Supplement to

# BOLT-BEARING PROPERTIES OF GLASS-FABRIC-BASE PLASTIC LAMINATES

## (Effect of Laminate Thickness)



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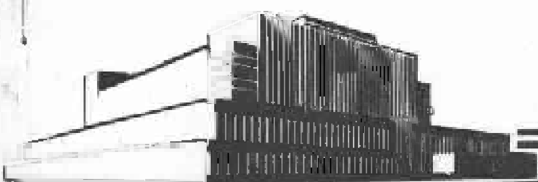

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

# SUPPLEMENT TO

# BOLT-BEARING PROPERTIES OF GLASS-FABRIC-BASE PLASTIC LAMINATES[1]

(Effect of Laminate Thickness)

By

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## Summary

This report presents the results of about 75 bolt-bearing tests of 181 Volan A polyester laminates of five thicknesses ranging from about 0.12 inch to 0.02 inch. The laminates were tested at angles of 0°, 90°, and 45° to the warp direction of the fabric, in the dry condition only, using a 1/8-inch-diameter pin. Failures were by crushing under the bolt only. Control data from tension and compression tests of the various laminates are also included.

Maximum bearing stress, bearing strength, and stress and deformation at proportional limit decreased as the laminate thickness decreased below 1/8 inch. The relationship of these properties to laminate thickness was somewhat similar to that previously established for tensile and compressive strength. Maximum stress in bearing was dependent on both laminate thickness and D/t ratio as laminate thickness was reduced below 1/8 inch. The effect of thickness was particularly noticeable at thicknesses of 1/16 inch and less.

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[1] This progress report is one of a series prepared and distributed by the Forest Products Laboratory under U. S. Navy Bureau of Aeronautics Order No. NAer 01610 and U. S. Air Force No. DO (33-616)53-20. 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.

## Introduction

Tensile and compressive tests of very thin glass-fabric-base plastic laminates[3] have shown that the unit strength of thin laminates, such as aircraft sandwich facings, is lower than the unit strength of laminates 1/8 inch or more in thickness of the same materials. This study was made to determine whether similar relationships hold for bolt-bearing properties.

The study was made at the Forest Products Laboratory in cooperation with the ANC-17 Panel on Plastics for Aircraft. It is a continuation of the work on bolt-bearing properties of glass-fabric-base plastic laminates described in Forest Products Laboratory Reports 1824 and 1824-A.[4]

In this report, as in Supplement A, the terms "edge and side distance" replace the terms "end and edge distance," respectively, that were used in the basic report.

## Material

The test panels were parallel-laminated of either 2, 3, 4, 6, or 12 plies of 181 glass fabric with Volan A finish. The thickness of these panels ranged from about 0.02 inch to 0.12 inch. All panels were 18 by 18 inches in size, and they were fabricated with Selectron 5003, a laminating resin of the polyester (alkyd-styrene) type conforming with the requirements of Specification MIL-R-7575A. The resin was catalyzed by the addition of 0.8 percent benzoyl peroxide by weight. Each panel was cured in a press at a pressure of 14 pounds per square inch for 90 minutes at a platen temperature that gradually increased from 220° to 250° F. Average values of thickness, resin content, specific gravity, and Barcol hardness, and the number of plies of fabric for each panel are given in table 23.

## Preparation of Specimens

Specimens for bolt-bearing tests were prepared essentially as outlined in the basic report, except that no specimens were prepared for wet tests. Each specimen was drilled and reamed to receive a 1/8-inch-diameter pin. The edge distance was 5/8 inch and the side distance was 1/4 inch in all

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[3]Effect of Thickness on Strength of Glass-Fabric-Base Plastic Laminates. Forest Products Laboratory Report No. 1831. May 1954.

[4]Bolt-Bearing Properties of Glass-Fabric-Base Plastic Laminates. Forest Products Laboratory Report No. 1824. June 1951, and Supplement A, August 1955.

specimens. These distances were shown by exploratory tests to be adequate to prevent failure to the edge or side. Five bolt-bearing specimens were prepared for tests at each of three angles, 0°, 90°, and 45°, to the warp direction of the fabric of each panel.

## Testing

### Bolt-Bearing Tests

Bolt-bearing tests were conducted essentially as described in the basic report. The specimens were gripped with a pin-connected, clamp-on device and loaded in tension against a 1/8-inch pin of hardened steel. Since there was danger of buckling the thin laminates used in this study, a supporting clamp consisting of two steel plates 1/16 inch thick and 3/8 inch wide was applied to the specimens at a distance of about twice the thickness of the laminate beneath the pin. This did not restrain the bearing deformation in any way. The test set-up is shown in figure 29. Specimens were loaded in a testing machine at a head speed of about 0.01 inch per minute, and deformation was measured by means of a dial gage reading to 0.0001 inch. All failures were by crushing under the bolt.

### Tension and Compression Tests

Control tests in tension and compression were each made in the dry condition on five specimens from each panel. All specimens were oriented to provide loading parallel (0°) to the warp direction of the fabric. Tension specimens were of Type 2, as specified for thin plastic laminates in Federal Specification L-P-406b, and they were tested to maximum load in a testing machine at a head speed of 0.05 inch per minute. Compression specimens were supported at each end by a pair of 5/16-inch-square steel bars with an unsupported center distance equal to 4 times the thickness of the laminate. The specimens were 1/2 inch wide and of a length equal to 5/8 inch plus 4 times the laminate thickness. They were tested to maximum load in a testing machine at a head speed of 0.05 inch per minute.

## Presentation of Data

The average bolt-bearing properties for each of the five thicknesses of 181 Volan A laminate are given in table 24. These data include the average values for each angle of loading at each thickness as well as an overall average for all tests at each thickness. The specimens were designed to have adequate edge and side distances to prevent failure at the edge or side. All failures were by crushing under the bolt; the laminates showed no evidence of the type of failure described in the basic report as being characteristic of stress-concentration effects. Values for bearing strength, deformation and stress at proportional limit, and deformation and stress at maximum load were determined as described in the basic report. Table 24 also includes values of tensile and compressive strength that were determined in control tests of the laminates.

Figure 30 shows the relationship between tensile strength, as determined from control tests, and laminate thickness. Also shown, for purposes of comparison, is a curve showing the relationship between tensile strength and laminate thickness, as reported for cross-laminated 181-114 laminates in Forest Products Laboratory Report 1831.[3] The curve was fitted to the data of the present study by use of the same basic equation used for tensile properties in Report 1831.

Figure 31 shows the relationship between compressive strength of the laminates used in this study, as determined from control tests, and laminate thickness. The curve was fitted to the compression data by use of the same basic equation used for compressive properties in Report 1831.[3] The relationship between compressive strength and laminate thickness for cross-laminated 181-114 laminates, as shown in Report 1831 is also reproduced here for comparison.

Figure 32 shows the relationship between laminate thickness and maximum bearing stress when loaded at each of three angles (0°, 90°, 45°) to the warp direction of the fabric. These empirical curves were drawn on the basis of the values given in table 24 for the individual angles of loading. The average values of maximum bearing stress given in table 24 form the basis of the solid curve shown in figure 33. The dashed curve shows a theoretical relationship calculated from the average maximum bearing stress values using the equation[3]

$$S_t = S_m - \frac{a}{t}$$

in which $\underline{S_t}$ is the maximum bearing stress at any thickness $\underline{t}$ within the range studied and $\underline{S_m}$ and $\underline{a}$ are constants calculated by the least-squares method described in Report 1831. This equation was shown in Report 1831 to describe fairly accurately the relationship, for several glass-fabric-base plastic laminates, between tensile or compressive strength and laminate thickness once the proper constants had been calculated from the data for each type of laminate and each condition of testing.

Since a 1/8-inch-diameter pin was used throughout the present study, varying the thickness of laminate resulted in a different value of the ratio D/t ($\underline{D}$ = pin diameter, $\underline{t}$ = laminate thickness) for each thickness of laminate, with an increase in laminate thickness resulting in a decrease in D/t. Figure 34 shows the relationship between these various D/t ratios and maximum bearing stress.

Figures 35, 36, and 37 show the effect of laminate thickness on bearing strength (stress at a deformation of 4 percent of the hole diameter), proportional limit stress, and deformation at proportional limit. In each of these, the values from table 24 for the individual angles of loading are shown, but the curve is plotted on the basis of the average values since there is no consistent relationship between those properties and the angle of loading.

Figure 38 shows typical load-deformation data for the various thicknesses of laminate tested. These are not average curves. They are designed merely to show the trends in deformation under load.

## Analysis of Results

The general pattern of stress-strain relationships in bolt-bearing of the 181 Volan A laminates studied appears to be about the same over the range of thicknesses from 0.02 inch to 0.12 inch as for the 181-114 laminates of 1/8- and 1/4-inch thicknesses previously studied. The thin laminates show greater deformation for a given load, as would be expected, and as is shown in the typical load-deformation curves in figure 38.

It is evident from an examination of figures 30 and 31 that the reduction in tensile and compressive strength with decreasing thickness of laminate is closely comparable to that found in a previous study.[2] The variations in this relationship from that shown in previous studies appears to be well within the limits of testing and laminate variability.

Figure 32 shows that a similar relationship holds for maximum bearing stress. There appears also to be a consistent relation between maximum bearing stress and angle of loading, with average values at each thickness decreasing in the order 0°, 45°, 90°. In spite of the fact that this relationship between maximum bearing stress and angle of loading seems quite distinct, its significance is somewhat questionable in view of the small number of tests at each angle and the fact that the manner of taking specimens from the test panels may have biased the results.

It was shown in Report 1824-A that at 0° and 90° loading a relationship exists between maximum stress in bearing and compressive strength. This relationship, however, has not been defined so that bolt-bearing properties can be predicted from compressive strength tests with any degree of accuracy. It was shown also that maximum bearing stress tends to decrease as the D/t ratio is increased. As laminate thickness is decreased over the range studied, using a constant pin diameter, the reduction in maximum bearing stress may be attributed to either the influences of reduced compressive strength in thin laminates, the higher D/t ratio, or both of these effects acting simultaneously.

If the reduction in maximum bearing stress with reduced laminate thickness were due primarily to the reduced compressive strength, it could reasonably be expected that the equation

$$S_t = S_m - \frac{a}{t}$$

which has been shown to be descriptive of the relationship between compressive strength and laminate thickness, would also describe the relationship between maximum bearing stress and laminate thickness. It is apparent from a comparison of the data with the curve calculated by means of the equation, shown in figure 33, that this is not the case. The thicker laminates give values of maximum bearing stress well above the values indicated by the curve, while the thinner laminates (approximately 1/16 inch and less in thickness) give values generally below those indicated by the curve. This indicates that some other effect, probably that of the D/t ratio, is at least partially responsible for the reduction of maximum bearing stress with reduced laminate thickness. The comparison points particularly to the effect of the D/t ratio since the thicker laminate, giving high maximum bearing stress values, had a low D/t ratio, while the thinner laminates, which gave values generally below the calculated values, had high D/t ratios and would be expected to give lower maximum stress values for this reason alone.

The fact that a definite relationship exists between D/t ratio and maximum bearing stress is shown by figure 34. When the observed values are compared with those previously reported for 181-114 laminates at similar D/t ratios but greater thicknesses, however, it is apparent that there is good agreement at a D/t ratio of 1 but considerable difference at a D/t ratio of 4. The previously reported value at a D/t ratio of 4 was obtained from tests of a laminate 1/8 inch thick. In the present study, the same D/t ratio was represented by a laminate of about 0.03 inch thickness. This indicates that the D/t ratio is not solely responsible for reduced maximum bearing stress in the thinner laminates.

It can be concluded, on the basis of the above observations and comparisons, that both D/t ratio and laminate thickness have an effect in establishing the level of maximum bearing stress. In laminates 1/8 inch or more in thickness, it appears that thickness has little effect on maximum bearing stress, and laminates of different thicknesses at the same D/t ratio would be expected to show similar values. In laminates 1/16 inch or less in thickness, the thickness appears to influence the maximum bearing stress quite strongly, so that the maximum bearing stress is dependent on both the thickness and the D/t ratio. In the range of thickness between 1/16 inch and 1/8 inch, the data are insufficient to evaluate the relative influence of laminate thickness and D/t ratio. It would appear, however, that laminate thickness has a slight effect on maximum bearing stress, which tends to reduce the values somewhat more than would be expected on the basis of D/t ratio alone.

Figures 35, 36, and 37 show that bearing strength, stress at proportional limit, and deformation at proportional limit are all reduced with decreasing thickness of laminate below approximately 1/8 inch. The relationship to thickness is similar to that shown by maximum bearing stress. Since data are not available for comparing these properties with similar observations in compression tests, and since they are generally of less importance than maximum bearing strength in engineering applications of glass-fabric reinforced plastic laminates, no detailed analysis is attempted. It was not possible to establish any relationship of thickness to deformation at maximum load, probably because of the rapidity of failure and the resultant uncertainty as to deformation at the point of failure.

## Conclusions

An analysis of the test results leads to the following conclusions:

1. Maximum stress in bearing, bearing strength, stress at proportional limit, and deformation at proportional limit are all reduced as laminate thickness is decreased below 1/8 inch.

2. The relationship of the above properties to laminate thickness is somewhat similar to that previously established for tensile and compressive strength.

3. The relationship of the above properties to laminate thickness appears to be generally independent of angle of loading.

4. Maximum bearing stress of laminates below 1/8 inch in thickness is dependent on both laminate thickness and D/t ratio. The effect of laminate thickness is especially noticeable as thickness is reduced to 1/16 inch or less. At thicknesses greater than 1/8 inch, maximum stress in bearing appears to be independent of laminate thickness and largely dependent on D/t ratio.

Table 23.--Average values of thickness, resin content, specific gravity, and Barcol hardness for laminated panels. All panels were parallel-laminated of 181 Volan A fabric and Selectron 5003 resin.

| Panel No. | Number of plies of fabric | Thickness | Resin content | Specific gravity | Barcol hardness |
|---|---|---|---|---|---|
| | | In. | Percent | | |
| 389 | 2 | 0.021 | 35.0 | 1.74 | (1) |
| 390 | 3 | .031 | 35.3 | 1.78 | 58 |
| 391 | 4 | .040 | 33.9 | 1.80 | 70 |
| 392 | 6 | .059 | 33.0 | 1.81 | 70 |
| 393 | 12 | .115 | 32.6 | 1.84 | 70 |

[1] Material of this thickness is too thin to give Barcol hardness values.

Table 24.--Bolt-bearing properties of plastic laminates of five thicknesses. All laminates were parallel-laminated with 181 Volan A glass fabric. Tests were conducted in the dry condition only using a 1/8-inch pin. Each value is an average of results from five tests in which failure was by crushing under the bolt.

| Thickness | Angle of loading | Bearing strength[1] | Proportional limit | | Maximum load | | Tensile strength | Compressive strength |
|---|---|---|---|---|---|---|---|---|
| | | | Defor-mation | Stress | Defor-mation | Stress | | |
| In. | Degrees | P.s.i. | In. | P.s.i. | In. | P.s.i. | P.s.i. | P.s.i. |
| 0.020 | 0 | 16,510 | 0.0018 | 8,960 | 0.0093 | 17,380 | 44,520 | 31,830 |
| | 90 | 15,120 | .0010 | 8,260 | .0061 | 15,600 | | |
| | 45 | 16,950 | .0012 | 9,130 | .0086 | 17,540 | | |
| | Av.[2] | 16,420 | .0013 | 8,780 | .0080 | 16,840 | | |
| .030 | 0 | 20,060 | .0015 | 10,980 | .0087 | 20,830 | 46,500 | 29,350 |
| | 90 | 15,890 | .0024 | 9,830 | .0092 | 17,220 | | |
| | 45 | 18,450 | .0018 | 9,670 | .0054 | 18,430 | | |
| | Av.[2] | 17,920 | .0019 | 10,160 | .0077 | 18,820 | | |
| .039 | 0 | 23,490 | .0022 | 14,370 | .0086 | 24,600 | 48,880 | 31,700 |
| | 90 | 21,180 | .0026 | 15,190 | .0088 | 22,200 | | |
| | 45 | 22,510 | .0027 | 16,160 | .0083 | 23,000 | | |
| | Av.[2] | 22,390 | .0025 | 15,240 | .0086 | 23,260 | | |
| .057 | 0 | [3]35,280 | .0029 | 25,080 | .0057 | 35,580 | 51,870 | 37,770 |
| | 90 | [4]31,440 | .0028 | 25,050 | .0051 | 32,700 | | |
| | 45 | [3]34,180 | .0029 | 25,430 | .0057 | 34,320 | | |
| | Av.[2] | 34,360 | .0029 | 25,180 | .0055 | 34,200 | | |
| .115 | 0 | 42,460 | .0038 | 34,970 | .0081 | 55,140 | 51,800 | 42,740 |
| | 90 | 41,420 | .0034 | 30,730 | .0070 | 49,110 | | |
| | 45 | 40,990 | .0034 | 30,180 | .0087 | 50,910 | | |
| | Av.[2] | 41,620 | .0035 | 31,960 | .0079 | 51,720 | | |

[1] Bearing stress at a deformation of 0.005 inch.

[2] Average values are average of all original test results at this thickness, rather than average of values presented for the individual angles.

[3] Based on four tests.

[4] Based on one test.

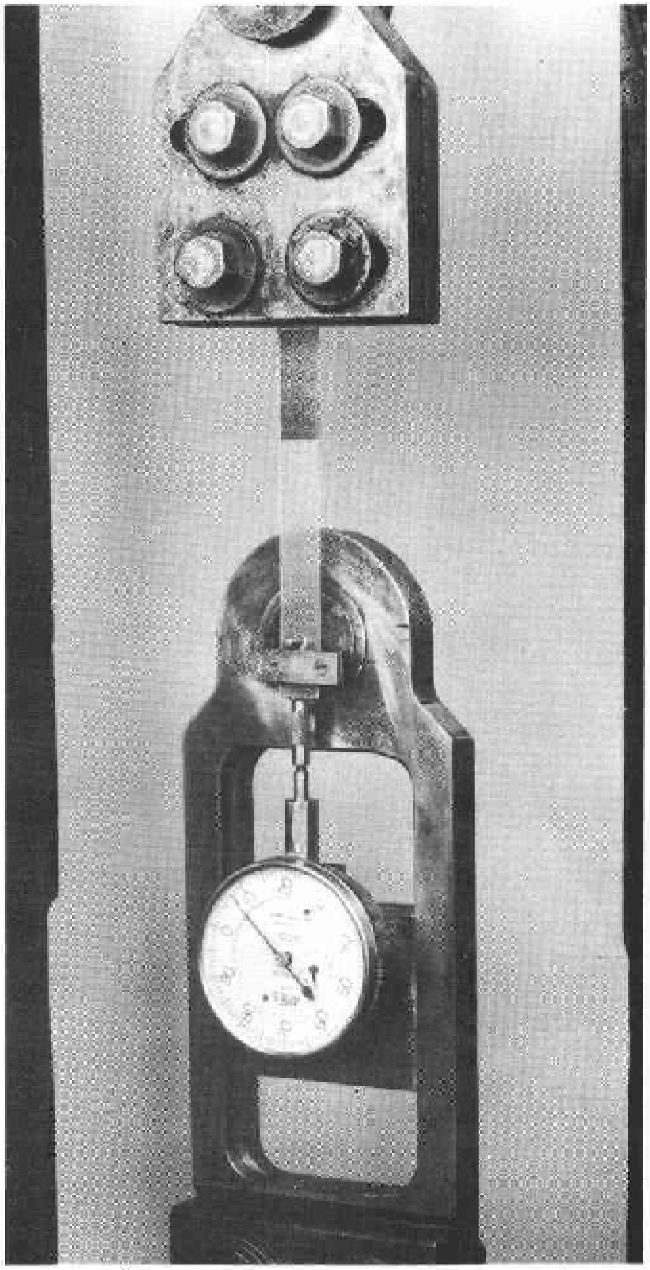

Figure 29.--Test set-up for bolt-bearing tests of thin, glass-fabric-reinforced laminates, showing steel supporting plates beneath pin to prevent buckling. Side plate on rear side has been removed for purposes of illustration. Specimen shown has failed by crushing under the bolt.

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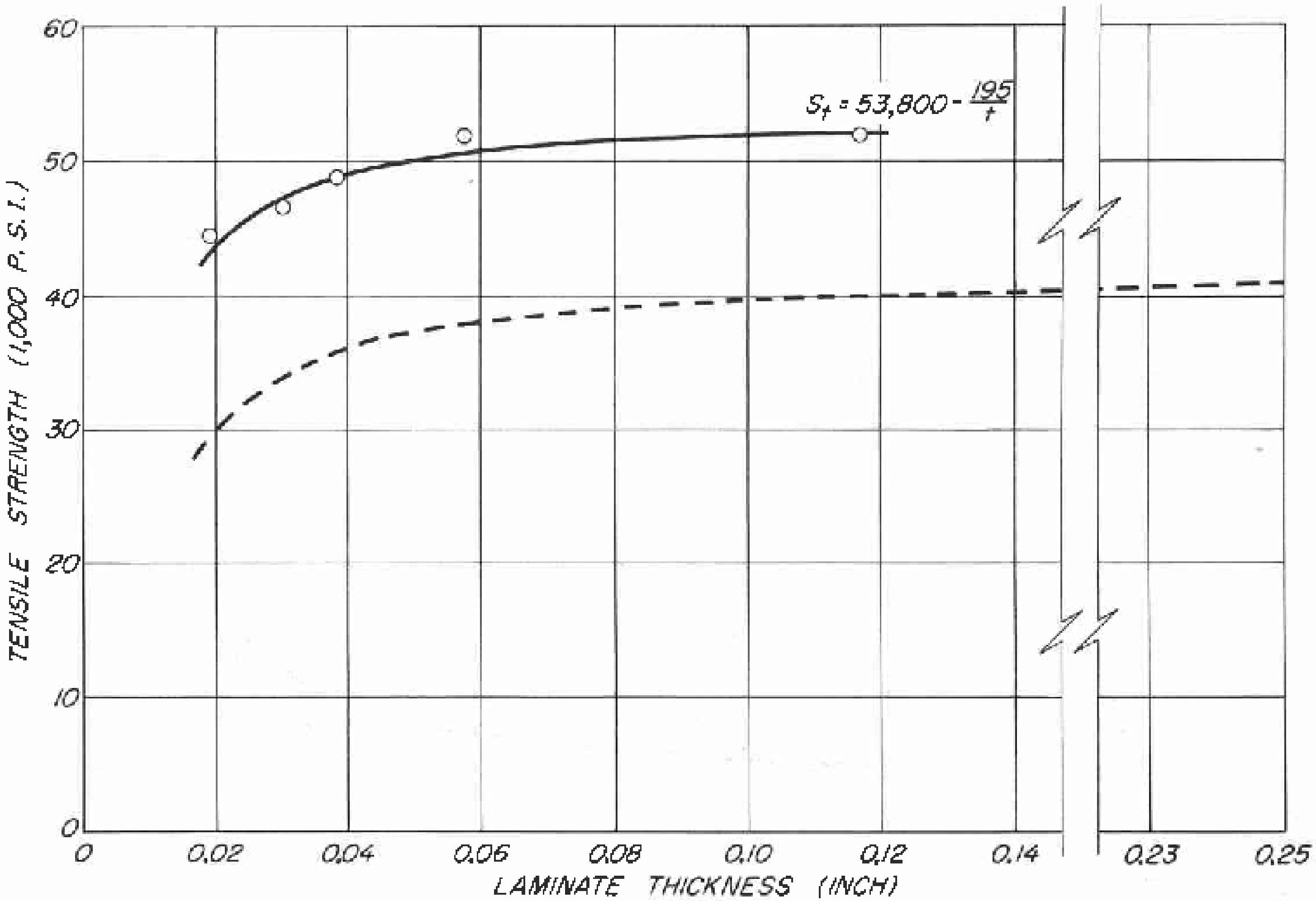


Figure 30.--Effect of thickness on tensile strength parallel to warp of parallel-laminated 181-Volan A laminate. Each point is the average of 5 tests. Dashed curve gives similar comparison for 181-114 cross-laminated laminate as reported in Forest Products Laboratory Report 1831.

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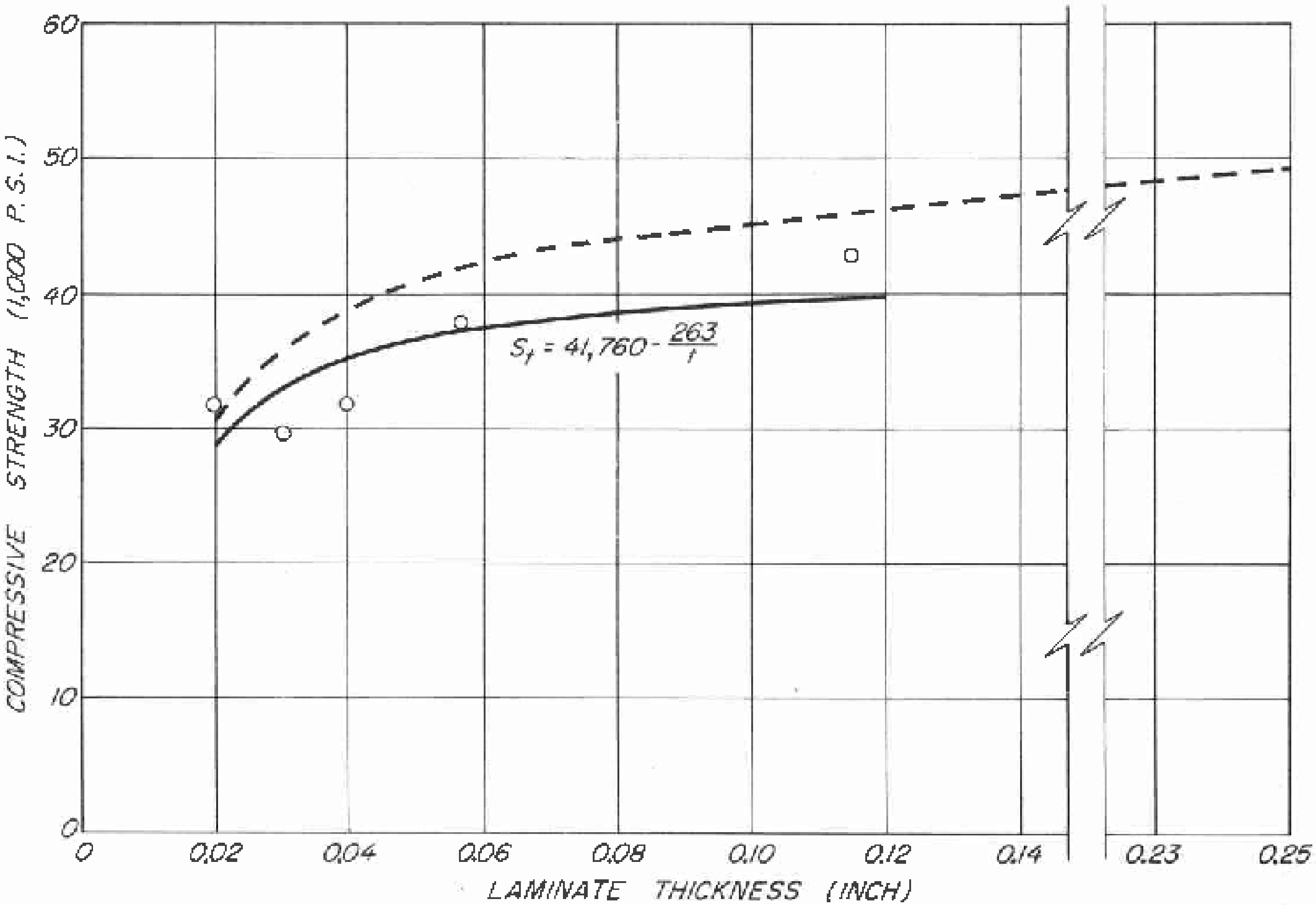


Figure 51.--Effect of thickness on compressive strength parallel to warp of parallel-laminated 181-Volan A laminate. Each point is the average of 5 tests. Dashed curve gives similar comparison for 181-114 cross-laminated laminate as reported in Forest Products Laboratory Report 1831.

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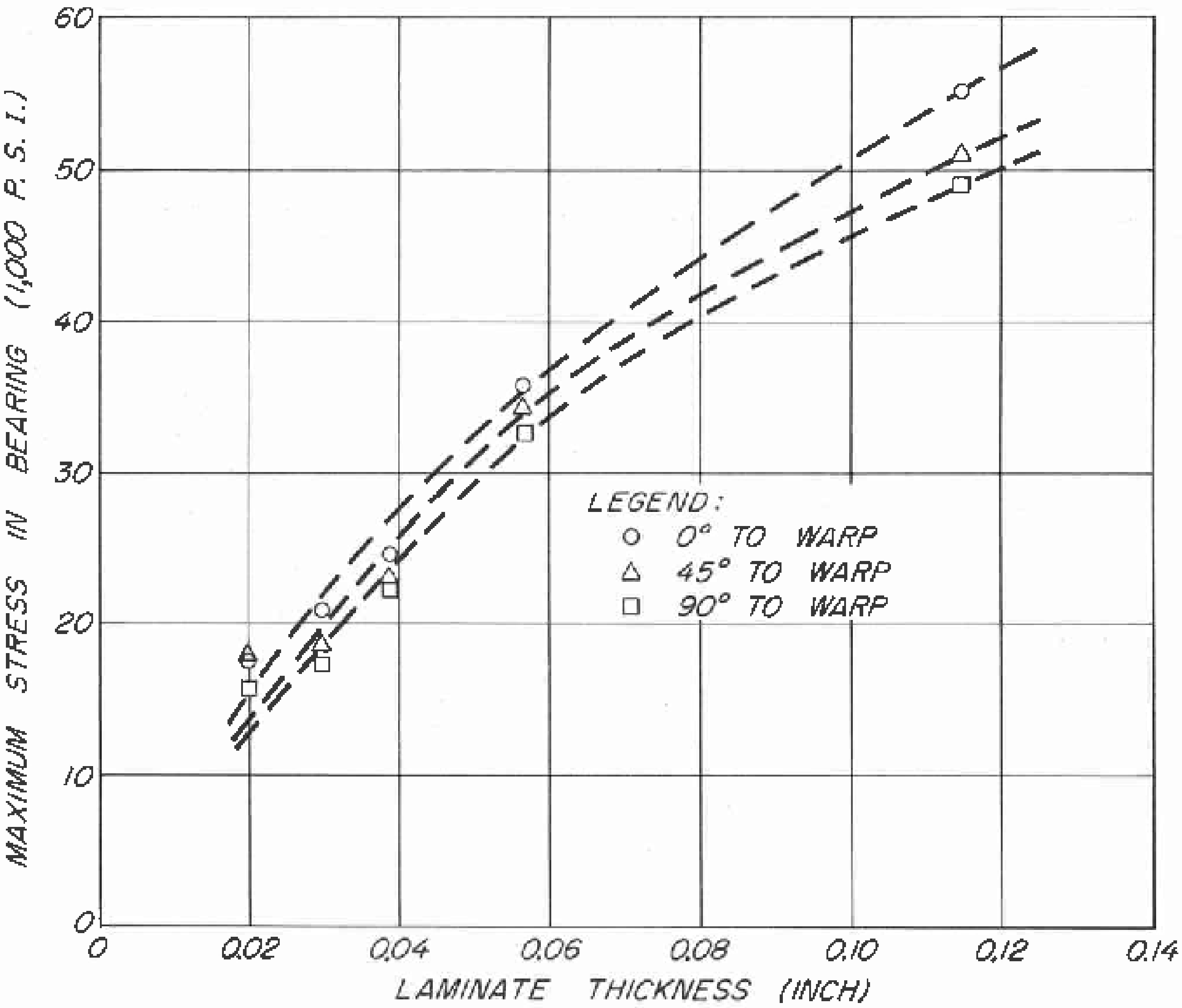


Figure 32.--Relationship between thickness and maximum stress in bearing of parallel-laminated 181-Volan A laminate. Each point is the average of 5 tests made with a 1/8-inch-diameter pin.

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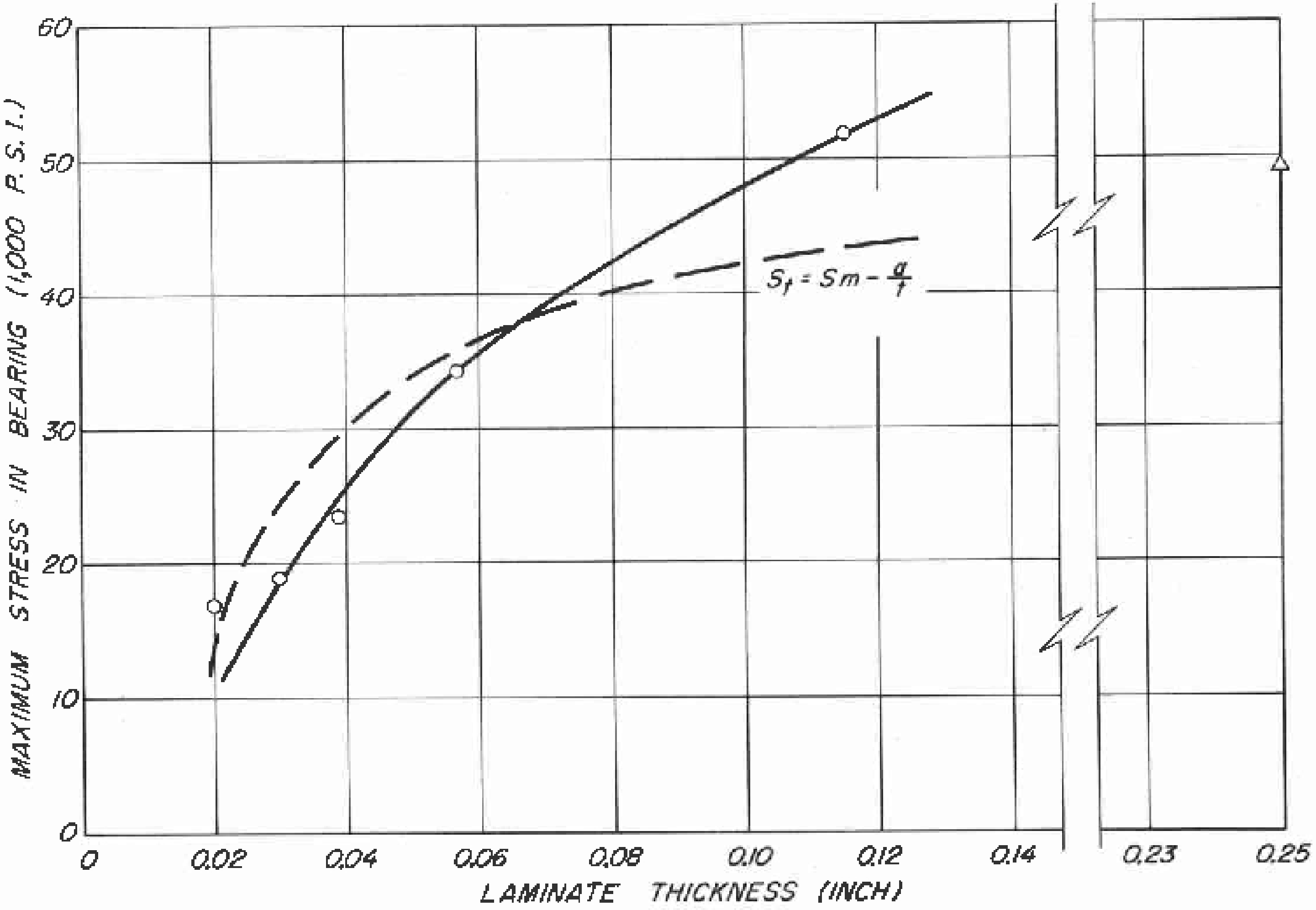


Figure 33.--Relationship between thickness and maximum stress in bearing of parallel-laminated 181-Volan A laminate. Each point is the average of test results at all angles of loading. Triangular plotted point gives comparable value for 181-114 parallel-laminated laminate 1/4 inch thick at a D/t of 1.

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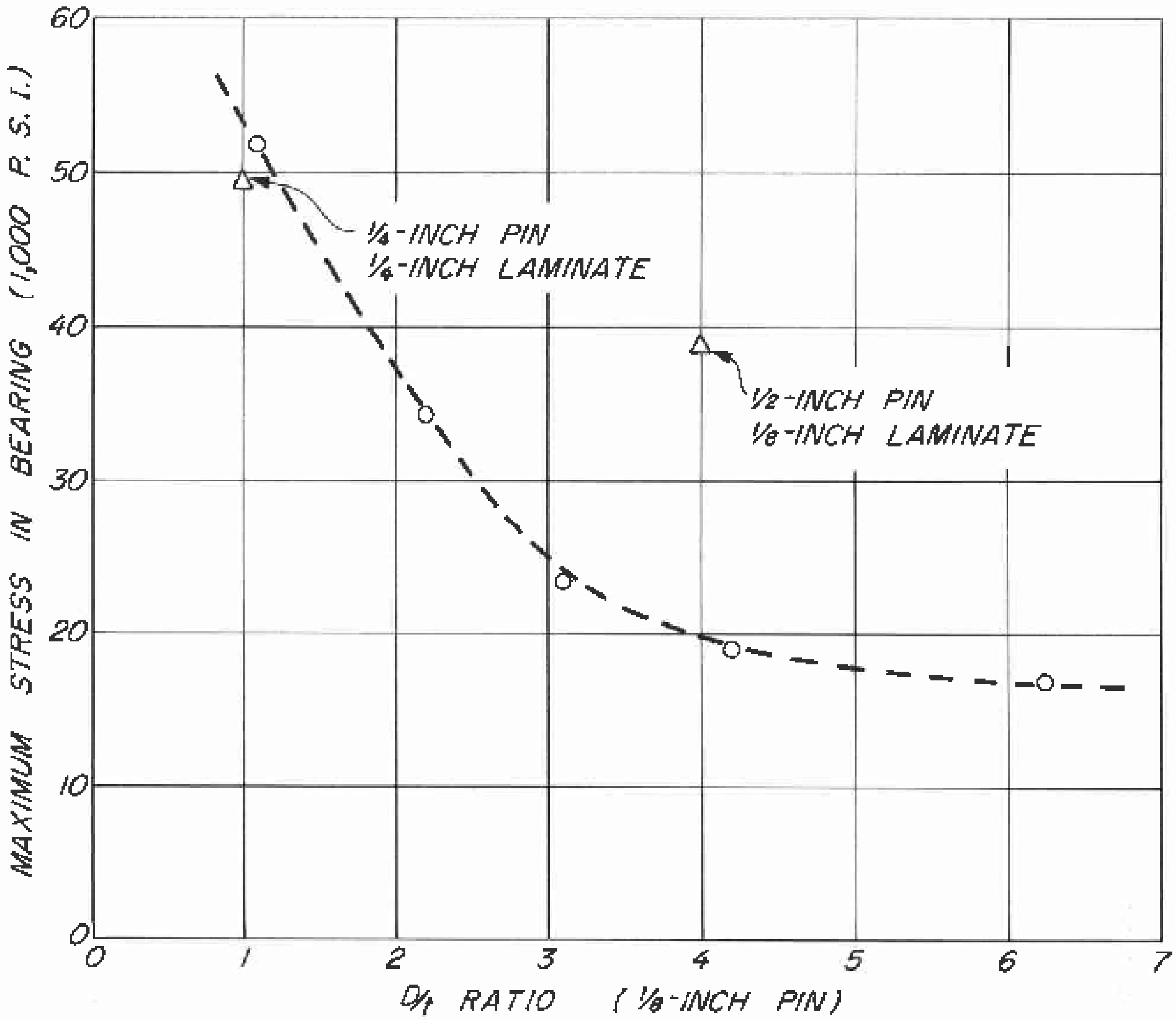


Figure 34.--Relationship between D/t ratio and maximum stress in bearing of parallel-laminated 181-Volan A laminate. Triangular plotted points give comparable values for 2 thicknesses of 181-114 laminate.

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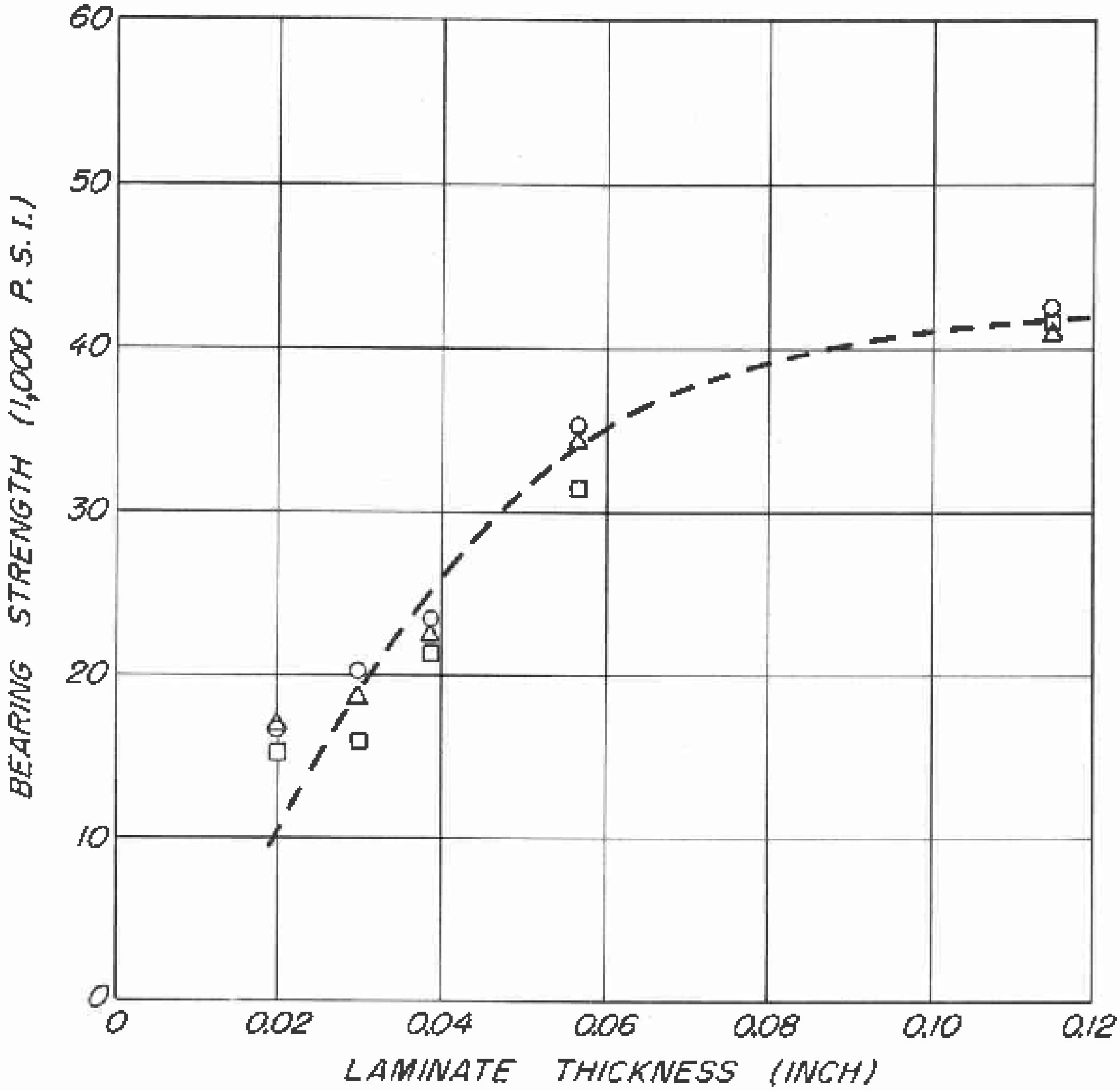


Figure 35.--Relationship between thickness and bearing strength (stress at 4 percent deformation) of parallel-laminated 181-Volan A laminate. Each point is the average of 5 tests made with a 1/8-inch-diameter pin.

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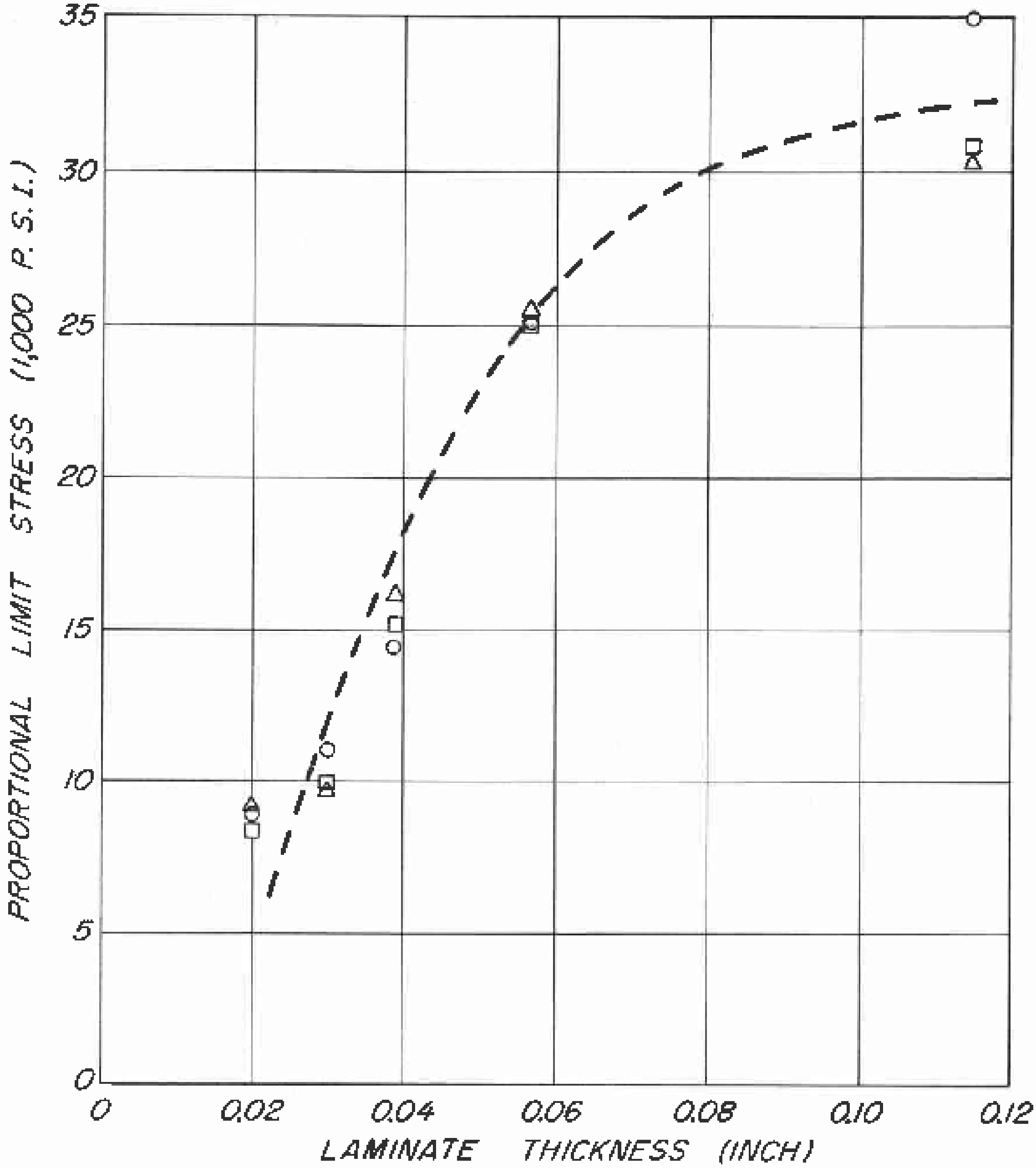


Figure 36.--Relationship between thickness and stress at proportional limit of parallel-laminated 181-Volan A laminate. Each point is the average of 5 tests made with a 1/8-inch-diameter pin.

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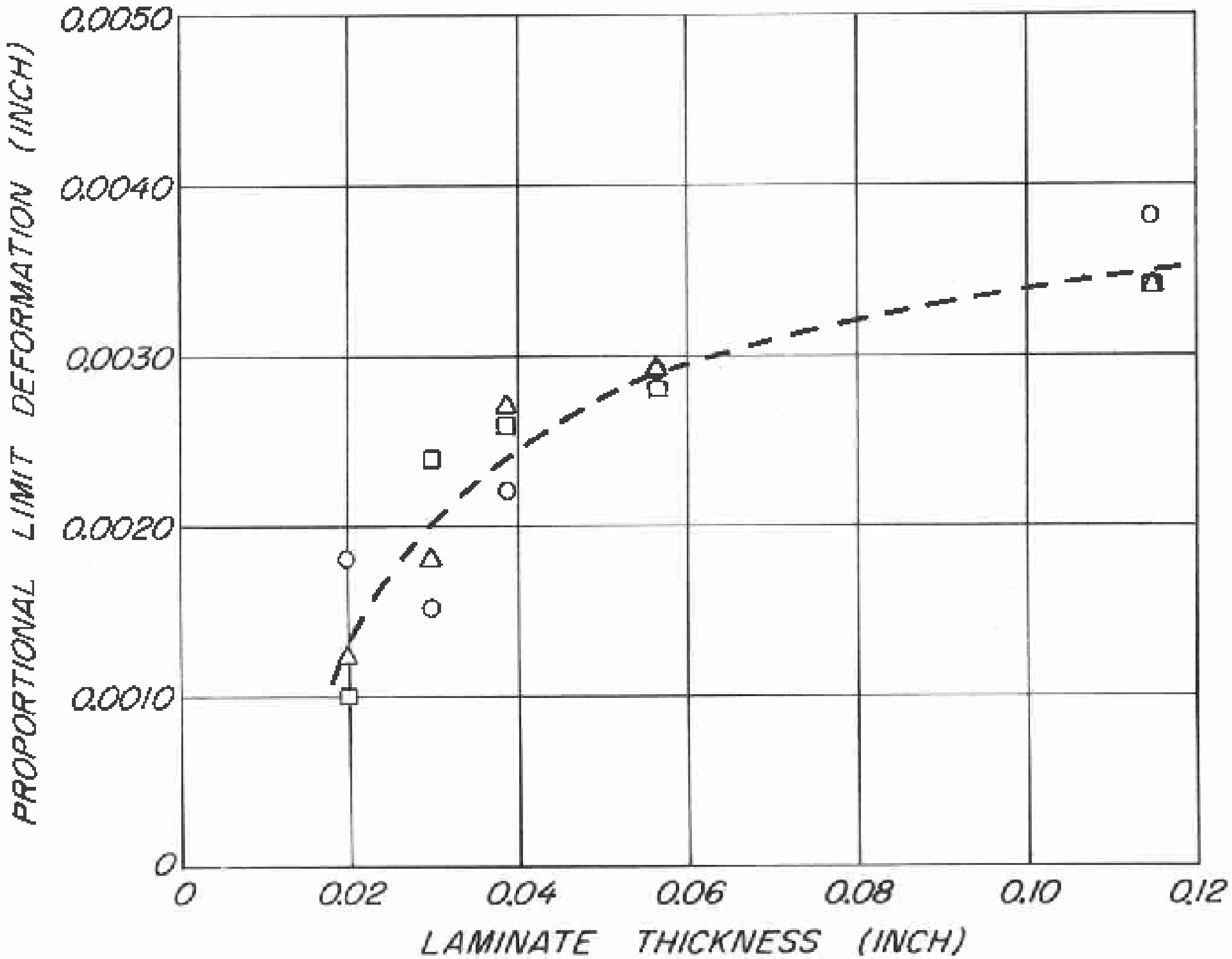


Figure 37.--Relationship between thickness and deformation at proportional limit of parallel-laminated 181-Volan A laminate. Each point is the average of 5 tests made with a 1/8-inch-diameter pin.

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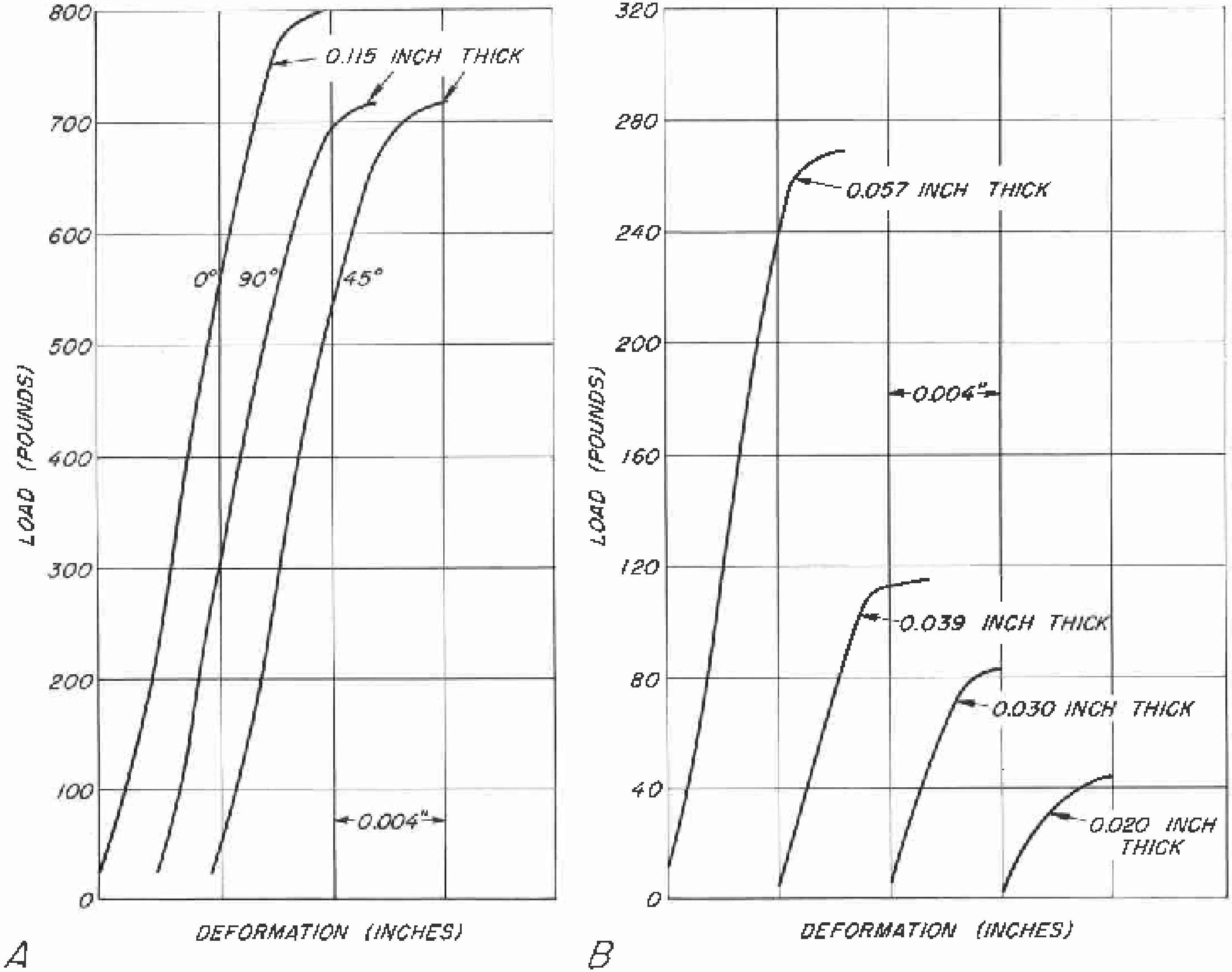


Figure 38.--Typical load-deformation curves in bearing for parallel-laminated 181-Volan A laminate of five thicknesses. All specimens were tested in the dry condition with a 1/8-inch-diameter pin. A, curves for 0.115-inch thickness; B, curves for other thicknesses as given.

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