent lower than the average. The strength of shear specimens from panel 4, cellular-hard-rubber core, varied from 51.7 pounds to 149.4 pounds per square inch. Failures of the rubber material frequently were on a plane parallel to the face and less than 1/8 inch from the surface. Only occasionally failures ran through the cellular-rubber core at about 45° to the plane of the facings. Several specimens, not tested, were damaged in sawing with the facings being loosened by failure of the core near the surface. It is possible that damage occurred during fabrication or cutting of some of the specimens tested and that it was not detected and caused the strength values of these specimens to be extremely low.

The pertinent data from the shear-creep tests include the percentage of control strength (col. 1) at which the specimens identified in column 2 were stressed. The magnitude of this constant stress is given in column 3. The duration of the constant stress either to failure or to termination of the test, is given in column 4. In column 5 is given the identification of the control specimens whose average strength was multiplied by the percentage given in column 1 to obtain the constant stress given in column 3. For example, in panel 1 line 1, the control strength for specimen 3-2 was obtained by averaging the strengths of specimens identified in column 5 (3M1 and 3M3). This average multiplied by the 90 percent given in column 1 gave the constant stress of 85.4 pounds per square inch given in column 3. For panel 2 the same control strength was used for all creep-test specimens (259.5 pounds per square inch), and was obtained as shown in column 5 by averaging the values for all specimens tested for shear strength. For each specimen the control strength was multiplied by the percentage given in column 1 to determine the constant stress.

The percentage of strength given in column 1, hereafter called the "stress level," was varied in an attempt to cover a range such that the relationship between the stress level and duration of stress (figs. 1-4) would be defined from 50 to 200 hours.

Stress level-duration curves.--The stress level is plotted against the time to failure for the different core materials in figures 1 to 4, inclusive. The stress level is plotted on a uniform scale and the time to failure on a logarithmic scale. In general, a straight line with a slight negative slope fits the plotted points reasonably well. The slope of the line for each core material cannot be accurately determined, however, because of the variations, previously referred to, in the strength of the materials. For example, reading to the straight line in figure 1, a change in stress level from 80 to 77 percent causes a change in duration from 50 to 200 hours. An error of less than 4 percent in the estimated strength of the creep specimens would account completely for this change in duration. The scatter of the plotted points roughly indicates the error in the estimated strength of the creep specimens. In figure 1 the slight scatter indicates an accurate estimate of strengths and a reliable curve. The moderate scatter in figures 2 and 3 indicates that the estimated strengths were slightly inaccurate, but the points show a trend and are adequate to determine a curve. The extreme scatter in figure 4 indicates that the variations between the specimens for strength tests and the specimens for creep tests were large. The scatter obscures any trend that might be present and, therefore, a curve was not drawn.

A comparison of the performance of the sandwich constructions may be made on the basis of the curves drawn, as follows:

Core material	Stress level to produce failure: At 50 hours	Stress level to produce failure: At 200 hours
	Percent	Percent
Cellular cellulose acetate	80	77
Glass honeycomb	62	57
Paper honeycomb	70	66

To make a comparison of unit stresses, these stress levels should be multiplied by the shear strengths of the various materials.

Strain-duration of stress curves.--These curves, one for each creep test made, are shown in figures 5 to 27, inclusive. Zero time is taken as the time at which the strain was read after constant stress was fully applied. The strains given are the total values, including both elastic and plastic strains. Information on each curve identifies the specimen and gives the value of the constant stress and its duration to failure. The last strain reading taken before failure and the time it occurred are shown by the circle at the end of each curve. The broken line from the circle to the vertical line, located at the time of failure, is an approximation. The range in time to failure at any one stress level was critically dependent on the accuracy of the control strength, as previously discussed.

The shapes of these curves are similar for all of the panels. They are roughly of an S shape and tangent, or nearly so, to the strain axis at zero time, and proceed concave downward to a point of inflection and continue concave upward to failure. However, some of the curves for cellular hard rubber indicate abrupt failure shortly after the point of inflection is passed. It might be considered that the failure of each specimen started when the strain reached the point of inflection. The position of this point is quite variable. For example, the strains at this point in figure 5 are approximately 0.025 inch per inch and occurred after 50 percent and before 60 percent of the time elapsed to failure. Curves for tests of this same material, cellular cellulose acetate, at other stress levels, figures 6 and 7, indicated smaller strains at a higher stress level, and slightly greater strains at lower stress levels. Similarly, the curves for glass honeycomb and cellular hard rubber pass through a point of inflection at total strains ranging from 0.020 to 0.030 inch per inch. In contrast, the curve for the construction with the paper honeycomb core passes through a point of inflection at total strains not exceeding 0.010.

A few specimens that failed after short durations of high stress, or as the stress was applied, were not plotted. For these specimens the time to failure is recorded in table 1.

Conclusions

The relationship between the duration to failure at constant stress and the magnitude of the stress expressed as a percentage of the strength is given by curves in figures 1, 2, and 3 for sandwich constructions with seven-ply glass-cloth faces and cores of either cellular cellulose acetate, glass-fabric-base honeycomb, or paper-base honeycomb. No relationship could be established from the points shown in figure 4 for the construction using the cellular-hard-rubber core.

Comparisons of the sandwich materials showed that the construction with cellular cellulose acetate was capable of maintaining the highest percentage of strength, and the one with paper honeycomb was the most rigid and was capable of maintaining the highest unit stress for any of the periods of time investigated.

The duration of constant stress to failure is extremely sensitive to the stress level at high percentages of the material's strength. To determine accurately the curves for stress level plotted against duration of stress to failure, a series of tests covering a wider range in stress level and greater duration of stress is necessary. Extreme care in obtaining uniform material and in matching the specimens for strength tests with the specimens for creep tests is imperative.

Table 1.--Mechanical properties and shear-creep data obtained by tests of sandwich panels made of seven-ply glass-cloth faces and various cores

Obtained by shear-creep test					Shear-strength test			Compression tests (edgewise)			Tension test (normal to facings)	
Percent of control strength	Specimen number	Constant stress	Duration of stress	Control specimen numbers	Specimen number	Shear strength	Modulus of rigidity	Specimen number	Compressive strength (of facings)	Modulus of elasticity (of facings)	Specimen number	Tensile strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
		P.s.i.	Hr.			P.s.i.	P.s.i.		P.s.i.	1,000 p.s.i.		P.s.i.
					Panel 1 -- Cellular-cellulose-acetate core							
90	3-2	85.4	0.18	3M1, 3M3	2M4	95.84	4,577	2c1	22,604	2,563	2t1	87
90	3-4	85.4	.08	3M1, 3M3	3M1	92.69	5,306	6c3	21,138	2,359	2t3	126
90	4-1	76.8	.12	4M2, 4M4	3M3	97.10	5,047	2c3	23,178	2,290	6t3	107
85	8-1	80.4	2.98	8M2, 8M4	4M2	89.58	4,244	11c2	19,833	2,204	11t2	166
85	9-2	69.1	5.17	9M1, 9M3	4M4	81.22	4,470	11c4	20,728	2,388	11t4	cull
85	9-4	69.1	5.27	9M1, 9M3	5M1	112.30	7,259					
80	5-2	87.3	47.37	5M1, 5M3	5M3	105.96	5,832					
80	5-4	87.3	123.08	5M1, 5M3	6M2	109.98	6,235					
80	6-1	85.7	262.07	6M2, 6M4	6M4	104.34	6,505					
76	7-2	63.9	404.53	7M1, 7M3	7M1	84.69	4,230					
76	8-3	71.9	484.25	8M2, 8M4	7M3	83.42	4,729					
76	10-3	83.2	115.75	10M2, 10M4	8M2	95.41	5,755					
					8M4	93.78	5,582					
					9M1	80.09	4,080					
					9M3	82.57	3,880					
					10M2	105.74	4,941					
					10M4	113.33	5,259					
					11M3	81.51	4,005					
					Panel 2 -- Glass honeycomb core							
75	1-1	194.6	1.20		1M3	264.4	9,822	2c	19,739	3,104	2t	337
75	1-2	194.6	.83		2M2	242.0	8,299	4c	23,929	2,925	4t	355
75	2-3	194.6	2.32		3M1	245.2	9,984	5c	19,846	2,860	5t	355
75	3-3	194.6	4.83		4M3	262.8	7,925	6c	25,935	3,411	7t	390
70	4-1	181.6	8.18	All	5M2	256.3	7,989	9c	18,662	3,100	9t	375
70	5-1	181.6	.01	specimens	6M3	268.4	7,830					
65	2-1	168.7	79.32	tested	7M2	282.5	8,418					
65	3-2	168.7	306.40	for shear	8M1	264.2	8,501					
65	4-2	168.7	29.53	strength	8M3	266.7	10,258					
65	5-3	168.7	3.45		9M1	251.0	8,389					
60	6-1	155.7	65.28		9M3	251.1	8,623					
60	6-2	155.7	277.90									
60	7-1	155.7	38.83									
60	7-3	155.7	38.05									
57	8-2	147.9	218.47									
57	9-2	147.9	297.13									
					Panel 3 -- Paper honeycomb core							
80	0-1	279.8	4.13	0M2, 1M1	0M2	354.6	26,170	2c1	17,008	2,512	2t1	395
80	0-3	274.0	0	0M2, 0M4 1M3	0M4	326.0	25,469	2c3	18,978	3,111	2t3	415
80	1-2	277.1	0	0M2, 1M1 1M3, 2M2	1M1	345.0	26,796	6c3	17,692	3,004	6t3	308
80	4-3	259.0	0	3M3, 4M2 4M4, 5M3	1M3	346.8	24,639	11c2	16,917	2,685	11t2	422
80	7-2	252.1	1.57	6M2, 7M3 8M2	2M2	339.1	29,045	11c4	19,004	2,568	11t4	395
80	7-4	243.7	.63	6M4, 8M2 7M3	2M4	342.4	27,725					
80	9-2	256.2	.15	8M2, 9M1	3M1	342.4	26,908					
75	1-4	253.8	0	0M4, 1M3 2M4	3M3	330.7	25,988					
75	3-2	260.6	0	2M2, 3M1 3M3, 4M2	4M2	378.0	31,765					
75	3-4	248.7	0	2M4, 3M3 4M4	4M4	321.7	25,431					
75	5-2	240.5	20.35	4M2, 5M1 5M3, 6M2	5M1	315.9	23,952					
75	5-4	214.6	.88	4M4, 5M3 6M4	5M3	264.2	22,295					
75	8-1	240.2	12.30	8M2, 9M1	6M2	304.1	23,851					
75	9-4	214.6	23.52	8M4, 10M4	6M4	272.5	21,373					
70	4-1	241.8	150.60	3M1, 4M2 5M1	7M3	323.4	22,936					
70	6-1	217.0	12.77	5M1, 6M2	8M2	317.8	24,732					
70	8-3	208.0	25.53	7M3, 8M2 8M4	8M4	250.4	22,357					
65	10-1	216.1	128.62	9M1, 11M1	9M1	322.6	24,256					
65	10-3	214.0	127.48	10M4, 11M3	10M4	321.8	22,662					
					11M1	342.5	24,377					
					11M3	336.8	24,230					
					Panel 4 -- Cellular-hard-rubber core							
85	1-2	118.1	0		1M3	51.7	2,694	1c5	23,338	2,450	2t5	171
85	2-1	118.1	2.70		2M2	133.4	5,995	3c5	20,996	2,380	3t5	191
85	6-4	118.1	0		2M4	140.2	6,231	5c5	20,073	2,212	4t5	233
85	8-4	118.1	58.33		3M2	132.8	5,366	7c5	21,718	2,342	5t5	278
80	3-1	111.2	0	2M2	4M3	119.8	4,205	8c5	21,574	2,522	6t5	252
80	4-4	111.2	.01	2M4	6M3	145.1	5,423					
80	7-4	111.2	62.95	3M2	7M2	132.8	5,903					
80	8-2	111.2	670	6M3	8M1	117.4	4,191					
75	6-1	104.2	3.92	7M2	8M3	149.4	6,047					
75	7-1	104.2	.50	8M3								
75	7-3	104.2	38.40									
70	2-3	97.3	404									
70	3-3	97.3	335									
70	4-1	97.3	4.98									
70	5-2	97.3	0									

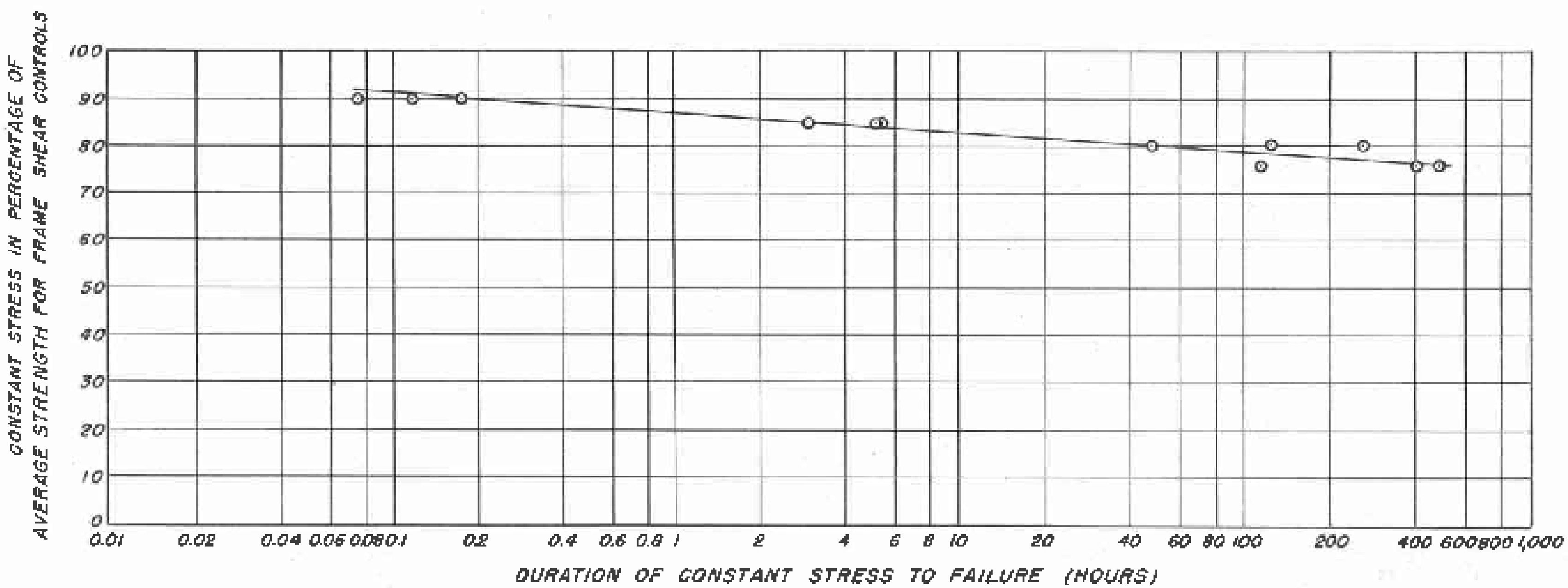

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Figure 1.--Curve and shear-creep-test data. Stress level plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-cellulose-acetate core). Shear was parallel to extruded direction of the core.

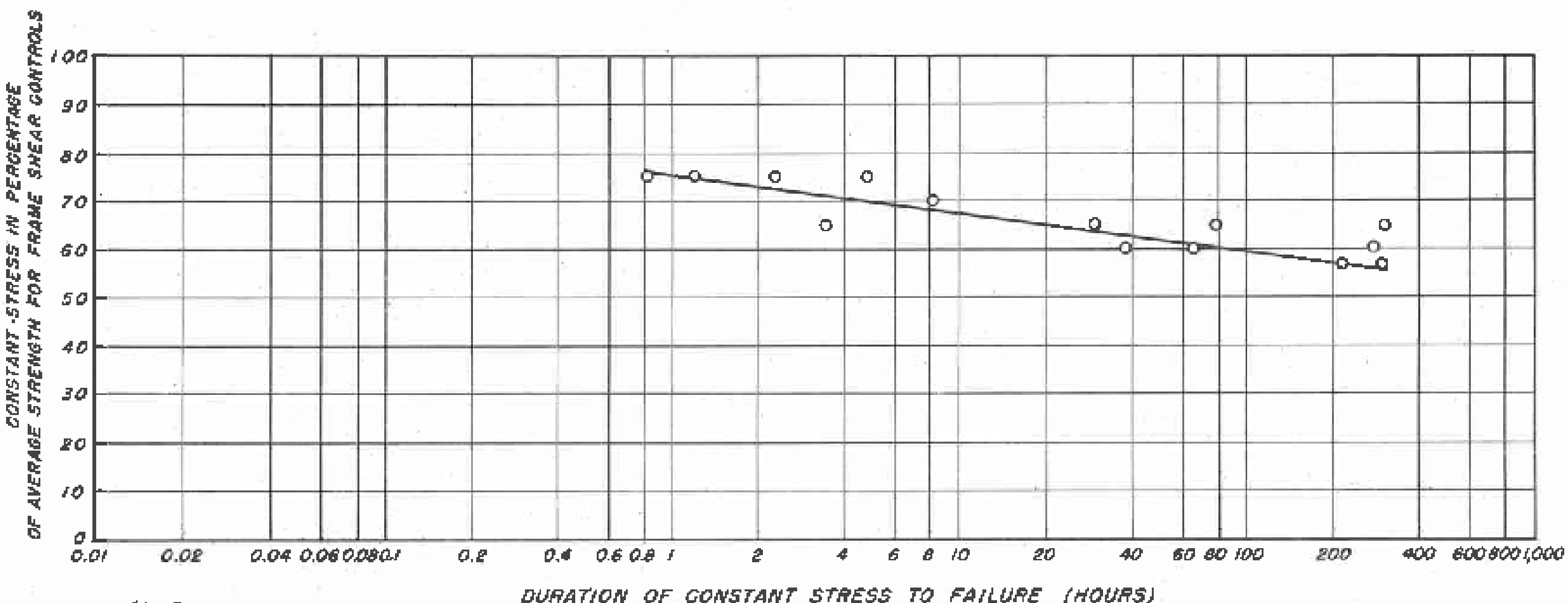

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Figure 2.--Curve and shear-creep-test data. Stress level plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core). Shear was parallel to LT direction.

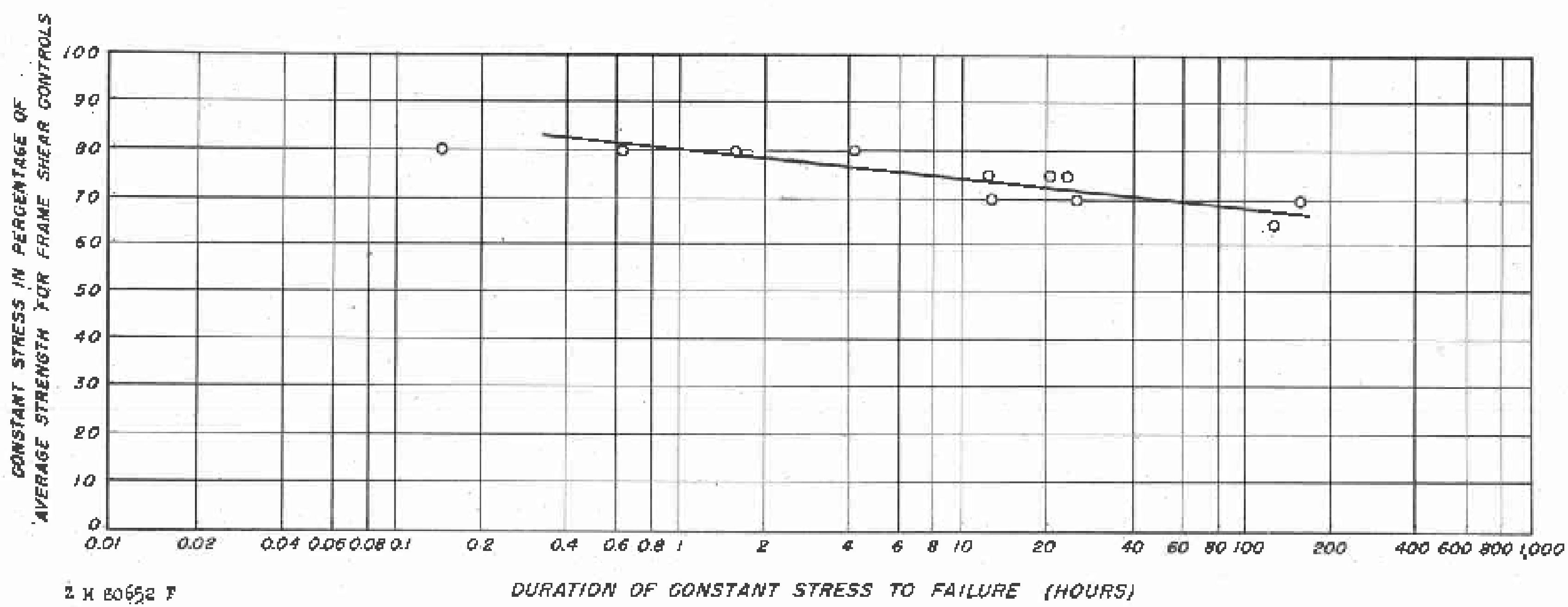

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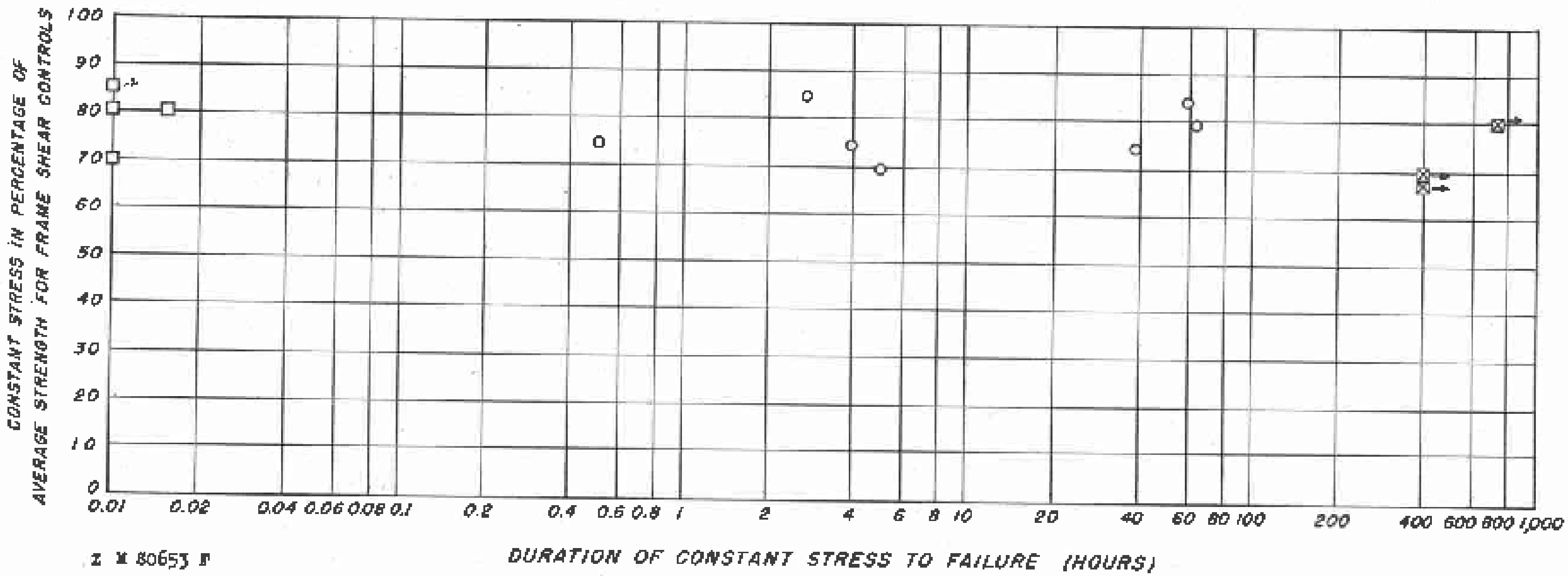
Figure 3.--Curve and shear-creep-test data. Stress level plotted against time to failure for sandwich material (seven-ply glass-cloth facings with paper-base honeycomb core). Shear was parallel to LT direction.



Z M 80653 F

Figure 4.--Shear-creep-test data. Stress level plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-hard-rubber core).

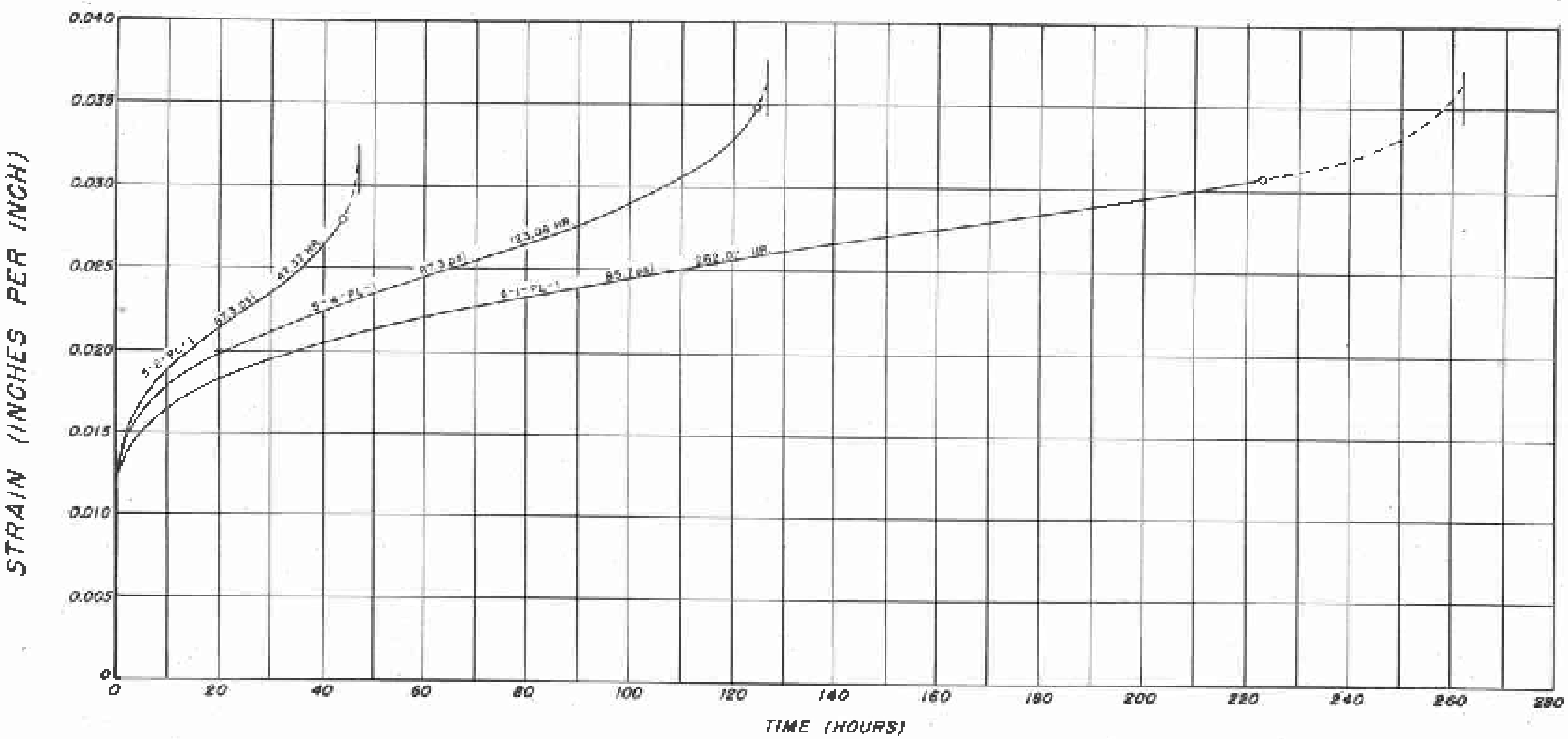
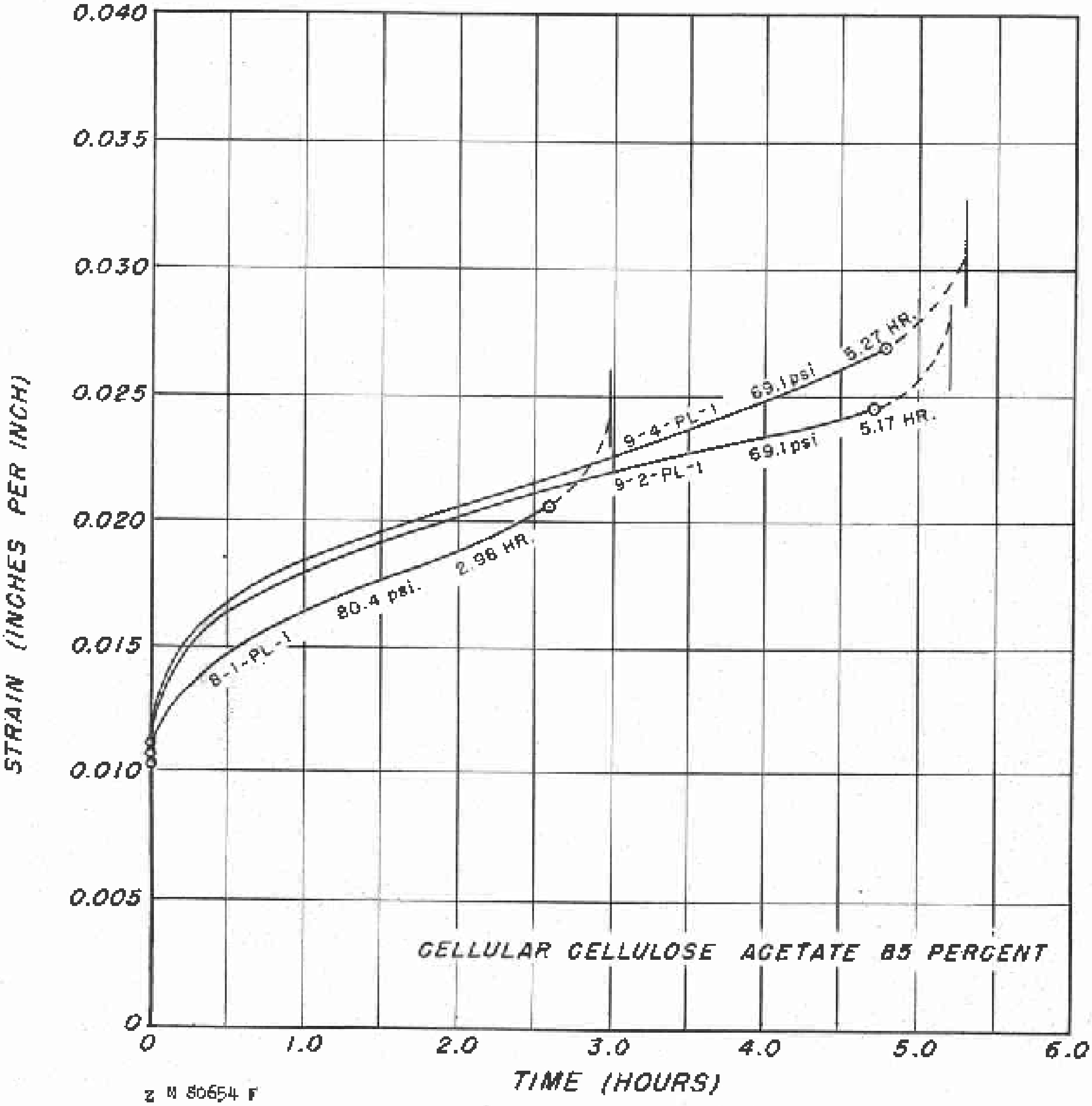


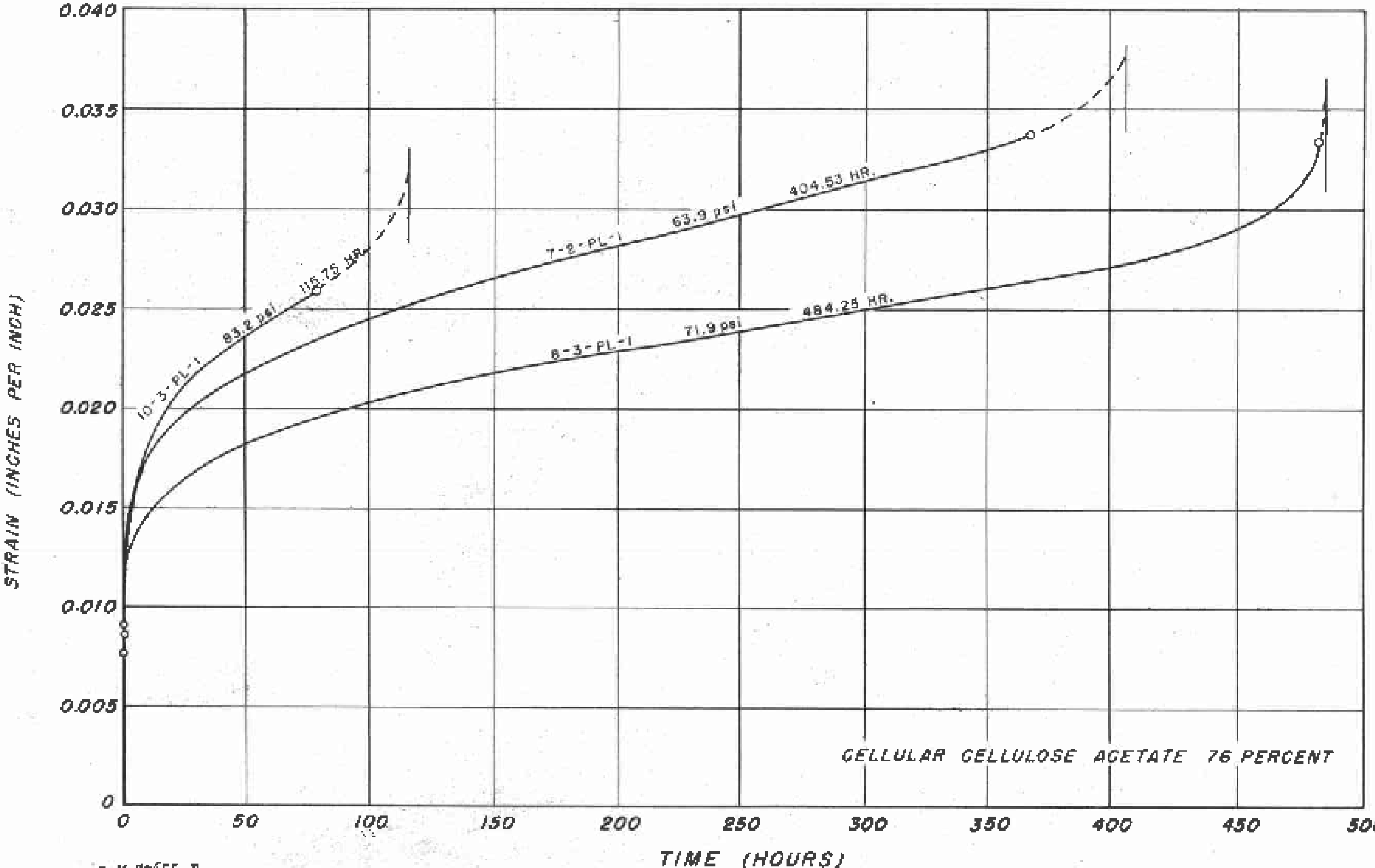
Figure 5.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-cellulose-acetate core) subjected to constant stress at 80 percent of the average ultimate stress of control specimens. Shear was parallel to the extruded direction of the core.

Z M 76242 F



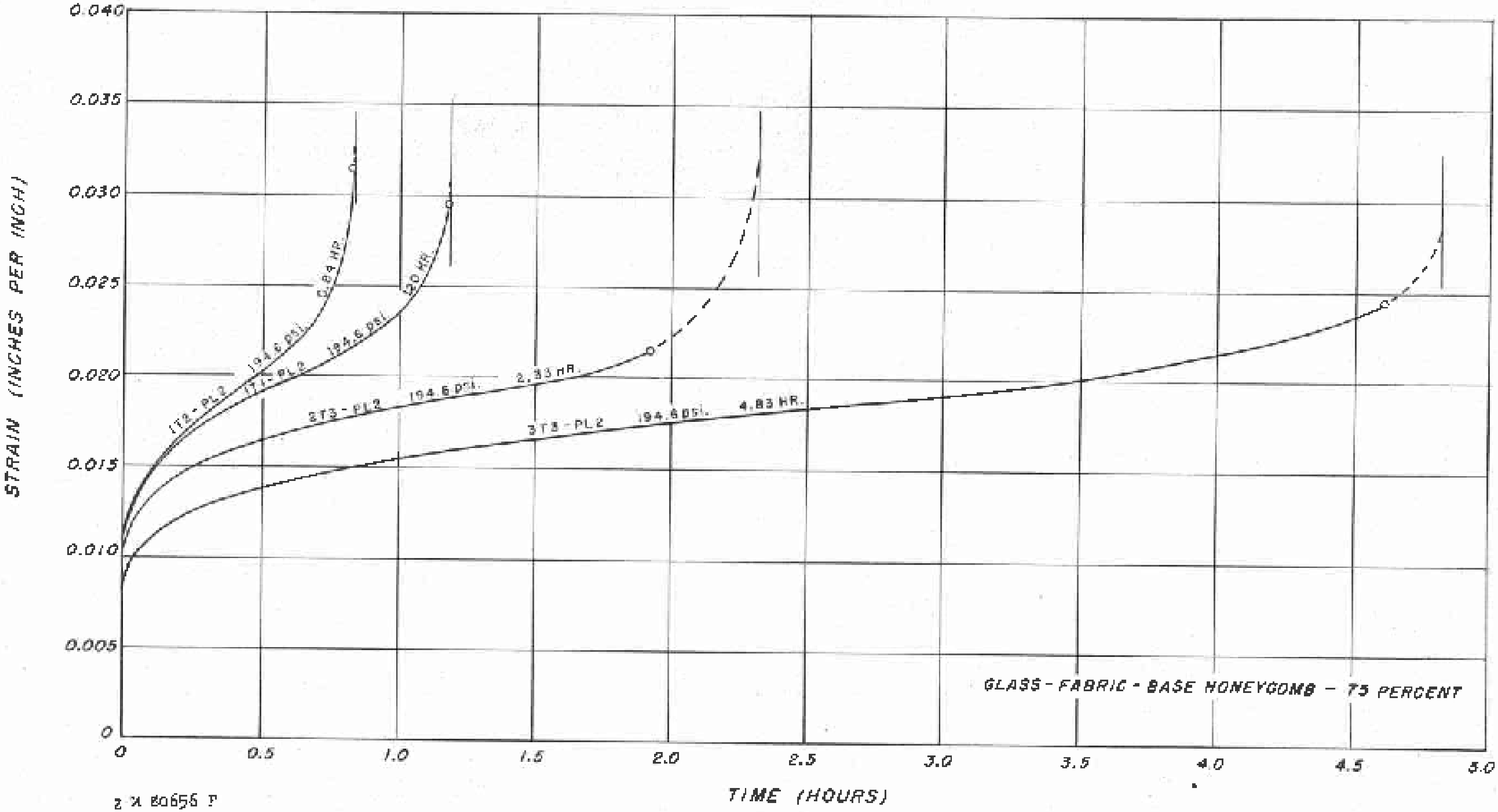
Z M 80654 F

Figure 6.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-cellulose-acetate core) subjected to constant stress at 85 percent of the average ultimate stress of control specimens. Shear was parallel to the extruded direction of the core.



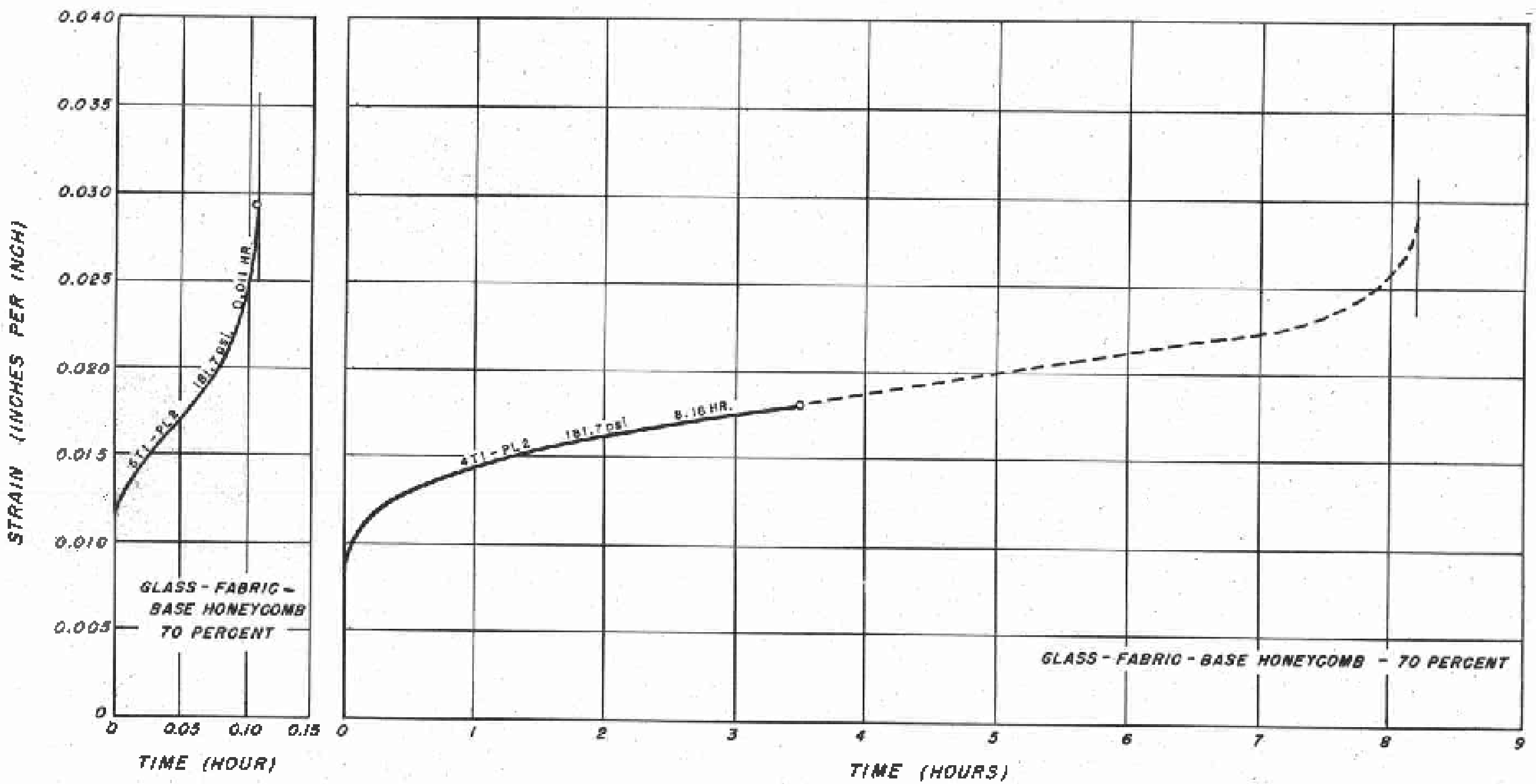
Z M 80655 F

Figure 7.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-cellulose-acetate core) subjected to constant stress at 76 percent of the average ultimate stress of control specimens. Shear was parallel to the extruded direction of the core.



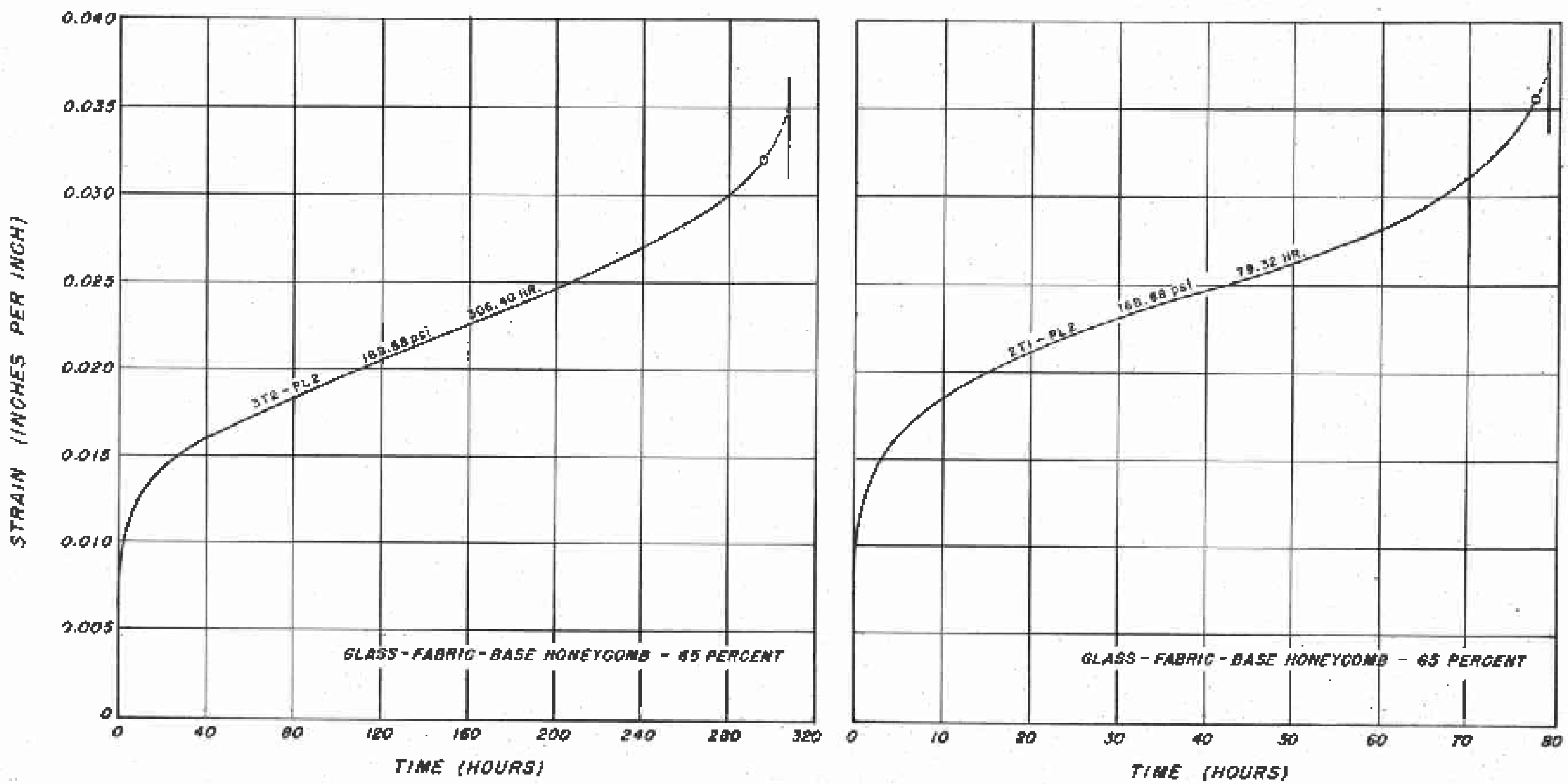
Z M 80655 F

Figure 8.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core) subjected to constant stress at 75 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.



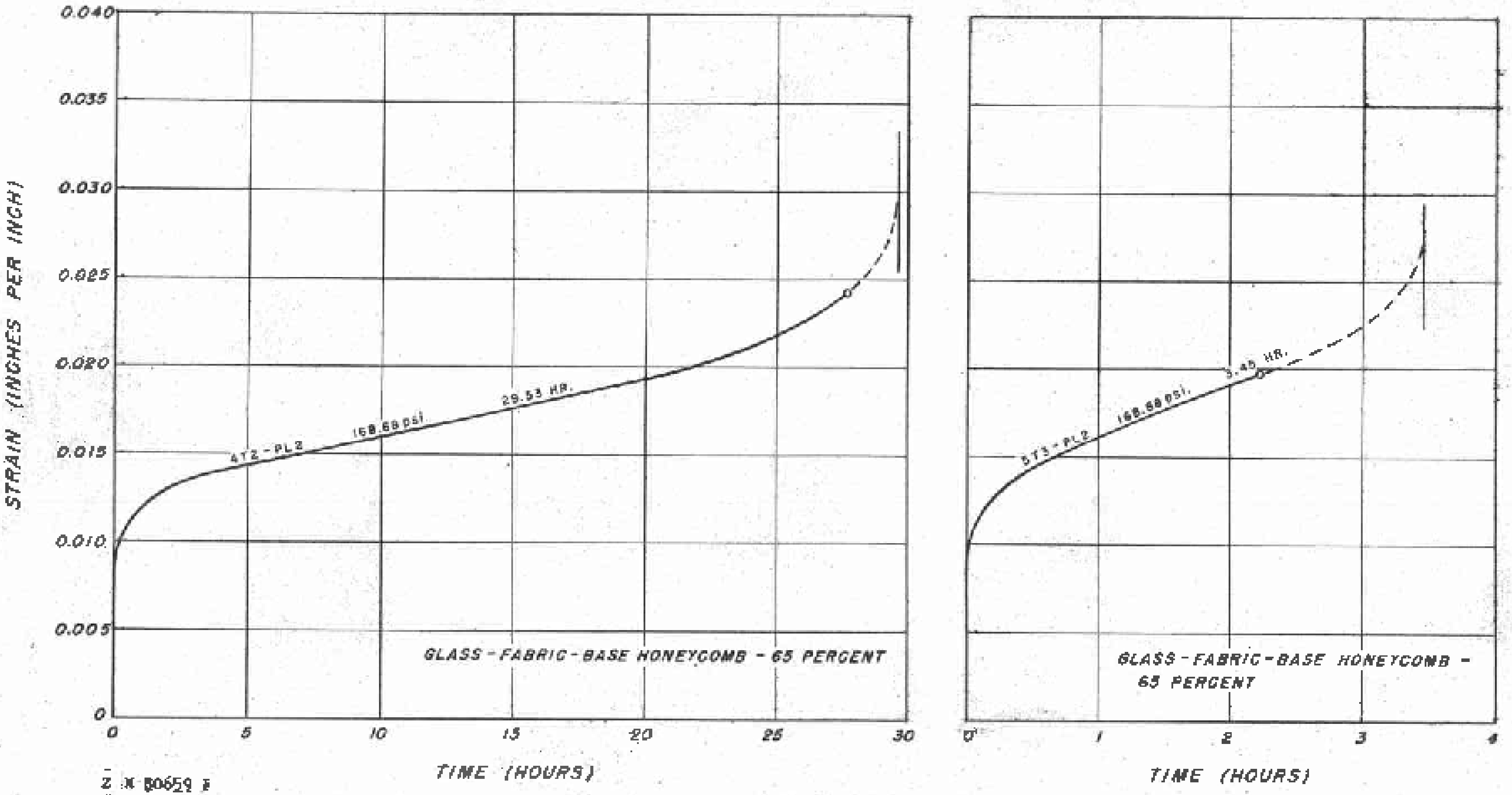
Z M 80657 F

Figure 9.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core) subjected to constant stress at 70 percent of the average ultimate stress of the control specimens. Shear deformation was in the LT plane of the core.



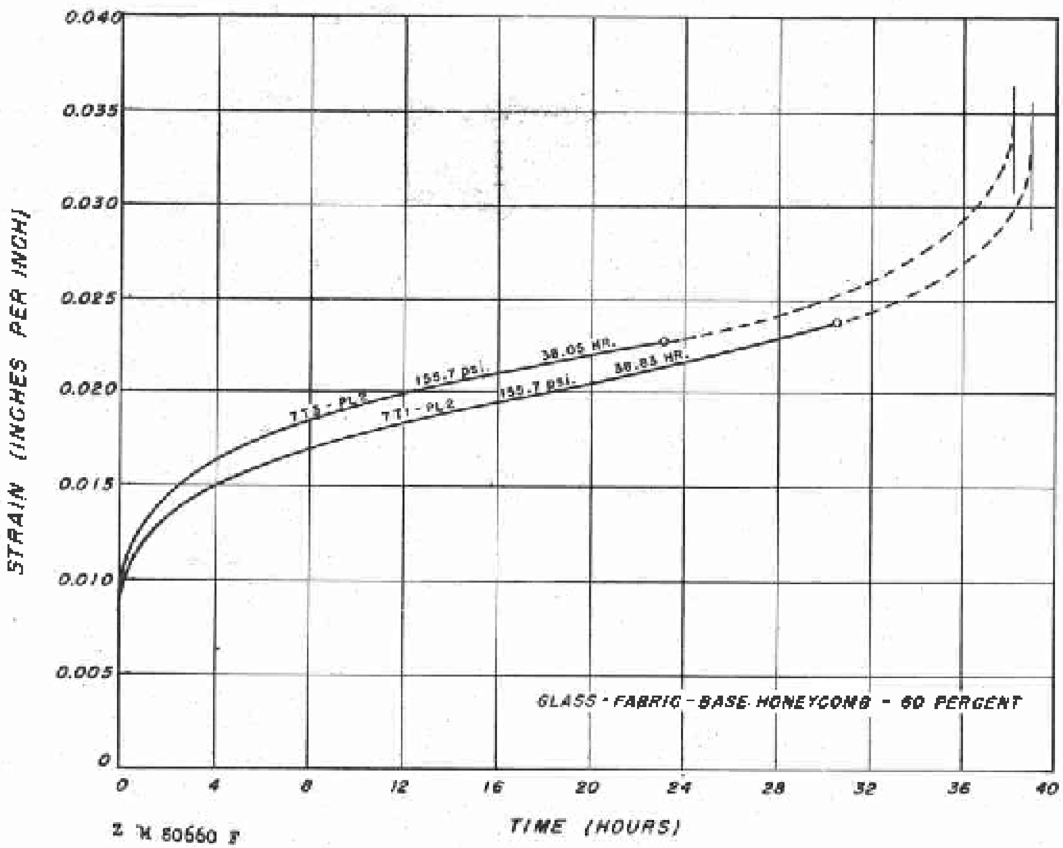
2 M 80658 F

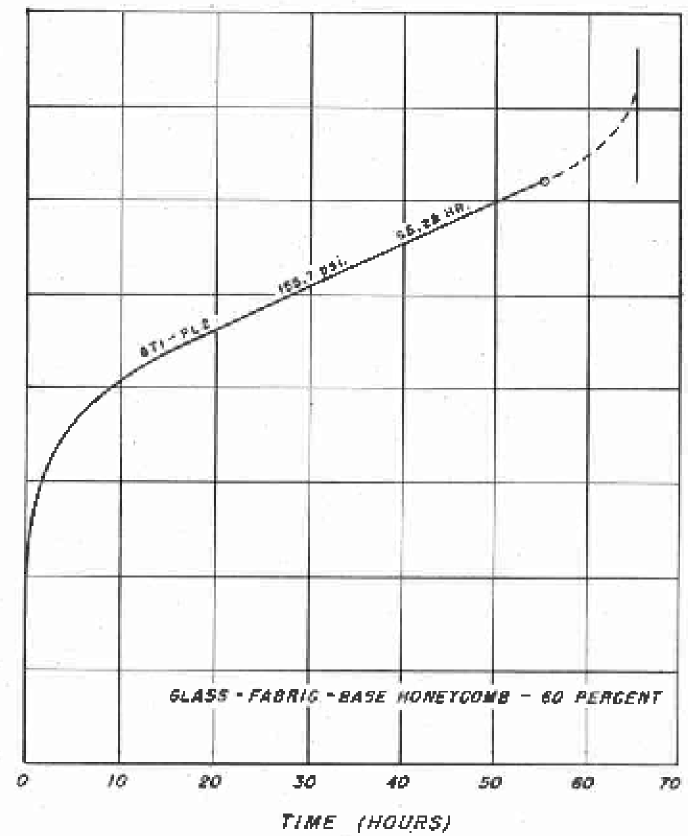
Figure 10.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core) subjected to constant stress at 65 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.



Z M 80659 F

Figure 11.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core) subjected to constant stress at 65 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.

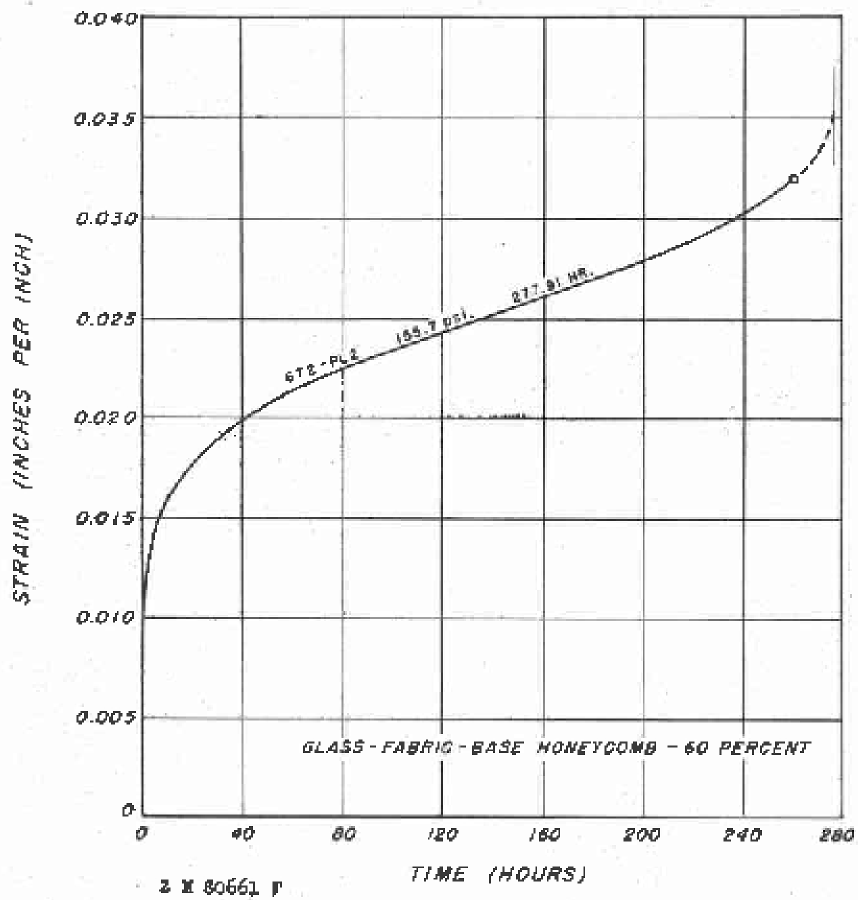


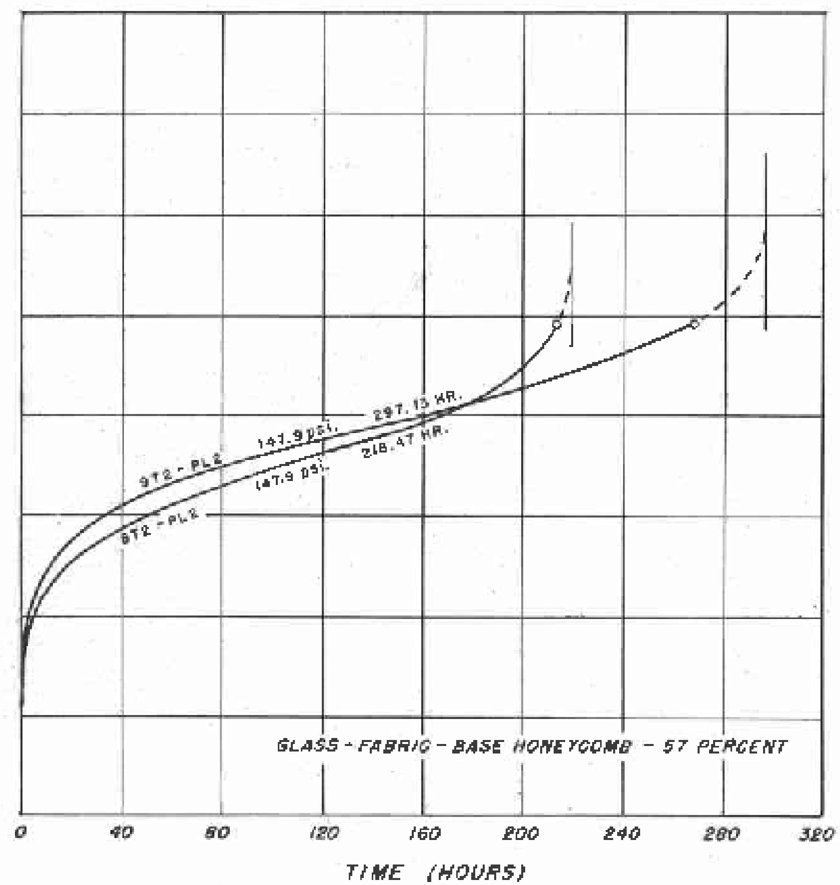


Z M 80660 F

Figure 12.(Left)--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core) subjected to constant stress at 60 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.

Figure 13.(Right)--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core) subjected to constant stress at 60 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.

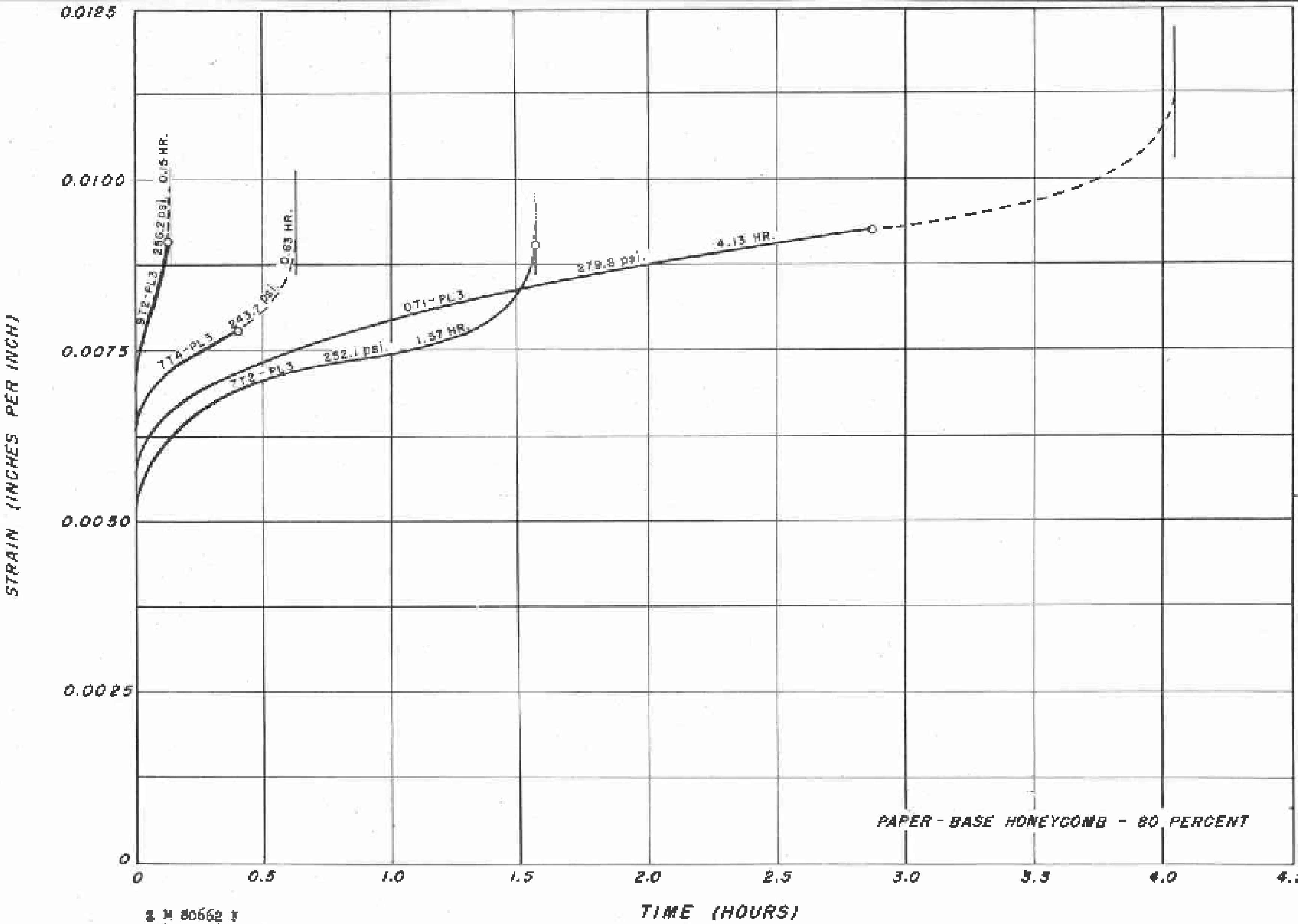




Z M 80661 F

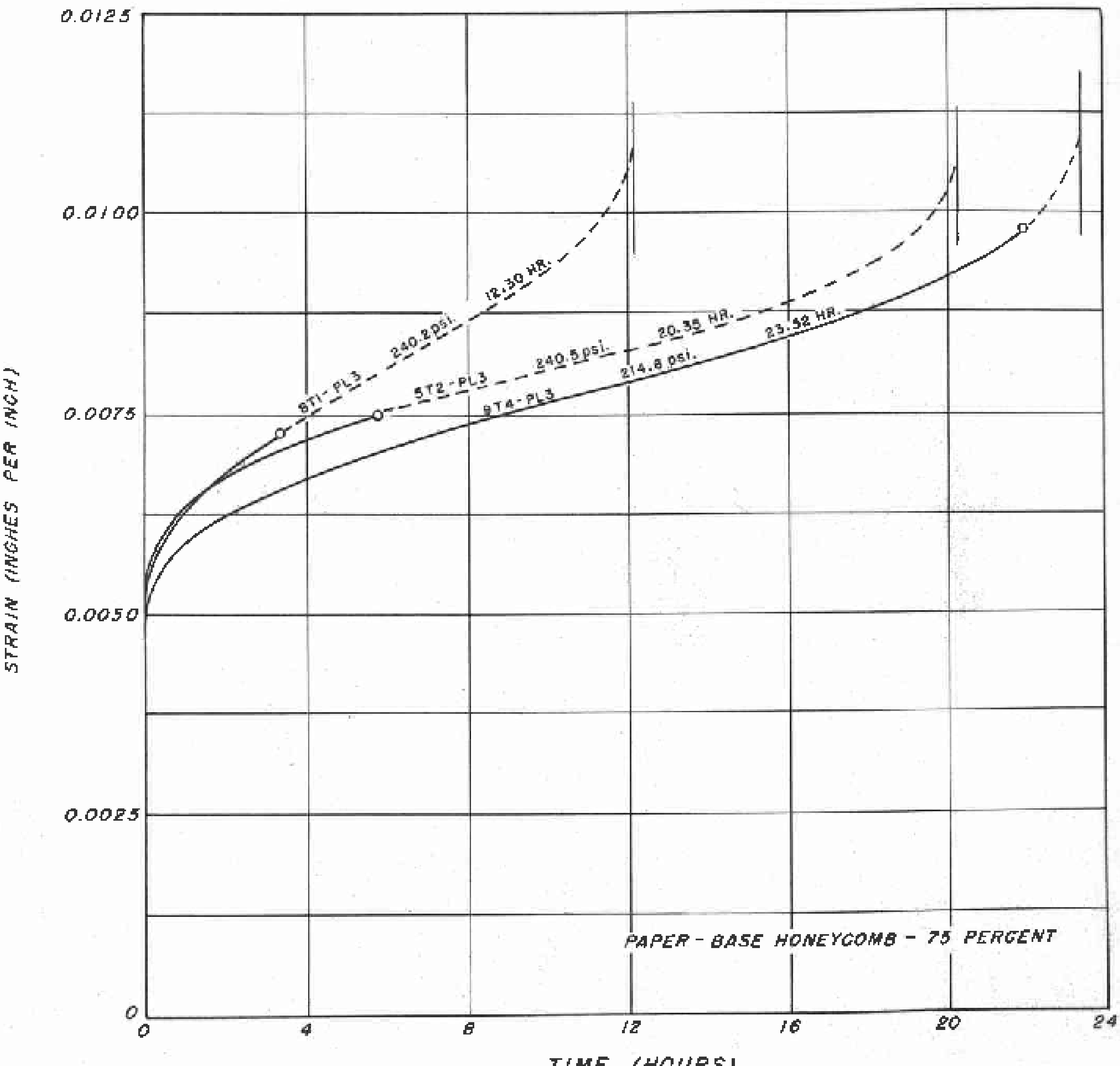
Figure 14. (Left)--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core) subjected to constant stress at 60 percent of the average ultimate stress of controll specimens. Shear deformation was in the LT plane of the core.

Figure 15. (Right)--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with glass-fabric-base honeycomb core) subjected to constant stress at 57 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.



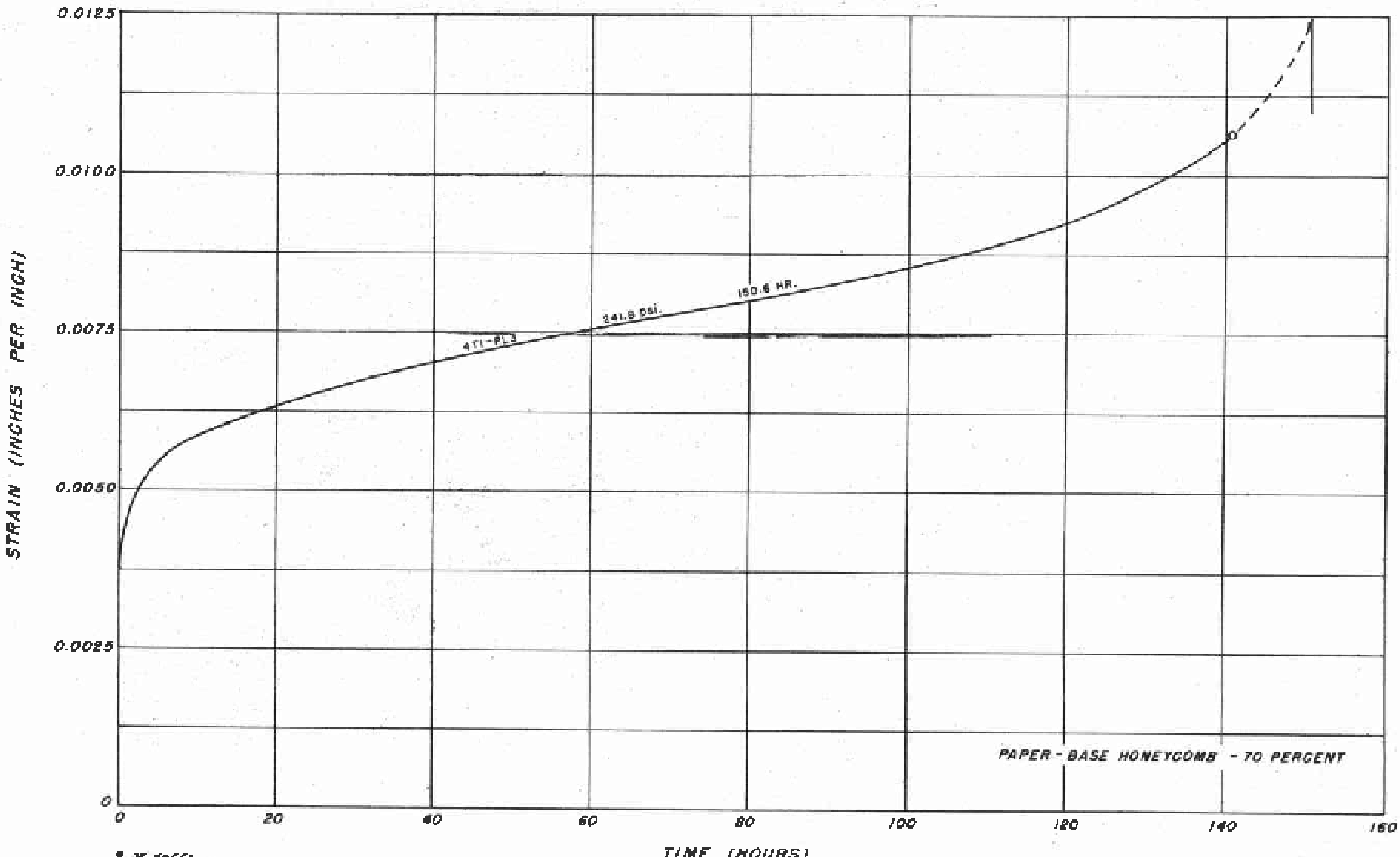
Z M 80662 F

Figure 16.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with paper-base honeycomb core) subjected to constant stress at 80 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.



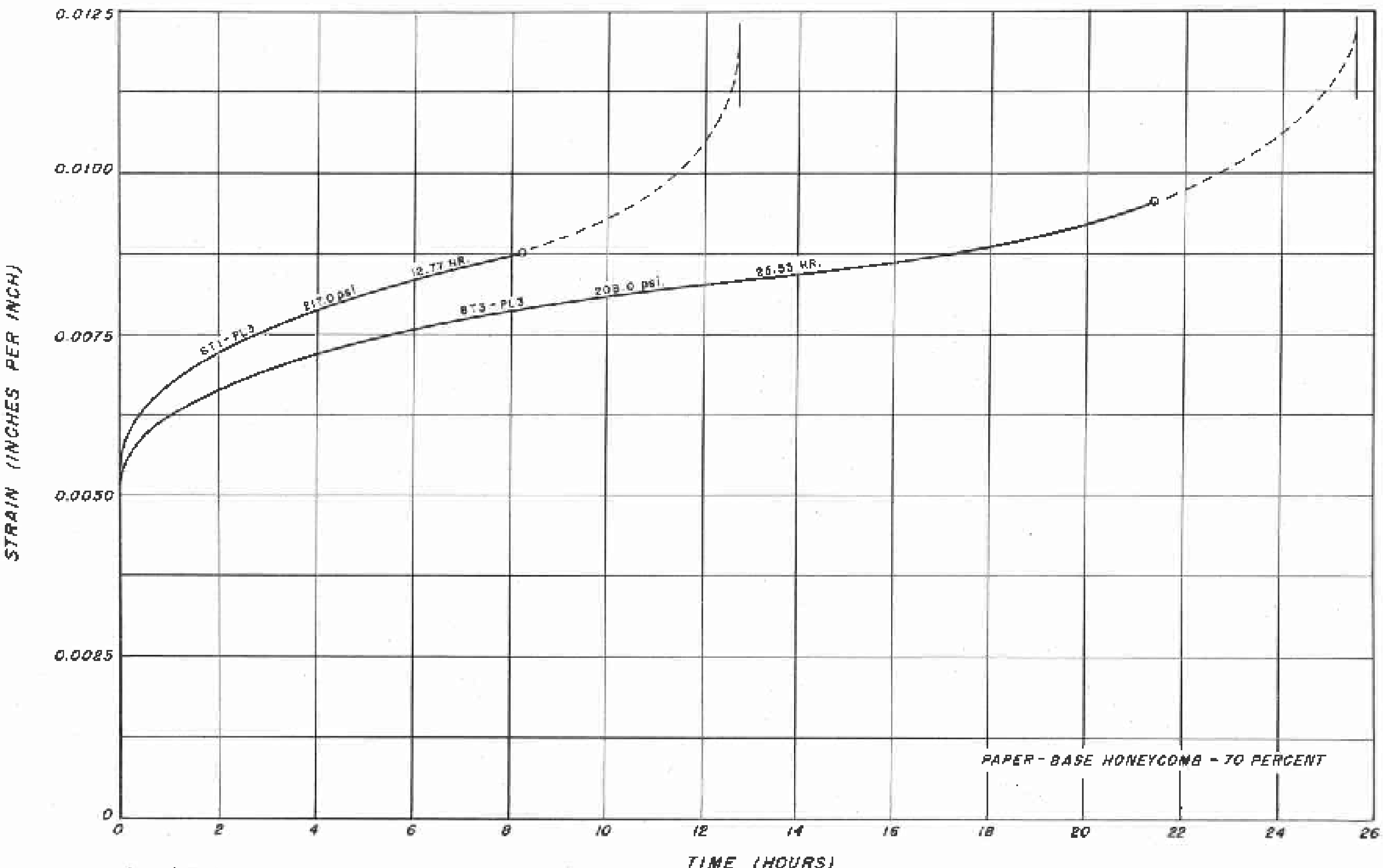
Z M 80663 F

Figure 17.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with paper-base honeycomb core) subjected to constant stress at 75 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.



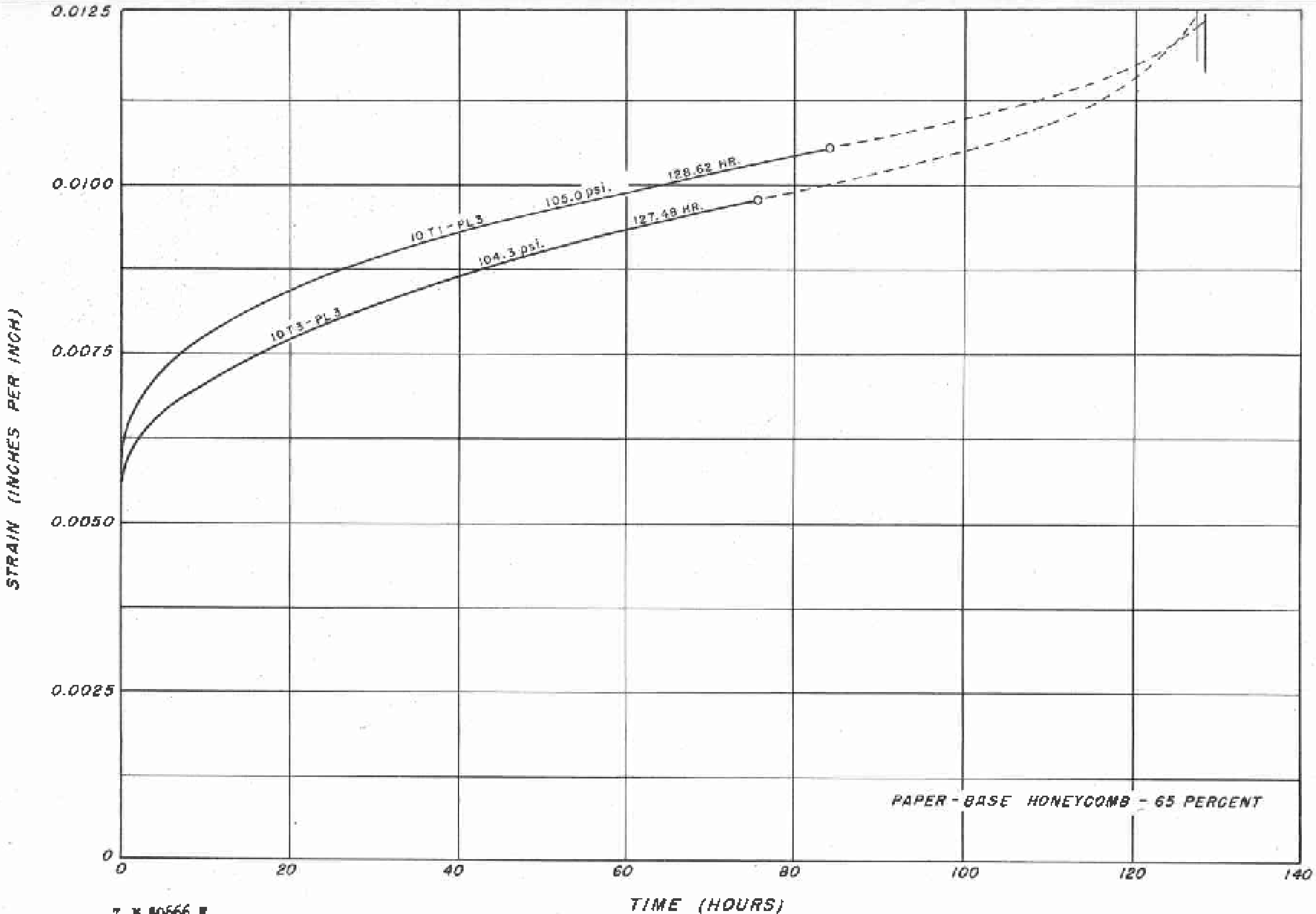
Z M 80664 F

Figure 18.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with paper-base honeycomb core) subjected to constant stress at 70 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.



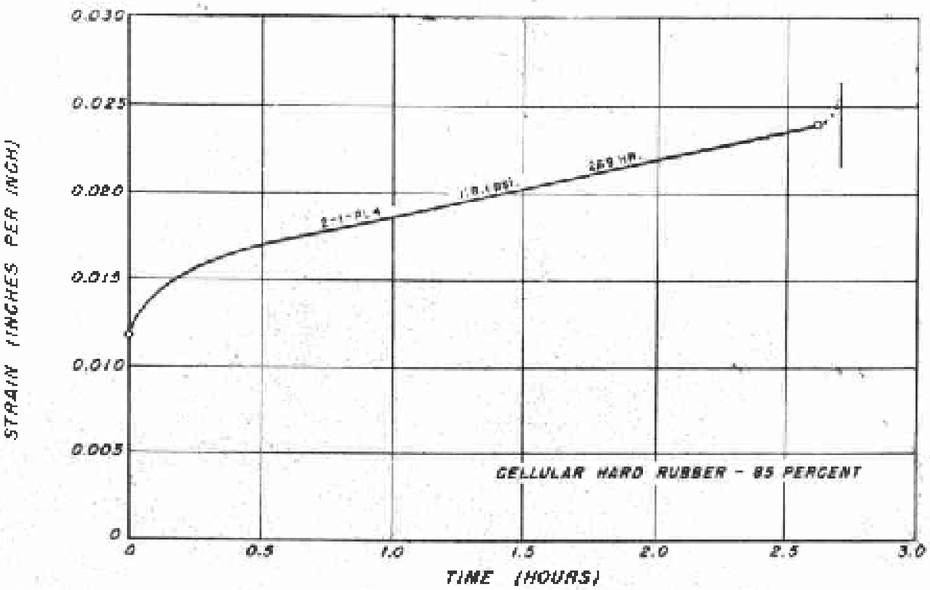
Z M 80665 F

Figure 19.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with paper-base honeycomb core) subjected to constant stress at 70 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.



Z M 80666 F

Figure 20.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with paper-base honeycomb core) subjected to constant stress at 65 percent of the average ultimate stress of control specimens. Shear deformation was in the LT plane of the core.



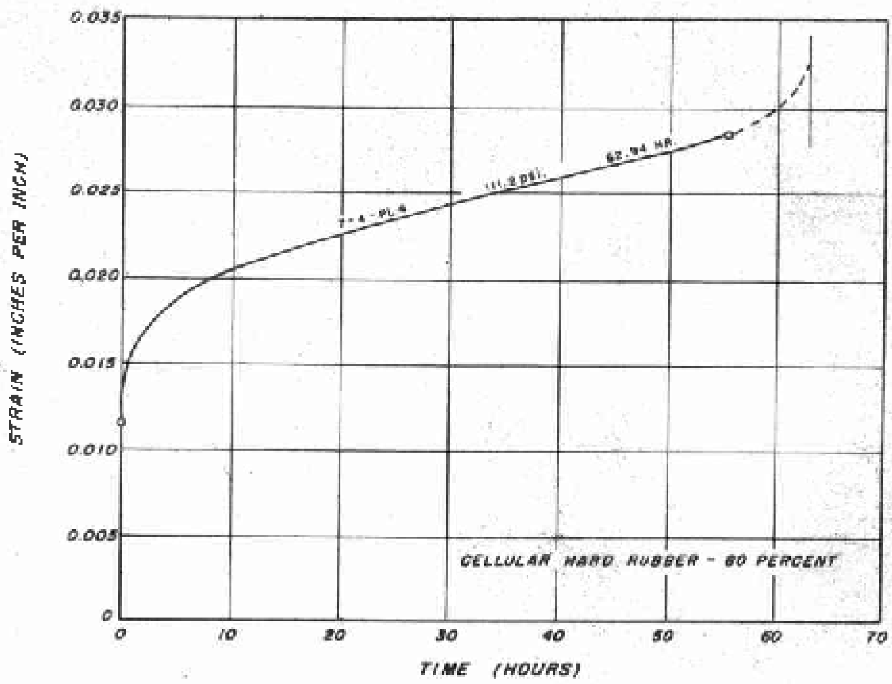
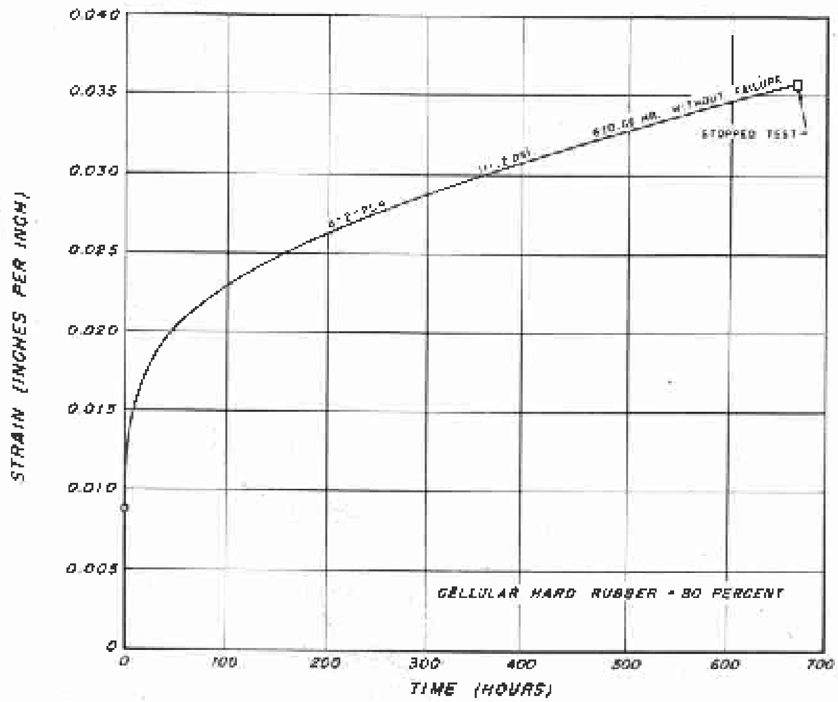


Figure 21. (Top)--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-hard-rubber core) subjected to constant stress at 85 percent of the average ultimate stress of control specimens.

Figure 22. (Bottom)--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-hard-rubber core) subjected to constant stress at 80 percent of the average ultimate stress of control specimens.

Z M 80667 F



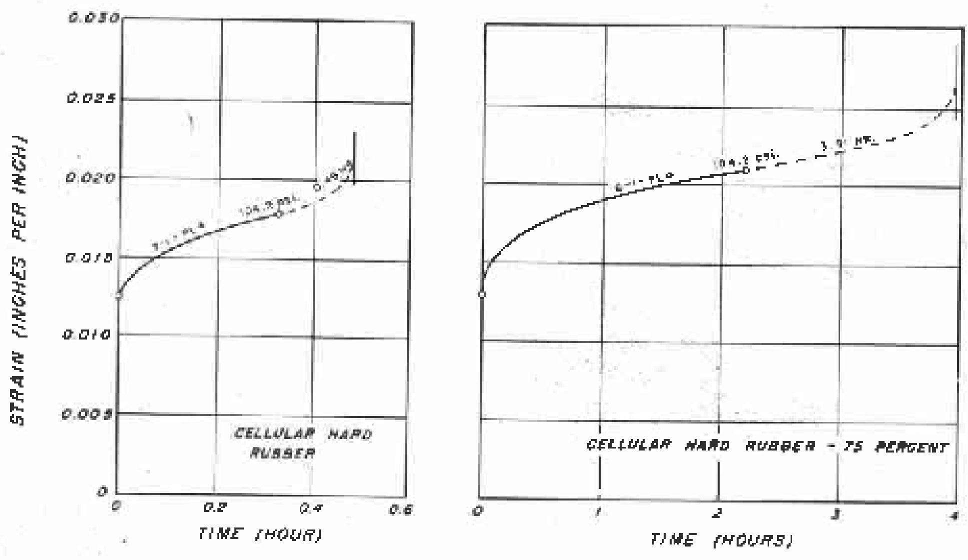
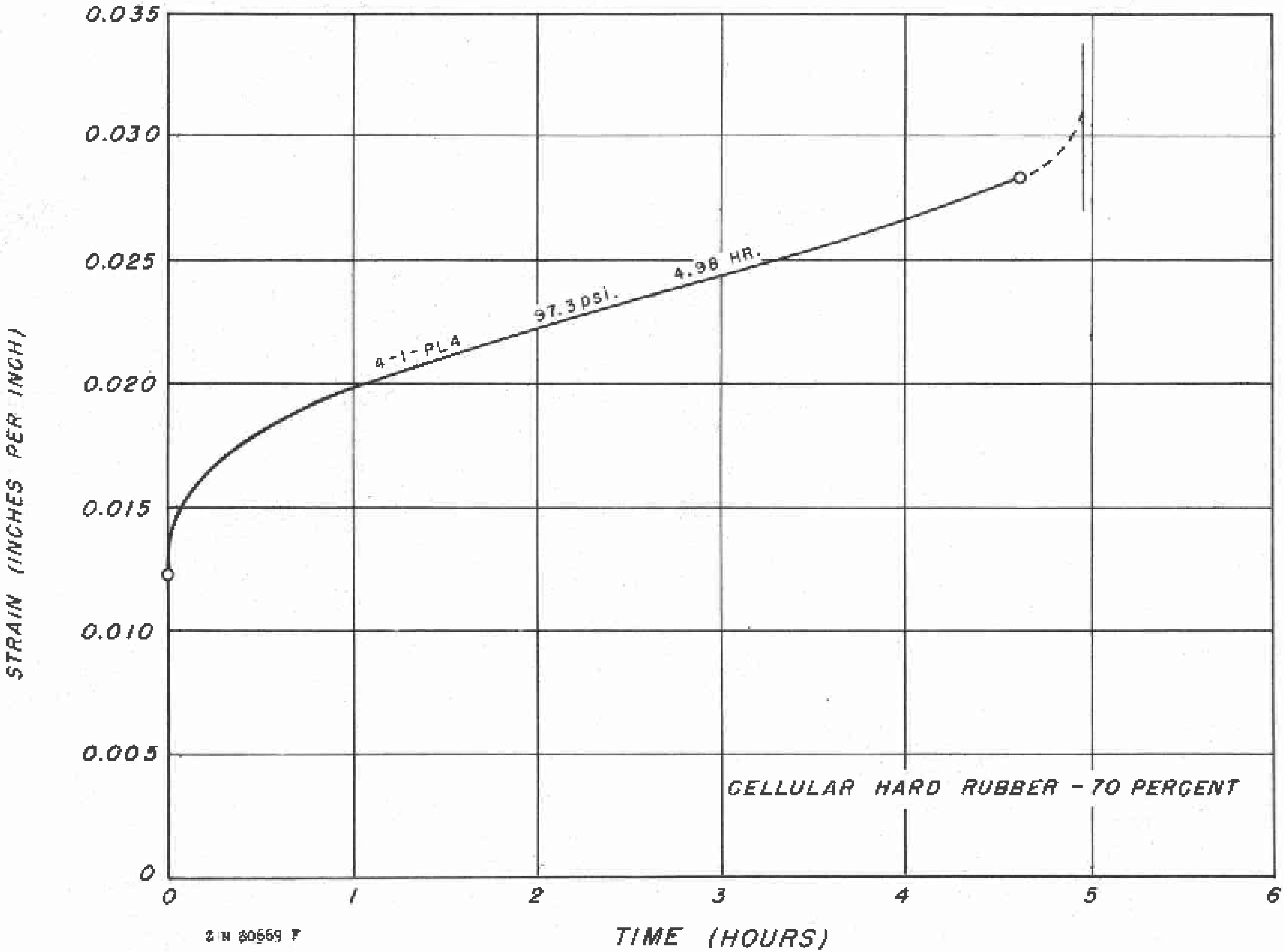


Figure 23. (Top) --Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-hard-rubber core) subjected to constant stress at 80 percent of the average ultimate stress of control specimens.

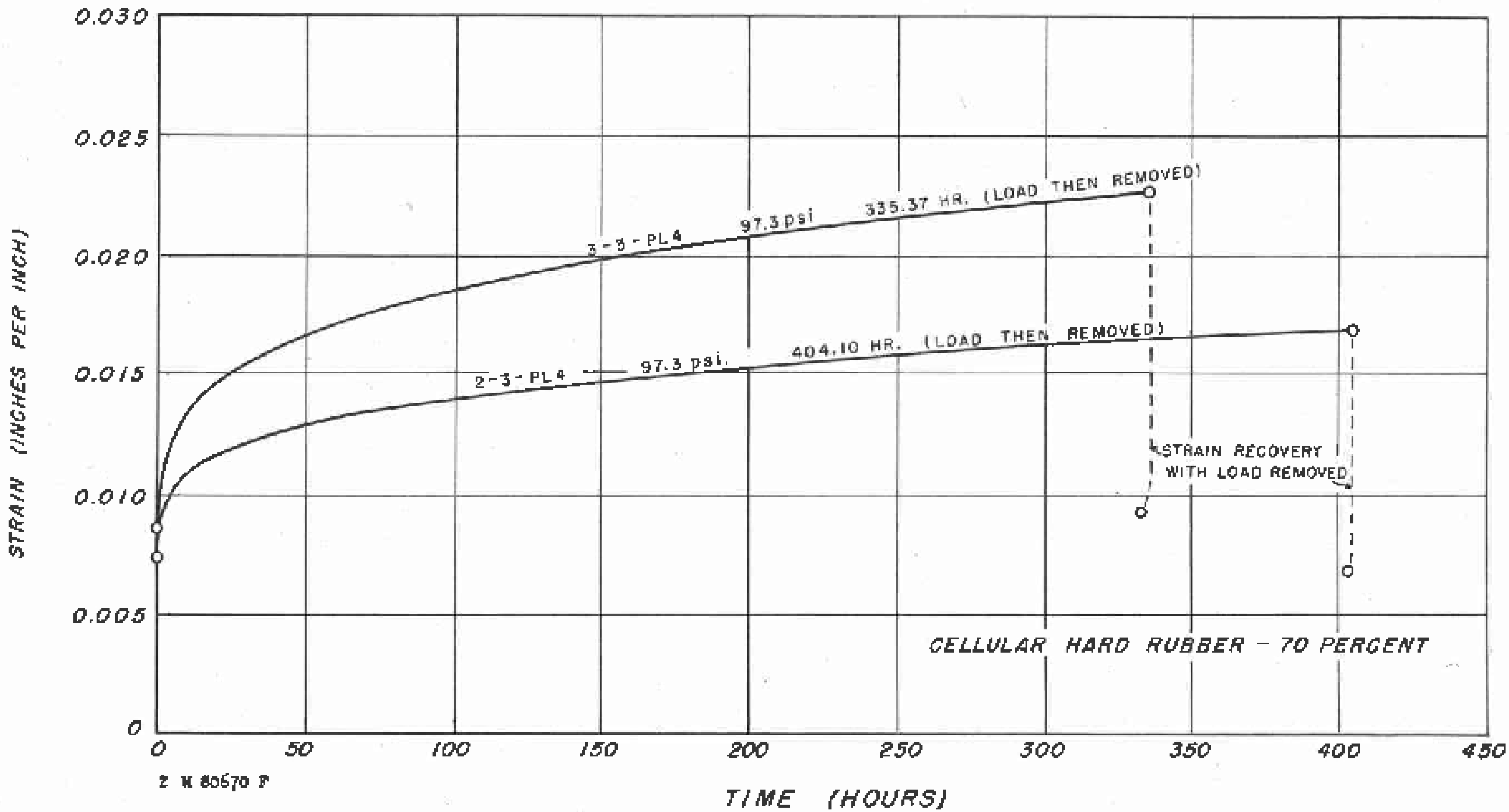
Figure 24. -- (Bottom) --Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-hard-rubber core) subjected to constant stress at 75 percent of the average ultimate stress of control specimens.

Z M 80666 F



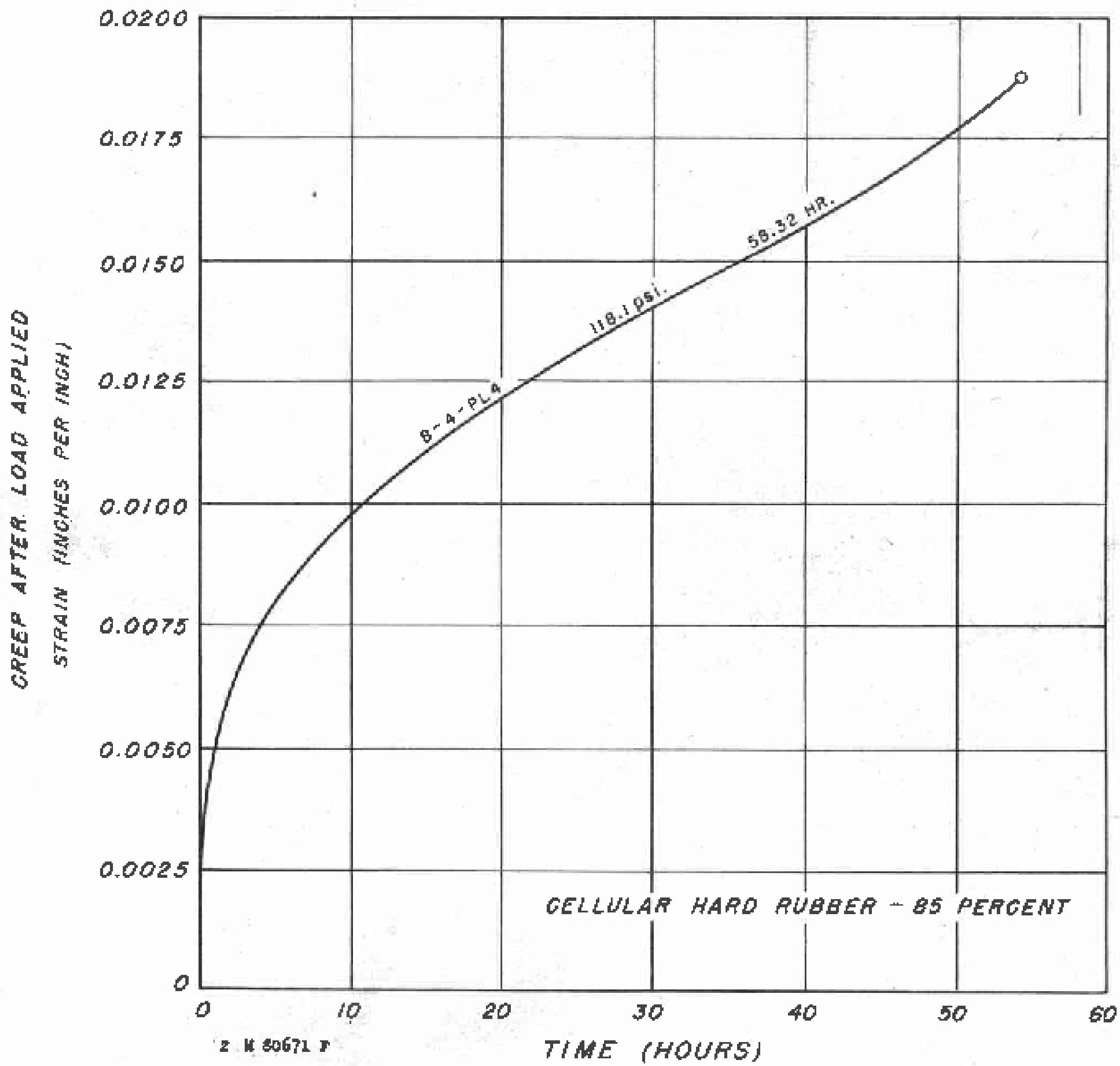
Z M 80669 F

Figure 25.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-hard-rubber core) subjected to constant stress at 70 percent of the average ultimate stress of control specimens.



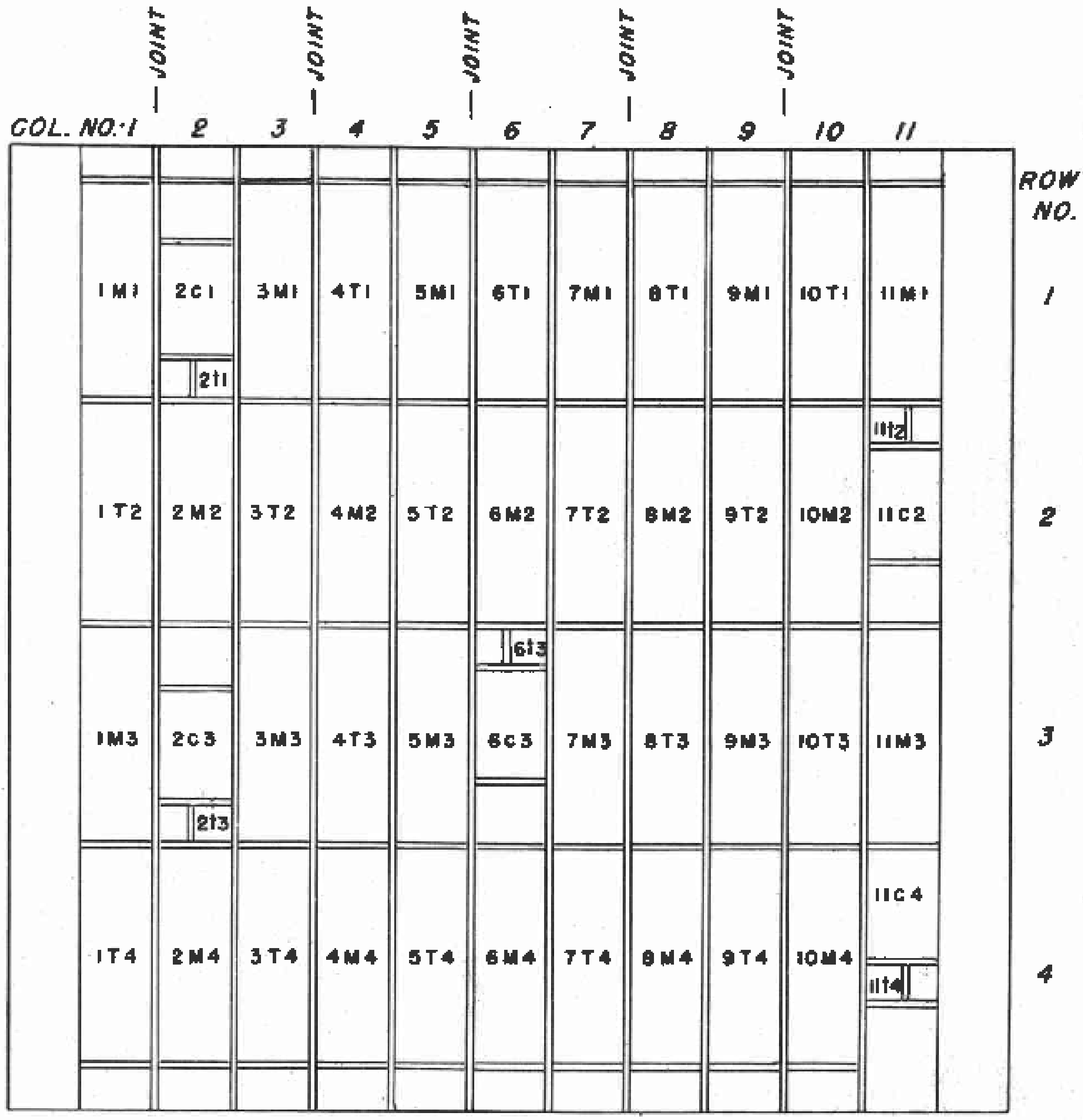
Z M 80670 F

Figure 26.--Shear-creep-test data. Strain between faces plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-hard-rubber core) subjected to constant stress at 70 percent of the average ultimate stress of control specimens.



Z M 80671 F

Figure 27.--Shear-creep-test data. Strain between faces after load was applied plotted against time to failure for sandwich material (seven-ply glass-cloth facings with cellular-hard-rubber core) subjected to constant stress at 85 percent of the average ultimate stress of control specimens.

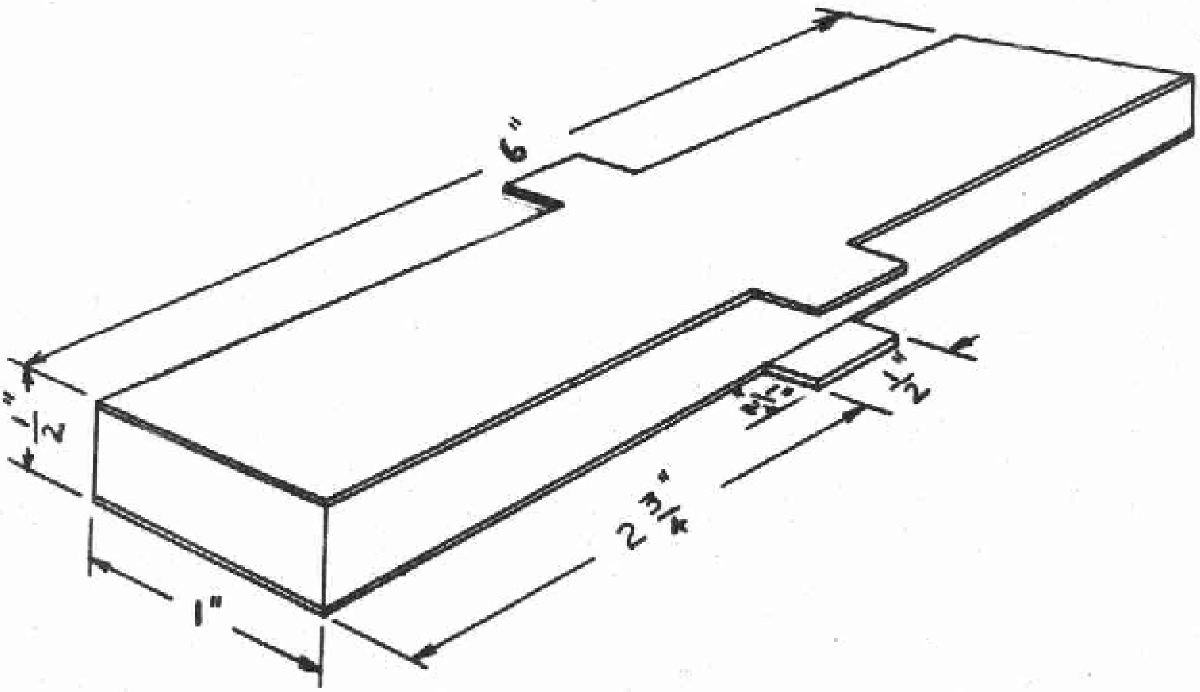


LAY-OUT OF SPECIMEN BLANKS

TEST	SPECIMEN SIZE
M - FRAME SHEAR	2" X 6"
T - SHEAR-CREEP	2" X 6"
t - TENSION NORMAL TO GLUE LINE	1" X 1"
c - EDGEWISE COMPRESSION	2" X 3"

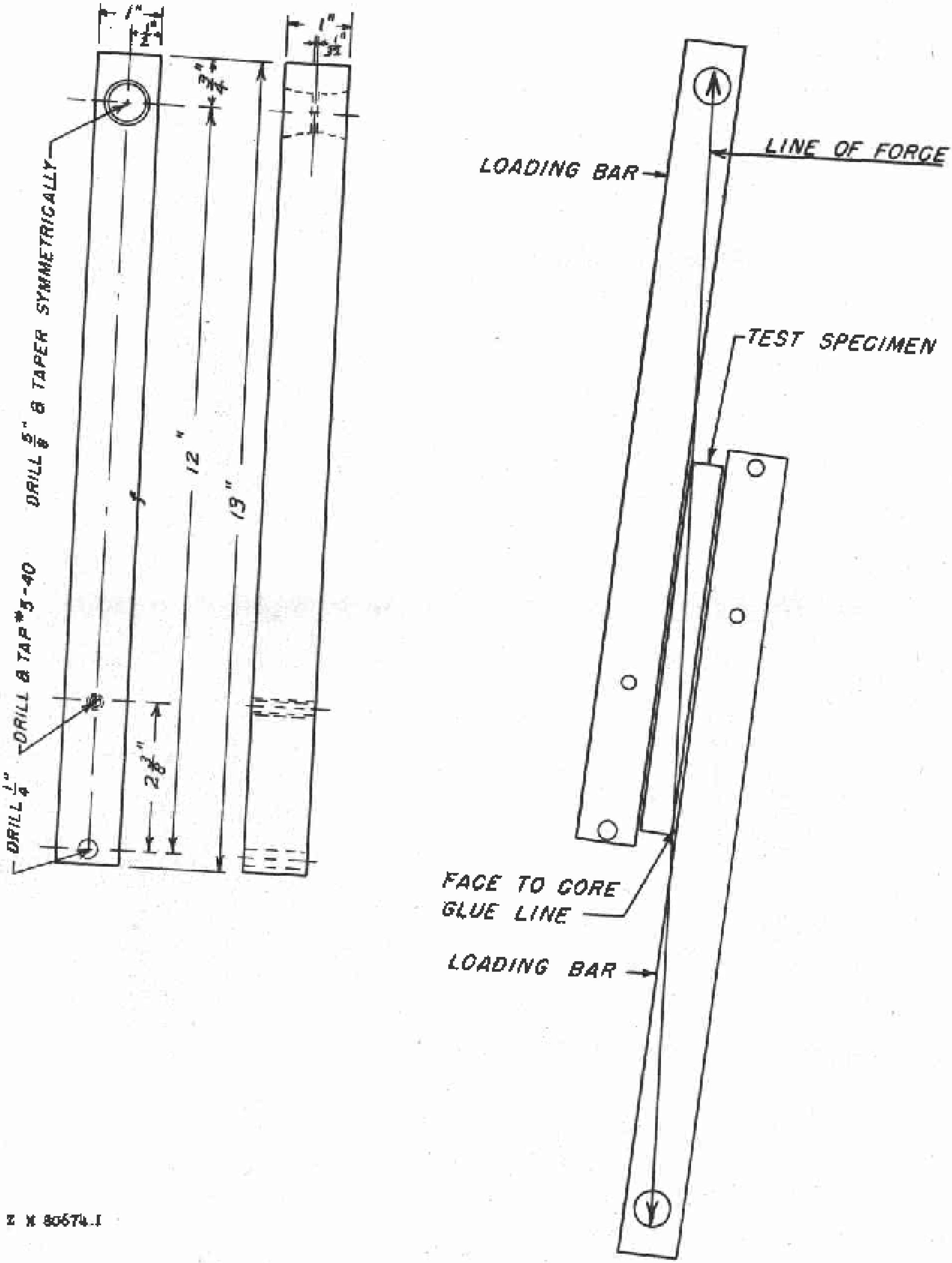
Z M 80672 F

Figure 28.--Lay-out of specimen blanks for panels 1 and 4.



Z M 80673 F

Figure 29.--Specimen detail for shear-creep tests and for shear-strength tests.



Z M 80674.I

Figure 30.--Loading-bar detail and line of force.

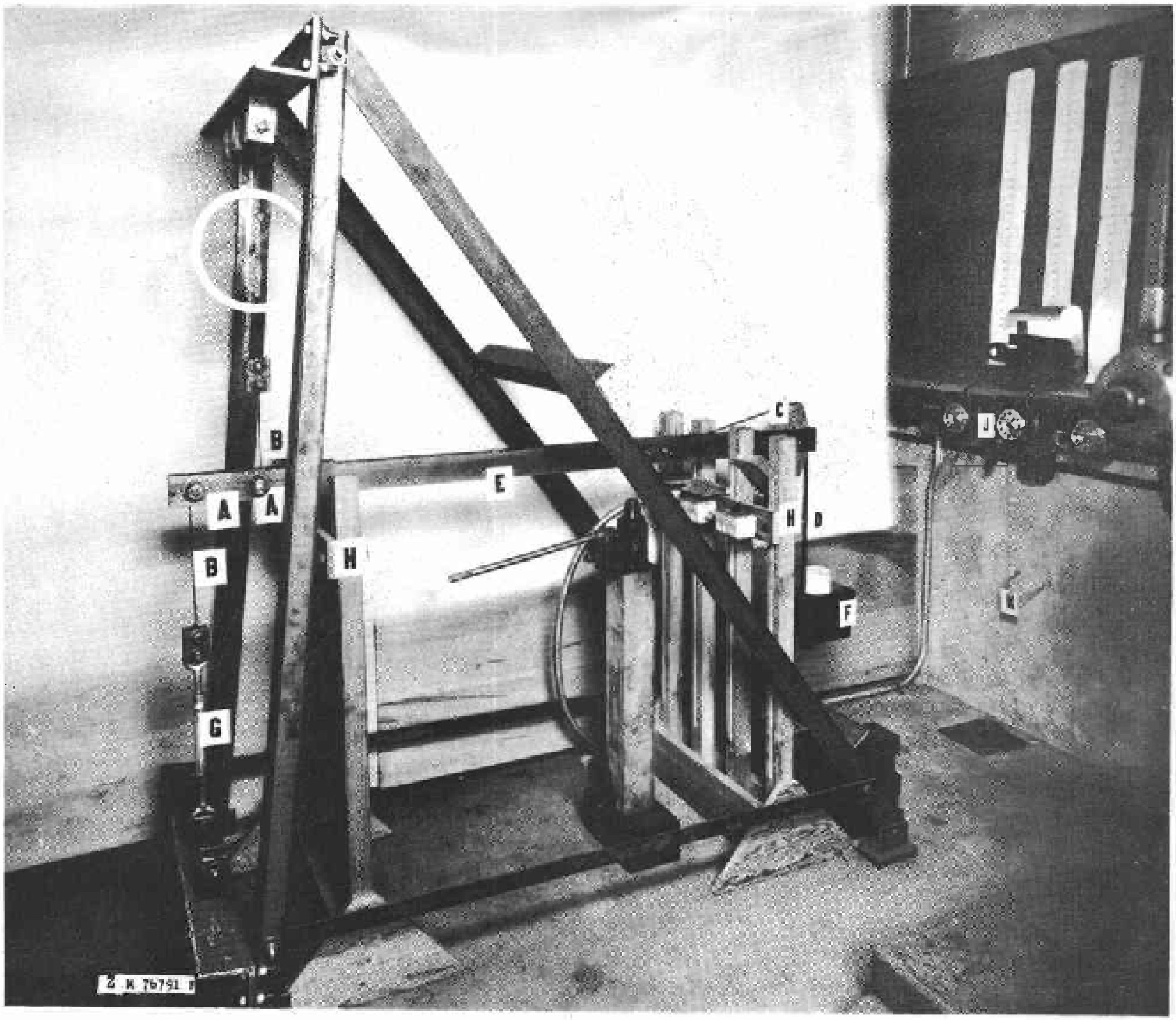


Figure 31.--Shear-creep test in progress in apparatus for maintaining constant load. (For description see page 5.)