POISSON'S RATIOS FOR GLASS-FABRIC-BASE PLASTIC LAMINATES

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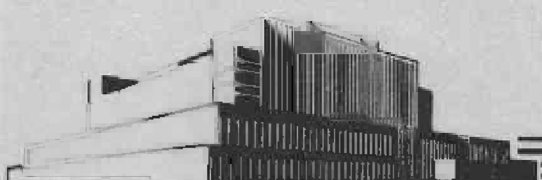

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

POISSON'S RATIOS FOR GLASS-FABRIC-BASE PLASTIC LAMINATES[1]

By

ROBERT L. YOUNGS, Technologist

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

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Summary

Poisson's ratios were determined by test for several glass-fabric-base plastic laminates after normal conditioning. Loads were applied parallel and perpendicular to the warp direction to obtain Poisson's ratios along the natural axes of the materials. A few tests were also made to determine the effects of wet conditioning and type of resin on Poisson's ratios.

For most of the laminates investigated, the Poisson's ratios were about 1/8.

Introduction

Values of Poisson's ratio are frequently required in the calculation of the elastic and strength properties of glass-fabric-base plastic laminates.

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[1] This progress report is one of a series (ANC-17, Item 56-4) prepared and distributed by the U. S. Forest Products Laboratory under U. S. Navy Bureau of Aeronautics No. NAer 01683 and U. S. Air Force Contract No. DO 33(616)-56-9. Results here reported are preliminary and may be revised as additional data become available.

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

Few data are available on Poisson's ratios for such laminates, and data from different sources are not consistent. In some cases the use of an approximate value is satisfactory, but in other cases a more reliable value is required.

Poisson's ratios have previously been obtained for parallel laminates reinforced with 162, 181, and 143 glass fabrics,[3] and values based on these data are included in this report. Limited data on Poisson's ratio for a few laminates at low stress levels are also presented in the ANC-17 Bulletin.[4]

The work here reported was done to determine Poisson's ratios for several different laminates, with the principal stresses applied both parallel and perpendicular to the warp direction. Most of the tests were made on parallel laminates after normal conditioning. A few tests, however, were conducted to investigate the effects of wet conditioning and the type of resin used.

This research was conducted at the Forest Products Laboratory from July to November 1956, at the request of, and in cooperation with, the ANC-17 Panel on Plastics for Aircraft.

Description of Material

One glass-fabric-base plastic laminate 1/8 inch thick, 18 inches wide, and either 18 or 24 inches long was made with Selectron 5003 resin and each of the following reinforcements:

(a) Plain weave	112 Volan A 128-114
(b) 4-harness satin weave	120-114

[3] Erickson, E. C. O., and Norris, C. B. Tensile Properties of Glass-Fabric-Laminates with Laminations Oriented in Any Way. Forest Products Laboratory Report No. 1853, November 1955.

[4] U. S. Forest Products Laboratory, ANC-17 Panel on Plastics for Aircraft. ANC-17 Bulletin, Plastics for Aircraft; Part I, Reinforced Plastics. Issued by Departments of the Air Force, Navy, and Commerce. 1955.

(c) 8-harness satin weave	181 Volan A 182-114 184 Volan A
(d) Unidirectional weave	143 Volan A

In addition, one laminate 1/8 inch thick, 18 inches wide, and 18 inches long was made with 181 Volan A fabric and Epon 828 resin with Curing Agent CL.

All panels were parallel laminated except the one reinforced with 143 Volan A fabric, which was cross laminated.

Selectron 5003 resin is a laminating resin of the polyester (alkyd-styrene) type conforming with the requirements of Military Specification MIL-R-7575A. Epon 828 is an epoxy laminating resin of the type required by Military Specification MIL-R-9300A.

Laminates made with fabric having 114 finish, an older type of fabric finish, are generally affected more by wet conditioning than laminates made with Volan A or one of the other improved finishes. For determination of Poisson's ratios of normally conditioned specimens, however, fabric finish is not considered important. For this reason, fabric having 114 finish was used in some of the laminates from which specimens were to be made for test after normal conditioning, in order to use glass fabric on hand. Laminates that were to be cut into specimens for tests after either normal or wet conditioning were reinforced with fabric having Volan A finish.

Polyester laminates were prepared by means of the usual wet lay-up procedures. The resin was catalyzed with 0.8 percent of benzoyl peroxide, by weight, and the resin and fabric were laid up between cellophane-covered aluminum cauls. The laminates were cured for 90 minutes in a press at a pressure of 14 pounds per square inch and a platen temperature that was gradually increased from 220° to 250° F.

The epoxy laminate was prepared by wet lay-up procedures with Epon 828 epoxy resin containing 14 percent by weight of curing agent CL. The resin-fabric assembly was cured in a press at 215° F. with contact pressure for 12 minutes followed by a pressure of 25 pounds per square inch for 48 minutes. This laminate was not post-cured. Fabrication details for this type of epoxy laminate are given in Forest Products Laboratory Reports Nos. 1820-C[5] and 1824-C.[6]

Information on the construction and physical properties of the laminates is listed in table 1.

Test Specimens

From each panel except those reinforced with 143 or 181 fabric, five specimens were cut with their longitudinal axis parallel (0°) to the warp direction and 5 with their longitudinal axis perpendicular (90°) to it. Five specimens were cut from the 143 cross laminate in the 0° direction, which was parallel to the warp of the face laminations. Ten specimens were prepared from each of the 181 parallel laminates in the 0° direction, and those from each panel were numbered consecutively. Odd-numbered specimens were tested after normal conditioning, and even-numbered specimens were tested after wet conditioning.

Each specimen was 16 inches long and 1-1/2 inches wide and was necked down at the center to a minimum section 0.8 inch wide and 2-1/2 inches long. The minimum section was connected to the wide ends by circular arcs of 20-inch radius that were tangent to the minimum section. Specimens were cut to approximate size on a bandsaw and finished to final size and shape with an emery wheel mounted on a shaper head.

Two metalectric strain gages were mounted near the center of the minimum section on each side of each specimen; one to measure elongation and one to measure contraction. On specimens that were to be tested after normal conditioning, 1-inch SR-4, Type A-1 strain gages were mounted longitudinally to measure elongation, and 1/2-inch, Type A-5 strain gages were mounted transversely to measure contraction. On specimens that were to be tested after wet conditioning, 1-inch, Type AB-3 strain gages were mounted longitudinally to measure elongation,

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[5] Youngs, R. L. Supplement to Mechanical Properties of Plastic Laminates. Forest Products Laboratory Report No. 1820-C, August 1956.

[6] Youngs, R. L. Supplement to Bolt-Bearing Properties of Glass-Fabric-Base Plastic Laminates. Forest Products Laboratory Report No. 1824-C, February 1957.

and 1/2-inch, Type AB-5 strain gages were mounted transversely to measure contraction.

Specimens that were to be tested after normal conditioning were conditioned for at least 2 weeks at 75° F. and 50 percent relative humidity. Specimens to be tested after wet conditioning were conditioned for 60 days at 100° F. and 100 percent relative humidity.

Testing Procedure

Specimens were removed from the conditioning area one at a time and measured for thickness and width at the minimum section by means of a micrometer caliper. They were then placed in Templin grips in a hydraulic testing machine and loaded in tension at a constant head speed of 0.035 inch per minute.

One specimen of each load-direction or conditioning group of each laminate was mounted in the testing machine and loaded until it failed. These tests were made to show the stress at which the initial and secondary proportional limits occurred in order to serve as a guide for Poisson's ratio tests. Specimens for determination of Poisson's ratio were mounted in the testing machine, given a small initial load, then loaded and unloaded four times in one continuous operation with no intentional rest or recovery periods. In the first two runs, loads reached about three-fourths of the secondary proportional-limit load of the specimen, as previously determined from the control test for the group. In the third and fourth runs, loads reached about the secondary proportional limit load. Each loading started at the initial load, and each unloading except the last ended at the same load.

Elongation and contraction strain data were taken during the first loading run, the first unloading run, the second loading run, the fourth loading run, and the fourth unloading run with the metalectric strain gages mounted on the specimens.

Tests of normally conditioned material were conducted on three specimens at each angle of loading from each laminate. Tests of wet-conditioned material were conducted on four specimens of each 181 laminate.

Calculation of Poisson's Ratios

Elongation and contraction strain data for each specimen were plotted to the same vertical load scale and suitable horizontal strain scales, as in figure 1. Straight lines were drawn through the plotted points to indicate the slopes of the elongation and contraction curves for each run. Initial and secondary slopes were clearly evident on the elongation curve for the first loading of each specimen, but were so indistinct on subsequent loadings that no attempt was made to distinguish between them, since this distinction would have had no significant effect on the values of Poisson's ratio calculated from them. All unloading runs were characterized by a single slope.

Poisson's ratios were then calculated for the initial and secondary portions of the first loading run and for the first unloading run, the second loading run, the fourth loading run, and the fourth unloading run by dividing the strain in contraction perpendicular to the direction of loading by the strain in elongation parallel to the direction of loading. The ratio of contraction in the perpendicular-to-warp direction, β, to elongation produced by a tensile load in the parallel-to-warp direction, α, was designated as $\mu_{\alpha\beta}$. The ratio of contraction in the parallel-to-warp direction, α, to elongation produced by a tensile load in the perpendicular-to-warp direction, β, was designated as $\mu_{\beta\alpha}$. Average values of $\mu_{\alpha\beta}$ and $\mu_{\beta\alpha}$ were calculated for the corresponding phase of loading or unloading of all specimens in a group.

The indications of the metalectric strain gages used to measure elongation and contraction strains were subject to error resulting from transverse sensitivity. This was particularly significant for the gages measuring contraction strain, which was quite small relative to the elongation strain. Each average value was therefore adjusted to eliminate this error by means of the relationships presented by Baumberger and Hines.[7]

Presentation and Discussion of Results

Values of Poisson's ratio calculated for each of the laminates tested in this work are presented in table 2. Also included in table 2 are values

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[7] Baumberger, R., and Hines, F., 1944. Practical Reduction Formulas for Use on Bonded Wire Strain Gages in Two-Dimensional Stress Fields. Experimental Stress Analysis 2:1:113-127.

of Poisson's ratio based on previous similar tests of laminates reinforced with 162, 181, and 143 glass fabrics. These values were adjusted for transverse sensitivity in order to make them more closely comparable to the values obtained in this work, although it is probable that the adjustment is of slight practical significance. Modulus of elasticity values calculated from the Poisson's ratio elongation data of this report are also presented in table 2.

A set of typical load-strain curves in elongation and contraction are shown in figure 1. These curves are based on data obtained in tests of a 181 epoxy laminate, and are similar in form to those based on polyester laminates tested in this work and to those based on a 181 polyester laminate previously tested.[3]

The data of table 2 show that the Poisson's ratio was highest for the initial portion of the first loading and lowest for the secondary portion of the first loading for each material except the 143 parallel laminate that did not have two distinct slopes in the first loading curve. In subsequent runs, the Poisson's ratios for both loading and unloading remained about equal to the average of the Poisson's ratios for the initial and secondary slopes of the first loading.

Since a structural component is usually subjected to repetitions of load, the Poisson's ratio value based on loadings after the first application of load will probably be the proper value to use in design. The data of table 2 indicate that a Poisson's ratio of 1/8 would probably be suitable for most of the laminates investigated. This is true for both $\mu_{\alpha\beta}$ and $\mu_{\beta\alpha}$. The outstanding exception to this was the 143 parallel laminate, for which $\mu_{\alpha\beta}$ was about 1/4 and $\mu_{\beta\alpha}$ about 1/16. An exception might also be made for the 182 laminate, for which $\mu_{\alpha\beta}$ was about 1/7 and $\mu_{\beta\alpha}$ about 1/10.

The data on 181 polyester and epoxy laminates tested in both the dry and wet conditions indicate that wetting produced a slight increase in Poisson's ratio in all loading and unloading runs for both types of laminate, although this increase was so slight that it would have little effect on most design calculations. These same data indicate that Poisson's ratio was higher for the epoxy laminate than for the polyester laminate in all loading and unloading runs in both the dry and wet conditions. Again, this difference probably has little practical significance.

It has previously been observed[8] that the tensile modulus of elasticity of glass-fabric-base polyester laminates that have been preloaded in tension to a high stress level is generally only slightly higher than that based on the secondary portion of the first loading curve. Similar relationships were observed in this research. Few data are available, however, on the effect of tensile preloading on the properties of epoxy laminates.

Table 2 lists ratios of modulus of elasticity obtained for the fourth loading to the secondary modulus obtained for the first loading. The ratio varies somewhat among laminates, the final modulus of elasticity of polyester laminates being about 3 to 10 percent higher than the secondary modulus for the first loading. There was, however, a distinct difference in this respect between the 181 polyester laminate and the comparable 181 epoxy laminate. The average ratio was about 1.06 for the polyester laminate and 1.17 for the epoxy laminate. Similar relationships might be expected for polyester and epoxy laminates reinforced with other fabrics, although the differences may vary. Thus, while the secondary tensile modulus of elasticity might be used as a design value for polyester laminates, it is possible that it may be too conservative for epoxy laminates.

Conclusions

Results of this work indicate that a value of 1/8 would be satisfactory for Poisson's ratio of most glass-fabric-base plastic laminates when loaded at either 0° or 90° to the warp of the fabric. For the parallel-laminated 143 laminate, Poisson's ratios of 1/4 for 0° loading and 1/16 for 90° loading were indicated. For the 182 laminate, Poisson's ratios of 1/7 for 0° loading and 1/10 for 90° loading were indicated.

Poisson's ratios were slightly higher for a 181 epoxy laminate than for a comparable polyester laminate. Poisson's ratios of the 181 laminates were increased somewhat by wet conditioning. In neither case, however, was the difference great enough to have any significant effect on most design calculations.

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[8] Werren, Fred. Effect of Prestressing in Tension and Compression on the Mechanical Properties of Two Glass-Fabric-Base Plastic Laminates. U. S. Forest Products Laboratory Report No. 1811, September 1950, and Supplement A, June 1951.

The ratios of tensile modulus of elasticity of the fourth loading run to the modulus of the secondary portion of the first run were considerably higher for the 181 epoxy laminate than for the comparable 181 polyester laminate or other polyester laminates. The secondary tensile modulus of elasticity of this epoxy laminate may be too conservative to use as a design value.

Table 1.--Construction and physical properties of laminated panels tested for determination of Poisson's ratios

Panel No.	Fabric	Resin	Direction of plies	Number of plies	Thickness	Resin content	Specific gravity	Barcol hardness
					Inch	Percent		
562	112 Volan A	Selectron 5003	Parallel	46	0.125	39.7	1.75	68
563	128-114	Selectron 5003	Parallel	18	.125	35.9	1.80	67
564	120-114	Selectron 5003	Parallel	30	.129	43.0	1.72	67
565	182-114	Selectron 5003	Parallel	9	.126	34.8	1.81	65
566	184 Volan A	Selectron 5003	Parallel	5	.142	33.2	1.83	64
567	143 Volan A	Selectron 5003	Cross	13	.120	29.8	1.84	64
568	181 Volan A	Selectron 5003	Parallel	12	.112	29.7	1.81	67
569	181 Volan A	Epon 828-CL	Parallel	13	.117	30.7	1.91	70

Table 2.--Poisson's ratios of glass-fabric-base plastic laminates. All laminates were parallel laminated, except the one reinforced with 143 Volan A fabric which was cross laminated. Each value for the dry condition is an average based on three tests. Each value for the wet condition is an average based on four tests.

Type of weave	Fabric	Resin	Condition[1]	Direction of loading		Poisson's ratio: First run: Loading: Initial slope[2]	Poisson's ratio: First run: Loading: Secondary slope[3]	Poisson's ratio: First run: Unloading	Poisson's ratio: Second loading run	Poisson's ratio: Fourth run: Loading	Poisson's ratio: Fourth run: Unloading	Modulus of elasticity: First loading run: Initial slope[2]	Modulus of elasticity: First loading run: Secondary slope[3]	Modulus of elasticity: Second loading run	Modulus of elasticity: Fourth loading run	Ratio of E of fourth run to secondary E of first run
				Degrees								1,000 P.s.i.	1,000 P.s.i.	1,000 P.s.i.	1,000 P.s.i.	
Plain	112 Volan A	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	0.13	0.08	0.11	0.11	0.10	0.10	3,050	2,550	2,800	2,750	1.08
				90	$\mu_{\beta\alpha}$	.13	.08	.11	.10	.10	.10	2,780	2,290	2,460	2,430	1.06
Do.	128-114	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	.14	.11	.13	.13	.12	.13	3,240	2,930	3,080	3,020	1.03
				90	$\mu_{\beta\alpha}$	.11	.08	.10	.10	.10	.10	2,520	2,100	2,340	2,280	1.09
Do.	162-114[4]	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	.17	.16	.16	.17	.16						
				90	$\mu_{\beta\alpha}$	.13	.11	.12	.12	.12						
4-Harness satin	120-114	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	.15	.09	.12	.12	.11	.11	2,960	2,310	2,600	2,550	1.10
				90	$\mu_{\beta\alpha}$	.14	.08	.11	.11	.11	.11	2,950	2,330	2,600	2,560	1.10
8-Harness satin	181-114[4]	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	.14	.09	.11	.11	.11						
				90	$\mu_{\beta\alpha}$	.13	.08	.10	.10	.10						
Do.	181 Volan A	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	.11	.07	.10	.10	.09	.09	3,190	2,790	2,980	2,950	1.06
			Wet	0	$\mu_{\alpha\beta}$	.13	.10	.11	.12	.12	.12	2,900	2,640	2,760	2,780	1.05
Do.	181 Volan A	Epon 828-CL	Dry	0	$\mu_{\alpha\beta}$	.17	.09	.13	.13	.12	.12	4,020	2,780	3,340	3,320	1.19
			Wet	0	$\mu_{\alpha\beta}$	.18	.11	.15	.15	.14	.14	3,780	2,900	3,420	3,330	1.15
Do.	182-114	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	.19	.11	.15	.15	.14	.13	3,290	2,800	2,980	2,930	1.05
				90	$\mu_{\beta\alpha}$	.11	.07	.10	.10	.09	.09	2,930	2,490	2,750	2,730	1.10
Do.	184 Volan A	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	.13	.11	.12	.12	.12	.12	2,980	2,620	2,800	2,750	1.05
				90	$\mu_{\beta\alpha}$	.12	.09	.11	.11	.11	.11	2,710	2,240	2,440	2,380	1.06
Crow foot satin (Unidirectional)	143-114[4]	Selectron 5003	Dry	0	$\mu_{\alpha\beta}$	.25		.25	.25	.25						
				90	$\mu_{\beta\alpha}$	.10		.06	.06	.06						
Do.	143 Volan A	Selectron 5003	Dry	[5]0	$\mu_{\alpha\beta}$	.12	.08	.10	.10	.09	.09	3,330	2,830	2,980	2,960	1.05

[1] Dry specimens were conditioned at 75° F. and 50 percent relative humidity. Wet specimens were conditioned for 60 days at 100° F. and 100 percent relative humidity and were tested at 75° F.

[2] Based on initial straight-line portion of load-deformation curve.

[3] Based on second straight-line portion of load-deformation curve.

[4] Values based on data of Forest Products Laboratory Report No. 1853.

[5] Cross-laminated material. Loaded parallel to warp of surface laminations.

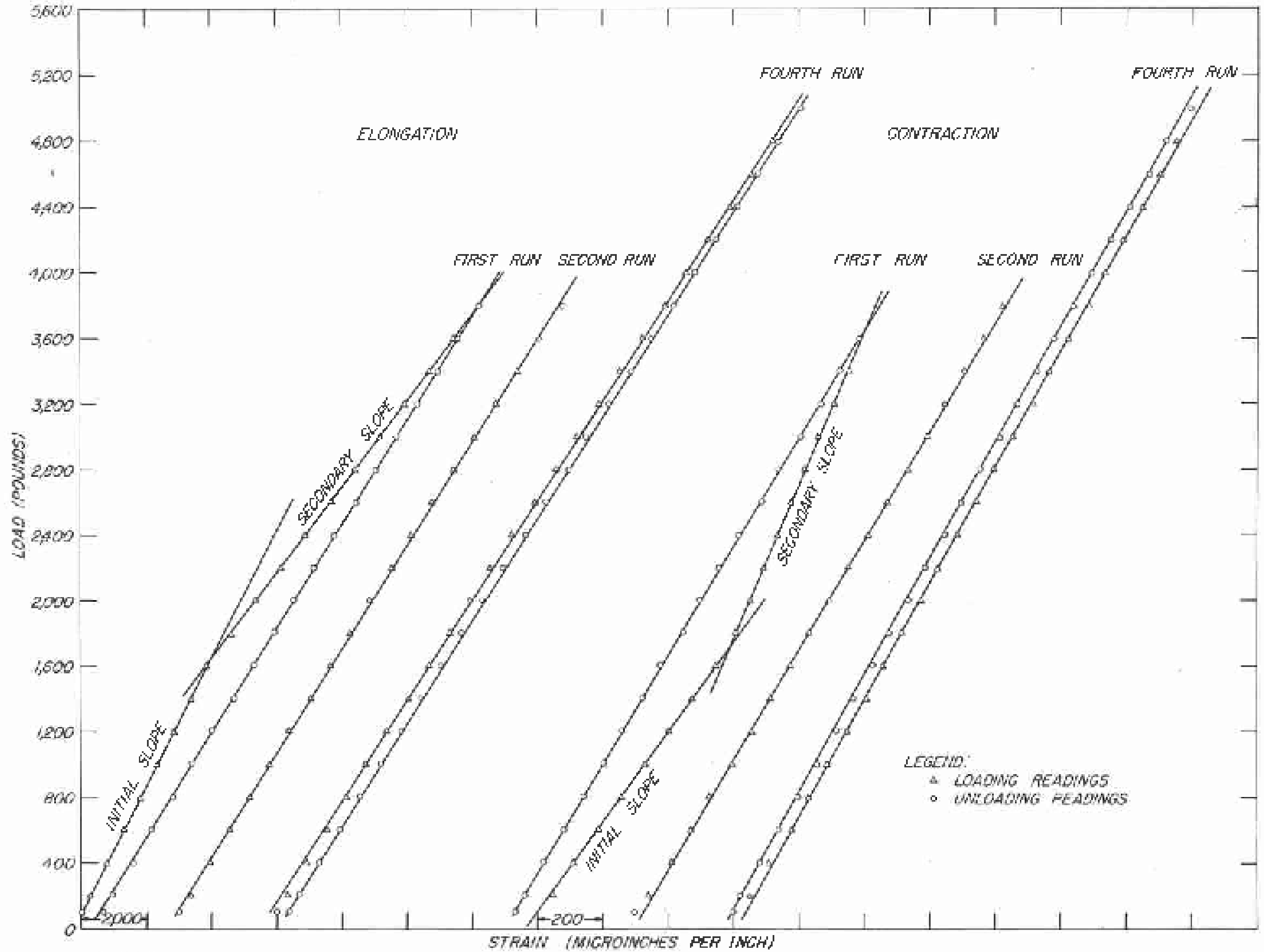

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Figure 1. --Load-strain curves in elongation and contraction for 181 epoxy laminate loaded in tension in the parallel-to-warp direction.