BOLT-BEARING STRENGTH OF WOOD AND MODIFIED WOOD

BOLT-BEARING STRENGTH OF LABORATORY-MADE CROSS-BANDED YELLOW BIRCH COMPREG UNDER AIRCRAFT BOLTS

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BOLT-BEARING STRENGTH OF WOOD AND MODIFIED WOOD

Bolt-bearing Strength of Laboratory-made Cross-banded Yellow Birch Compreg Under Aircraft Bolts[1, 2, 3]

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Summary

This report presents the results of 354 bearing tests of single-bolt specimens of Laboratory-made, cross-banded yellow birch compreg under steel aircraft bolts. The tests were made to obtain information concerning (1) the bolt-bearing strength of the material for different combinations of thickness, grain direction, and bolt diameter, and (2) the minimum edge clearances and end margins required to develop the full bolt-bearing strength of the material. Edge clearance is defined here as the dimension perpendicular to the direction of loading from the center of the bolt hole to the edge of the member. End margin is defined as the dimension from the center of the bolt hole to the free end of the member. Three thicknesses (1/4, 1/2, and 1 inch) of compreg and three bolt diameters (1/4, 1/2, and 1 inch) were investigated under compressive, modified compressive, and tensile loading. Loads were applied at angles of 0°, 45°, and 90° to the face grain of the compreg.

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[1] This report is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data become available.

[2] This is one of a series of reports dealing with bolt-bearing strength of wood and modified wood. The first report was Report No. 1523. Other reports will be issued as data become available.

[3] For information on other properties of Laboratory-made cross-banded yellow birch compreg, see table 2-14 of ANC Bulletin No. 18.

The average ultimate bearing stresses, under 1/4-, 1/2-, and 1-inch bolts, as indicated by these tests, were approximately 34,000, 30,000, and 28,000 pounds per square inch, respectively. With one exception, the minimum values were at least 83 percent of these averages. The average bearing stresses at proportional limit were about 50 percent of the average ultimate stresses under tensile loading and about 60 percent under compressive loading.

With adequate edge clearance and end margin, the grain direction of the face plies had no apparent effect on either the proportional limit or the ultimate bearing stress of the compreg. The bearing stress decreased as the diameter of the bolt increased. The thickness of the compreg showed no consistent effect on the bearing stress.

Under compressive loading, an edge clearance equal to twice the diameter of the bolt was adequate to develop the full bearing capacity of the compreg regardless of the angle between the direction of loading and the grain of the face plies. Under tensile loading, however, the necessary edge clearance was larger than for compressive loading, and was influenced by the grain direction. The necessary edge clearances were 3, 2-1/2, and 4 diameters for 0°, 45°, and 90°, respectively. The necessary end margins for 1/4-inch bolts under tensile loading were 5, 3, and 4 diameters for 0°, 45°, and 90°, respectively, and slightly less for bolts of larger diameter. The necessary end margins as determined by modified compressive loading were essentially in agreement with those determined by tensile loading.

The bearing strength of compreg was sufficient to develop the double shear strength of a steel aircraft bolt at a bearing length equal to at least four times the diameter of the bolt.

No definite relationship between bolt-bearing strength and compressive strength is indicated by the results of these tests.

The most consistent critical edge clearances and end margins and the most consistent bearing stress values were obtained for compreg having face grain at 45° to the direction of loading.

Introduction

The bolt-bearing strength of compreg is greater than that of either wood or plywood. Although a comparatively new material, compreg has found application as a reinforcing material in bolted connections in wood aircraft. Designers have not been able to take full advantage of its greater bolt-bearing strength, however, because of lack of appropriate information. This investigation of the bearing strength of Laboratory-made compreg under steel aircraft bolts was undertaken at the request of the ANC Subcommittee on Wood Design Criteria to provide preliminary design data. Specific information was desired concerning (1) the bolt-bearing strength of cross-banded yellow birch compreg for different combinations of thickness, grain direction, and bolt diameter, and (2) the minimum edge clearances necessary under both tensile and compressive loading and the minimum end margins necessary under tensile loading to develop the full bolt-bearing strength of the material.

Edge clearance is defined as the dimension perpendicular to the direction of loading from the center of the bolt hole to the edge of the member. End margin is defined as the dimension from the center of the bolt hole to the free end of the member. Referring to either edge clearance or end margin, the critical dimension is that which is barely adequate to prevent failure under load in a manner other than in bearing.

The investigation covered by this report was preparatory to a more comprehensive study of the bolt-bearing properties of commercial cross-banded compregs. It afforded an opportunity to develop testing techniques and served to define the scope of the subsequent work. The conclusions presented herein should be regarded as tentative pending confirmation by the tests of commercial compreg.

Description of Material

The compreg was made at the Forest Products Laboratory from 1/16-inch yellow birch veneers impregnated with water-soluble phenol-formaldehyde resin and bonded together without the use of additional adhesives. The number of plies varied with the finished thickness of compreg, the 1/4-, 1/2-, and 1-inch material containing 7, 13, and 25 plies, respectively. The veneers were cross banded, placed between metal cauls, and pressed at 1,300 to 1,800 pounds per square inch for periods of 25 to 60 minutes, the length of time depending on the thickness of the panel. The temperature of the panels during pressing was 310° F. All panels were removed from the press while still hot. Additional detailed information including specific gravity for each panel is presented in table 1.

Steel aircraft bolts conforming to Army-Navy Specification AN-B-3a were used. This specification contemplates the use of bolt stock with a tensile yield strength of approximately 96,000 pounds per square inch and an ultimate strength of approximately 125,000 pounds per square inch. It provides the following tolerances in bolt diameters: 1/4 inch, 0.249 (+0.0000:-0.0030) inch; 1/2 inch, 0.499 (+0.0000:-0.0035) inch; and 1 inch, 0.999 (+0.0000:-0.0055) inch.

Preparation of Specimens

The variables studied in this investigation included diameter of bolt, thickness of compreg, edge clearance, end margin, grain direction of face ply, and type of loading. For the bolt-bearing tests each initial series consisted of from 2 to 5 specimens, the majority containing 3, in which either edge clearance or end margin was varied over a range intended to bracket the critical dimension. Supplemental specimens were prepared, where required, to extend the range of dimensions or to reduce the increments and thus facilitate more precise determination of the critical dimension. Specimens of each initial series were cut adjacent to each other; supplemental specimens were cut from locations in the same panel as near as possible to the initial series. Specimens for minor compression and specific gravity tests were taken at random from each panel and were presumed to represent the entire panel.

Each bolt-bearing specimen was marked to indicate the panel number, manner of loading, and the numerical order of specimens taken from that panel for that manner of loading. For example, the marking 1-BT-3 designated the third bolt-bearing specimen selected from panel No. 1 for tensile loading. A layout sheet was made for each panel to show the locations of all specimens.

Specimens were cut by means of hollow-ground high-carbon steel saws, such as are used for cutting soft metals. Saws varied from 8 to 14 inches in diameter and were rotated at speeds varying from 870 to 2,670 revolutions per minute, with the larger saws and slower speeds used for the thicker material.

All holes were drilled 1/64 inch undersize with a twist drill, sharpened as for metal, and then reamed to the finished dimension. Specimens with a 1/4- or 1/2-inch hole were drilled and reamed on a hand-feed drill press using a speed of about 500 revolutions per minute for drilling and about 300 revolutions per minute for reaming. A rate of feed less than 1 inch per minute was used for drilling and about 10 inches per minute for reaming. Specimens with a 1-inch hole were drilled and reamed on a vertical boring mill using a speed of about 100 revolutions per minute for drilling and about 50 revolutions per minute for reaming. The hand-feed attachment of the boring mill was used to secure a rate of feed similar to that employed for the 1/4- and 1/2-inch holes. The lower reaming speed was used for all holes to lessen the possibility of overheating and damaging the reamer. As a safety precaution, all specimens were clamped tightly to the bed of the machine before drilling and reaming. The edges of the reamed holes were sharp and clean-cut, and the walls had a pronounced shine. The fit of the bolt in the hole was such that insertion required only hand pressure.

All specimens were conditioned at 70° F. and 64 percent relative humidity for at least 48 hours before testing. This conditioning was intended to relieve internal stresses that might have been caused by sawing, drilling, or reaming, but was not of sufficient duration to bring the specimens to moisture equilibrium. Attainment of moisture equilibrium would have necessitated a much longer conditioning period and would have delayed the testing schedule excessively.

Test Procedure

General Discussion of Bolt-bearing Tests

The methods and apparatus employed in all bolt-bearing tests were designed to determine the true bearing properties of compreg, uninfluenced by friction or other mechanical restraint between the compreg and the fittings. It was recognized that these factors are present in varying degrees in all bolted fastenings and that they tend to augment the actual bearing strength of the material. Because the degree of restraint thus imposed, however, cannot be readily evaluated, accurate appraisal of the results of bolt-bearing tests cannot be made unless their influence is eliminated.

In order to minimize errors due to external restraint, all fittings used in this investigation were equipped with interchangeable, hardened steel, recessed bushings of the type shown in figure 1. This type of bushing was developed through exploratory bolt-bearing tests. In experiments employing unrecessed bushings, accurate determination of the ultimate bearing load was virtually impossible because of the added restraint imposed by compacting the extruded fibers of compreg between the specimen and the bushing.

In the improved bushing, the projecting lug supports the bolt at the face of the specimen and, together with the slotted recess above the bolt, provides clearance of 1/4 inch along the loaded surface of the bolt. This clearance permits free lateral movement of the crushed fibers of compreg and prevents their being compacted against the bushing. The width of the recess is equal to the diameter of the bolt hole; that of the lug is made slightly less to avoid sharp, easily broken edges and corners. Proper orientation is insured by either a set screw or a key inserted in the fitting so as to engage the flattened side of the bushing.

As an added precaution, a clearance of at least one-sixteenth inch was left between the specimen and the vertical fittings and between the head of the test bolt and the bushing. The nut was omitted from the bolt.

The rate of loading was such as to produce a deformation of about 0.01 inch per minute. In general, this rate made possible at least 10 readings of load and deformation below the proportional limit. Bolts were inspected before use and after each test, and bent bolts were discarded.

Bolt-bearing strengths and critical dimensions were determined by tests employing three different methods of loading: compressive, modified compressive, and tensile. Supplementary tests were made to determine compressive strength.

With few exceptions, all combinations of diameter of bolt and thickness of compreg were tested with the load applied at angles of 0°, 45°, and 90° to the grain of the face plies.

Bolt-bearing Tests Under Compressive Loading

The specimen was supported on an aircraft bolt resting in two vertical mild steel fittings as shown in figure 2. The fittings were separated at the base by steel spacer blocks of various lengths to accommodate specimens of different thicknesses. Figure 3 shows the inner face of half of the fitting with the test bolt, bushing, and spacer blocks in place. Load was applied to the entire top surface of the specimen by means of a flat plate attached rigidly to the upper platen of the testing machine. No spherical bearing block was used because of difficulties encountered in obtaining correct seating of the head in tests of wide specimens of 1/4-inch compreg. To achieve uniformity in all tests with compressive and modified compressive loading, the rigid plate was used throughout.

The deformation of the specimen at the bolt hole was measured by means of a 1/10,000-inch dial mounted on the extension arm shown in figure 2. This equal-lever extension arm was calibrated and found to be sufficiently rigid to operate satisfactorily the comparatively stiff spring in such a dial.

Only bearing strength and edge clearance were determined by this method. The specimens used for 1/4- and 1/2-inch bolts were 4 inches high with the center of the hole 2 inches from the top or loaded end; those used for 1-inch bolts were 6 inches high with center of hole 4 inches from the top. Five specimens, each of a different width, usually constituted a series.

This series was repeated for three grain directions and for eight combinations of thickness and bolt diameter, consisting of 1/4- and 1/2-inch bolts in 1/4-, 1/2-, and 1-inch compreg and 1-inch bolts in 1/2- and 1-inch compreg.

Bolt-bearing Tests Under Modified Compressive Loading

The tests with modified compressive loading differed from those with compressive loading only in the area of contact between the specimen and the loading head. In modified compressive loading, the load was applied symmetrically to the top of the specimen for a distance of only 1-1/2 inches from each edge by means of steel blocks (fig. 4). The desirable gap between the loading blocks was determined by exploratory tests. This method was intended to produce stresses in the specimen and a type of failure resembling those produced by tensile loading. The unloaded middle portion of the specimen above the bolt was free to fail by shearing or bending as long as the end margin was insufficient to develop the full bearing strength. This method permitted approximate determination of critical end margins for tensile loading more rapidly and for wider ranges of diameter of bolt and thickness of compreg than was possible by the method employing tensile loading.

Tests made by this method included 1/4-inch bolts in 1/4- and 1/2-inch compreg, 1/2-inch bolts in 1/4-, 1/2-, and 1-inch compreg, and 1-inch bolts in 1/2- and 1-inch compreg. Most of these combinations were tested with the face grain at angles of 0°, 45°, and 90° with the direction of loading. Specimens for both 1/4- and 1/2-inch bolts were 5 inches wide; those for 1-inch bolts were 6 inches wide. Sufficient margin was maintained below the bolt in all tests so that the specimen as a whole could not fail as a beam. In general, five specimens, each with a different end margin, constituted a series for a given bolt and thickness of compreg.

Bolt-bearing Tests Under Tensile Loading

In the tests to determine the bolt-bearing strength under tensile loading the specimen was suspended on an aircraft bolt between two fittings of a specially designed tension jig, and a self-aligning tension grip was attached to the lower end (figs. 5 and 6). Both the jig and the tension grip were equipped with spherical bearing blocks to facilitate alignment of the entire assembly. For specimens not more than 2 inches wide, the jaws of the grip were at least as wide as the specimen; for all specimens wider than 2 inches, the 2-inch jaws were used. The deformation of the specimen at the bolt hole was measured by two symmetrically placed, 1/10,000-inch dial gages attached to the fittings and actuated by a cross-bar in knife-edge contact with the top of the specimen.

Both edge clearance and end margin were determined by tensile loading for 1/4- and 1/2-inch bolts in 1/4- and 1/2-inch compreg. Tensile loading was limited to this range because the loads obtained for 1/2-inch bolts in 1/2-inch compreg approached the capacity of the apparatus. Although the gripped surfaces were sanded, considerable difficulty was experienced in preventing slippage of the more heavily loaded specimens.

In general, five specimens of varying width constituted an edge-clearance series, and five specimens of varying end margins constituted an end-margin series. All specimens were 7 inches long. In the edge-clearance specimens, the centerline of the hole was 2-1/2 inches from the top of the specimen. After the critical edge clearance was determined for a given combination of diameter and thickness, this dimension was increased by at least the diameter of the bolt, and the increased dimension was used as the constant edge clearance for the end-margin specimens for that particular combination.

Tests for Compressive Strength

In the tests to determine the compressive strength of 1/4-inch compreg, 1/4- by 1- by 4-inch specimens were supported laterally in the apparatus shown in figure 7. Loads were applied parallel to the grain of the face plies, and deformations measured over a 2-inch gage length by means of a Martens' mirror compressometer. The rate of loading corresponded to a no-load speed of 0.012 inch per minute. The proportional limit and modulus of elasticity were determined by this method. After the proportional limit was attained, the test was suspended to avoid injury to the apparatus, and each specimen was cut to produce three 1/4- by 1- by 1-inch specimens, which were reconditioned for at least 48 hours and loaded to failure in compression without lateral support. Exploratory tests had demonstrated that ultimate strengths determined by this method were comparable with those obtained in tests of laterally supported 1/4- by 1- by 4-inch specimens.

For 1/2-inch compreg, 1/2- by 1/2- by 2-inch specimens, with grain of face plies parallel to the 2-inch dimension, were loaded axially and deformations measured over a 1-inch gage length by means of a Martens' mirror compressometer as shown in figure 8. The rate of loading corresponded to a no-load speed of 0.006 inch per minute. After the proportional limit was attained, the compressometer was removed and the test continued to failure.

For 1-inch compreg, 1- by 1- by 4-inch specimens were tested in a similar manner except that deformations were measured over a 2-inch gage length by means of a roller-type compressometer with averaging optical levers (fig. 9). The rate of loading corresponded to a no-load speed of 0.012 inch per minute.

Explanation of Tables

General information including dimensions, number of plies, manufacturing data, and specific gravity of each of the compreg panels from which specimens were prepared is presented in table 1.

A summary of the information obtained from both the bolt-bearing and compression tests is given in tables 2 through 5. In tables 2, 3, and 4, the data for bolt-bearing tests under compressive and modified compressive loadings are combined for angles of 0°, 45°, and 90° to the grain of the face plies, respectively. Table 5 consists of data for bolt-bearing tests under tensile loading for all three grain directions. In column 3 of each table are listed the numbers of the panels from which the specimens were cut. This information is included (1) to relate bolt-bearing specimens cut from the same panel of compreg, (2) to explain the duplication of compressive strengths associated with various bolt-bearing specimens cut from the same panel, and (3) to correlate information given in these tables with that given in table 1. Column 4 shows the total number of bolt-bearing specimens tested for each combination of bolt diameter and panel thickness.

Columns 5 and 6 show the number of specimens averaged to provide the data presented in columns 7 through 12. The number of specimens as listed in column 5 is usually smaller than in column 4 because the dimensions of some of the specimens were inadequate to develop the full proportional limit. The number in column 6 is always smaller than in column 5 because the minimum dimensions adequate for porportional limit were inadequate to develop the full bearing load. In table 2, for example, six 1/4-inch specimens were tested for edge clearance with 1/2-inch bolts under compressive loading, and four for end margin under modified compressive loading. Two of the total of 10 failed to develop the full proportional limit. Of the remaining eight, two failed before reaching the full bearing load.

Columns 8 through 11, tables 2, 3, and 4, contain values of bearing strength and deformation obtained under both compressive and modified compressive loading, since there was no marked difference between the values obtained by these two methods. Maximum, average, and minimum values are included. The relationship between proportional limit and ultimate strength in bearing is shown by the ratios listed in column 12.

Similar data with respect to compressive strength are presented in columns 13 through 18. No values were obtained for deformation at the ultimate compressive stress because of precautions taken to protect the measuring apparatus. Values of the modulus of elasticity in compression are shown in column 19.

The relationship between the bearing and compressive stresses at proportional limit and ultimate is shown by the ratios in columns 20 and 21. Critical edge clearances and end margins are shown in columns 22 and 23. In tables 2, 3, and 4, the edge clearances shown were determined only by compressive loading; the end margins for tension, only by modified compressive loading. Where both critical dimensions are shown, the values of bearing stress and deformation obtained by both methods of testing have been combined. In table 5, however, both dimensions recorded were determined by tensile loading.

In table 6, the critical dimensions are summarized according to diameter of bolt, thickness of compreg, method of loading, and grain direction. Average values of bearing stresses at proportional limit and ultimate are summarized in a similar manner in table 7, and average deformations at both proportional limit and ultimate in table 8.

Analysis of Results

Bolt-bearing Strength

Proportional limit loads were determined from load-deformation curves (fig. 10), which were obtained for all bolt-bearing tests. The rate of loading was such that at least 10 readings were obtained within the straight-line portion of the load-deformation curve. The departure of the curve from a straight line was usually so gradual that the exact limit of proportionality was not clearly defined. Wherever such uncertainty existed, the lowest probable value was selected; hence, the values presented in column 8, tables 2 through 5, are conservative.

Most specimens exhibited definite ultimate loads as illustrated by the load-deformation curve in figure 10. The curves for a limited number of tests became horizontal, but did not begin to decline immediately. Occasionally, after the curve had become horizontal or had even begun to decline, the load again increased. This behavior was attributed to lack of complete freedom of the specimen to deform, and loads thus attained were disregarded in recording the ultimate load. In those tests in which the ultimate load was not clearly defined, it was assumed to be the first load at which the curve remained horizontal or declined during an increment of deformation of at least 0.004 inch. The ultimate loads and the corresponding deformations determined in this manner agreed closely with clearly defined ultimate loads obtained for similar specimens.

In this investigation the determination of critical dimensions (edge clearance and end margin) was based on ultimate loads. Specimens in which the dimension under study was inadequate failed in some manner other than bearing, and usually at loads less than the true ultimate bearing load. The critical dimension was considered to have been attained when any further increase failed to produce an increase in the ultimate load. In general, all specimens in which the dimension was equal to or greater than the critical value, thus determined, failed in bearing.

Typical failures of specimens for each of the four kinds of bolt-bearing tests made in this investigation are shown in figures 11 through 14. The magnitude of the dimension under study and the loads at proportional limit and ultimate are shown for each specimen. The proportional limit loads in each of these four series were approximately the same for all specimens; hence, all were averaged in determining the bearing stress at proportional limit. The ultimate load, however, increased progressively with increases in the dimension until bearing failure was attained, after which they were practically uniform. Only these uniform values were averaged in determining the ultimate bearing stress.

The bearing area of each specimen was obtained by multiplying the measured thickness of the compreg by the measured diameter of the bolt. The unit bearing stress at the proportional limit or ultimate was found by dividing the appropriate load by the bearing area. This method is based on the assumption that the load is uniformly distributed over the projected area of the bolt.

In general, the proportional limit values obtained under tensile loading were from 10 to 35 percent lower than those obtained under compressive loading. The values of ultimate bearing stress, however, were about the same as those obtained under compressive loading. The average ultimate bearing stress of cross-banded compreg under 1/4-inch aircraft bolts was approximately 34,000 pounds per square inch; under 1/2-inch bolts, 30,000 pounds per square inch; and under 1-inch bolts, 28,000 pounds per square inch. The average proportional limit stresses under compressive loading were approximately 22,500, 18,000, and 15,000 pounds per square inch, respectively. The average proportional limit stresses under tensile loading were approximately 17,500 and 14,500 pounds per square inch for 1/4- and 1/2-inch bolts, respectively.

The average values for bearing stress at both proportional limit and ultimate, shown in tables 2 through 5, appeared to be unaffected by the grain direction of the face plies, although there was slightly less variation among individual values for angles of 45°, than for angles of 0° and 90°. There was a definite reduction in both proportional limit and ultimate bearing stress with an increase in the diameter of bolt. For any one diameter of bolt there was no consistent relationship between these stresses and the thickness of compreg. The ratio of the average proportional limit to average ultimate varied from 0.39 to 0.78 (average 0.60) for compressive and modified compressive loading, and from 0.40 to 0.60 (average 0.50) for tensile loading.

The results obtained in this investigation do not indicate any definite relationships between bolt-bearing strengths and average compressive strengths. Columns 20 and 21 in tables 2 through 5 show the computed ratios of bolt-bearing stress to compressive stress at both the proportional limit and ultimate. Both ratios vary over a wide range and exhibit no consistent trends. It is possible that more definite relationships would have been apparent had the materials studied provided a wider range in bearing and compressive strength.

Edge Clearance and End Margin

The critical dimensions determined by these tests under both tensile and compressive loading, recorded in table 6, were influenced but little by the thickness of the compreg within the range from 1/4 to 1 inch, but varied directly with the diameter of the bolt. It is convenient, therefore, to express these dimensions in terms of diameter, "D".

An edge clearance of 2D was adequate under compressive loading regardless of the angle between the direction of loading and the grain of the face plies. An edge clearance of 3D was adequate under tensile loading parallel to the grain of the face plies, 2-1/2D at an angle of 45°, and 4D at an angle of 90°.

Since exploratory tests had indicated that the end margin did not affect the proportional limit and ultimate bearing loads under compressive loading, this dimension was not determined.

An end margin of 4D was adequate under modified compressive loading parallel to the grain of the face plies and 3D at angles of 45° and 90°. An end margin of 5D was adequate under tensile loading parallel to the grain of the face plies, 3D at an angle of 45° and 4D at an angle of 90°. Where both methods of loading were employed, end margins determined under modified compressive loading, although slightly smaller, agreed reasonably well with those obtained under tensile loading. This agreement justified the use of modified compressive loading to determine critical end margins for tensile loading in the heavier combinations of diameter and thickness, for which tests under tensile loading were impracticable.

Wherever a difference in critical dimensions occurred between specimens of different grain orientation, the material having the grain of the face plies at an angle of 45° to the direction of the loading yielded the most consistent values.

Limit of L/D Ratio for Steel Aircraft Bolt in Cross-banded Compreg

It was planned originally to test 1-inch compreg under 1/4-inch steel aircraft bolts under compressive loading for all three grain directions. It was found, however, that the ultimate bearing loads for such combinations exceeded the double-shear strength of the bolts. One of the sheared bolts is shown in figure 15.

A supplementary edge-clearance series of four 1-inch compreg specimens was tested with 3/8-inch bolts under compressive loading parallel to the grain of the face plies to determine more closely the limiting ratio of bearing length to diameter. The average ultimate bearing load obtained was only 75 percent of the calculated ultimate shearing strength of a 3/8-inch aircraft bolt and there was no indication of shearing failures in the 3/8-inch aircraft bolts. It was concluded, therefore, that the strength of a bolted connection in compreg in which the ratio of bearing length to bolt diameter (L/D) is 4 or more is limited by the shearing strength of the bolt rather than by the bearing strength of the compreg.

Deformations

The average, maximum, and minimum deformations for each combination of type of loading, diameter of bolt, and thickness of compreg are shown in columns 9 and 11 of tables 2 through 5. A summary of all average deformations is presented in table 8. In general, the deformations at both the proportional limit and ultimate increased with an increase in the thickness of compreg, but did not change consistently with an increase in the diameter of the bolt. For most combinations of diameter and thickness, the deformations were greater for compressive loading. On the basis of these tests, it could be expected that the deformation would not exceed 0.015 inch under normal working loads and 0.075 inch at the ultimate.

Conclusions

The ultimate bolt-bearing stress of cross-banded compreg as determined by these tests was approximately 34,000 pounds per square inch under 1/4-inch steel aircraft bolts, 30,000 pounds per square inch under 1/2-inch bolts, and 28,000 pounds per square inch under 1-inch bolts. These are average values and apply to either compressive or tensile loading. With one exception, the minimum values were at least 83 percent of these averages. The average proportional limit stresses were about 50 and 60 percent of the average ultimate stresses for tensile and compressive loading, respectively.

The grain direction of the face plies has no apparent effect on either the proportional limit or the ultimate bearing stress of the compreg. The bearing stress decreased as the diameter of the bolt increased. The thickness of the compreg showed no consistent effect on the bearing stress.

An edge clearance equal to twice the diameter (2D) of the bolt was adequate to develop the bearing capacity of the compreg under compressive loading for L/D (ratio of bearing length to diameter) values from 1/2 to 2, regardless of the orientation of the grain of the compreg.

An edge clearance of 3D was ample to develop the full bearing capacity of the compreg under tensile loading parallel to the grain of the face plies, 2-1/2D at an angle of 45°, and 4D at an angle of 90°. An end margin of 5D was ample under tensile loading parallel to the grain, 3D at an angle of 45°, and 4D at an angle of 90°.

At an L/D ratio of about 4, compreg developed the double shear strength of the steel aircraft bolt.

No definite relationship between bolt-bearing strength and compressive strength was indicated by these tests.

Bolt-bearing deformations not exceeding 0.015 inch under normal working loads and 0.075 inch under ultimate loads can be expected on the basis of this study.

The most consistent critical dimensions and the most consistent bearing stress values were obtained in the tests of compreg having face grain at an angle of 45° to the direction of loading.

Table 1.--Physical data pertaining to laboratory-made, cross-banded yellow birch compreg used for bolt-bearing tests.

Panel number[1]	Dimensions				Number of plies	Date pressed	Pressure	Time of pressing	Resin content[2]	Specific gravity[3]
	Width	Length	Thickness							
			Nominal	Actual average						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Inches	Inches	Inch	Inch			Psi.	Minutes	Percent	
1	29.5	29.5	1/4	0.27	7	1/22/43	1,300	25	29.3	1.308
2	29.5	29.5	1/2	.49	13	1/22/43	1,300	30	29.3	1.295
3	29.5	29.5	1	.95	25	1/22/43	1,300	50	29.3	1.272
4	24	24	1/4	.25	7	5/7/43	1,800	25	26	1.369
5	24	24	1/4	.26	7	5/8/43	1,800	25	26	1.362
6	24	24	1/4	.26	7	5/10/43	1,800	25	26	1.375
7	24	24	1/2	.47	13	5/7/43	1,800	30	26	1.368
8	24	24	1/2	.47	13	5/8/43	1,800	30	26	1.373
9	24	24	1/2	.48	13	5/10/43	1,800	30	26	1.376
10	24	24	1	.92	25	5/7/43	1,800	60	26	1.375
11	24	24	1	.89	25	5/8/43	1,800	60	26	1.359
12	24	24	1	.88	25	5/10/43	1,800	60	26	1.368
17	24	24	1/4	.26	7	5/19/43	1,800	25	26	1.367
18	24	24	1/2	.46	13	5/19/43	1,800	30	26	1.379
19	24	24	1/2	.46	13	5/19/43	1,800	30	26	1.362

[1] Panels 13 through 16 were used for other purposes.
[2] Based on weight of veneer.
[3] Based on weight and volume at time of test.

Table 2.--Bolt-bearing and compressive strength and related properties for laboratory-made, cross-banded, yellow birch compreg. Bolt-bearing tests were made under compressive and modified compressive loading. All tests were made with the load parallel to the grain of the face plies.

Nominal bolt diameter	Nominal panel thickness	Panel number	Bolt bearing: Number of specimens: Total tested	Bolt bearing: Number of specimens: Tested for proportional limit	Bolt bearing: Number of specimens: Tested for ultimate load	Bolt bearing: Variation	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Ratio of proportional limit to ultimate	Compression: Number of specimens	Compression: Variation	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Ratio of proportional limit to ultimate	Compression: Modulus of elasticity	Ratio of bolt-bearing stress to average compressive stress: Proportional limit[1]	Ratio of bolt-bearing stress to average compressive stress: Ultimate[2]	Critical dimensions: Edge clearance	Critical dimensions: End margin[3]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
Inch	Inch						Psi	Inch	Psi	Inch				Psi	Inch per inch	Psi		1,000 psi			Bolt diameters	Bolt diameters
						Minimum	19,170	0.00405	32,040	0.0250			Minimum	6,700	0.00225	20,610		1,677	1.95	1.32		
1/4	1/4	1	11	9	7	Average	22,600	.00698	34,810	.0257	0.655	20	Average	9,850	.00415	24,190	0.407	2,456	2.31	1.44	1-1/2	4
						Maximum	26,080	.00890	38,190	.0300			Maximum	11,460	.00648	29,450		2,989	2.65	1.58		
						Minimum	16,960	.00540	30,620	.0300			Minimum	8,980	.00373	18,660		2,300	1.69	1.50		
1/4	1/2	2	11	9	6	Average	20,690	.00794	34,240	.0350	.604	25	Average	10,060	.00412	20,440	.492	2,445	2.06	1.67	2	4
						Maximum	24,300	.01125	36,710	.0400			Maximum	11,340	.00463	22,480		2,578	2.42	1.80		
						Minimum	12,770	.00725	32,040	—			Minimum	7,130	.00258	19,120		2,520	1.59	1.57		
1/4	1	3	4	4	2[4]	Average	13,420	.00913	34,030	.0180	.394	10	Average	8,040	.00310	20,480	.392	2,595	1.67	1.66	2	—
						Maximum	13,720	.01095	36,020	—			Maximum	8,840	.00350	22,840		2,764	1.71	1.76		
						Minimum	15,660	.00865	29,920	.0500			Minimum	7,130	.00258	19,120		2,520	1.95	1.46		
3/8	1	3	4	3	2	Average	16,570	.01083	33,160	.0588	.500	10	Average	8,040	.00310	20,480	.392	2,595	2.06	1.62	—	4
						Maximum	17,140	.01295	36,410	.0675			Maximum	8,840	.00350	22,840		2,764	2.13	1.78		
						Minimum	13,910	.00291	22,880	.0150			Minimum	6,700	.00225	20,610		1,677	1.41	.95		
1/2	1/4	1	10	8	6	Average	16,130	.00561	26,910	.0250	.599	20	Average	9,850	.00415	24,190	.407	2,456	1.64	1.11	1-1/2	3
						Maximum	19,860	.00880	29,350	.0350			Maximum	11,460	.00648	29,450		2,989	2.02	1.21		
						Minimum	14,460	.00520	25,710	.0250			Minimum	8,980	.00373	18,660		2,300	1.44	1.26		
1/2	1/2	2	25	22	14	Average	16,980	.00614	27,670	.0328	.614	25	Average	10,060	.00412	20,440	.492	2,445	1.69	1.35	1-3/4	4
						Maximum	19,410	.00715	29,260	.0400			Maximum	11,340	.00463	22,480		2,578	1.93	1.43		
						Minimum	13,690	.00590	26,410	.0350			Minimum	7,130	.00258	19,120		2,520	1.70	1.29		
1/2	1	3	12	12	7	Average	15,740	.01015	29,120	.0471	.540	10	Average	8,040	.00310	20,480	.392	2,595	1.96	1.42	2	3
						Maximum	18,140	.01570	31,780	.0550			Maximum	8,840	.00350	22,840		2,764	2.26	1.55		
						Minimum	12,150	.00490	27,080	.0250			Minimum	8,980	.00373	18,660		2,300	1.21	1.32		
1	1/2	2	12	9	2	Average	13,720	.00749	27,300	.0400	.502	25	Average	10,060	.00412	20,440	.492	2,445	1.36	1.34	1-1/2	—
						Maximum	15,620	.01070	27,530	.0550			Maximum	11,340	.00463	22,480		2,578	1.55	1.35		
						Minimum	15,040	.00800	26,900	.0400			Minimum	8,740	.00347	19,780		2,332	1.39	1.17		
1	1/2	7	4	4	3	Average	16,060	.00963	28,150	.0437	.570	26	Average	10,840	.00385	22,900	.473	2,822	1.48	1.23	--	2-1/2
						Maximum	17,000	.01100	28,920	.0460			Maximum	12,760	.00440	24,900		3,160	1.57	1.26		
						Minimum	11,590	.00590	25,710	.0250			Minimum	7,130	.00258	19,120		2,520	1.44	1.26		
	1	3	22	17	11	Average	14,700	.00879	27,160	.0450	.541	10	Average	8,040	.00310	20,480	.392	2,595	1.83	1.32	1-1/2	3
						Maximum	17,160	.01530	28,950	.0750			Maximum	8,840	.00350	22,840		2,764	2.14	1.41		

[1]Column 8 divided by column 15.

[2]Column 10 divided by column 17.

[3]End margin for tensile loading determined by modified compressive loading.

[4]Bolt-bearing load exceeded double shear strength of 1/4-inch bolt (Fig. 15).

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Table 3.--Bolt-bearing and compressive strength and related properties for laboratory-made, cross-banded, yellow birch compreg. Bolt-bearing tests were made under compressive and modified compressive loading, with the load at an angle of 45° to the grain of the face plies. Compression tests were made with the load parallel to the grain of the face plies.

Nominal bolt diameter	Nominal panel thickness	Panel number	Bolt bearing: Number of specimens: Total tested	Bolt bearing: Number of specimens: Tested for proportional limit	Bolt bearing: Number of specimens: Tested for ultimate load	Bolt bearing: Variation	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Ratio of proportional limit to ultimate	Compression: Number of specimens	Compression: Variation	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Ratio of proportional limit to ultimate	Compression: Modulus of elasticity	Ratio of bolt-bearing stress to average compressive stress: Proportional limit[1]	Ratio of bolt-bearing stress to average compressive stress: Ultimate[2]	Critical dimensions: Edge clearance	Critical dimensions: End margin[3]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
Inch	Inch						Psi.	Inch	Psi.	Inch				Psi.	Inch per inch	Psi.		1,000 psi.			Bolt diameters	Bolt diameters
						Minimum	18,680	0.00695	29,280	0.0250			Minimum									
1/4	1/4	5	10	9	7	Average	21,390	.00854	30,730	.0276	0.696	--	Average	--	--	--	--	--	--	--	2	3
						Maximum	24,220	.01150	32,040	.0350			Maximum									
						Minimum	19,690	.00810	31,330	.0250			Minimum	8,990	0.00301	22,100		2,686	1.94	1.34		
1/4	1/2	8	10	10	7	Average	22,250	.0102	34,060	.0390	.653	23	Average	10,170	.00355	23,430	0.434	2,870	2.19	1.45	2	3
						Maximum	25,500	.01265	37,200	.0600			Maximum	11,180	.00397	25,110		3,073	2.51	1.59		
						Minimum	15,970	.00530	26,850	.0200			Minimum									
1/2	1/4	5	10	10	7	Average	18,500	.00758	28,360	.0259	.652	--	Average	--	--	--	--	--	--	--	2	3
						Maximum	21,800	.01095	29,650	.0300			Maximum									
						Minimum	18,300	.00860	27,980	.0300			Minimum	8,990	.00301	22,100		2,686	1.80	1.19		
1/2	1/2	8	10	8	7	Average	19,940	.01020	30,660	.0352	.650	23	Average	10,170	.00355	23,430	.434	2,870	1.96	1.31	2	3
						Maximum	22,330	.01137	33,210	.0400			Maximum	11,180	.00397	25,110		3,073	2.19	1.42		
						Minimum	15,320	.01230	33,600	.0400			Minimum									
1/2	1	10	5	5	4	Average	17,010	.01271	34,140	.0438	.498	--	Average	--	--	--	--	--	--	--	--	3
						Maximum	18,490	.01320	34,600	.0500			Maximum									
						Minimum	18,250	.01100	33,180	.0350			Minimum	--	--	--		--	1.79	1.45		
1/2	1	11	5	5	3	Average	18,690	.01156	34,020	.0383	.549	1	Average	10,220	.00349	22,960	.445	2,927	1.83	1.48	2	--
						Maximum	19,150	.01240	34,890	.0400			Maximum	--	--	--		--	1.87	1.52		
						Minimum	13,710	.00725	26,200	.0220			Minimum	9,380	.00290	22,420		2,639	1.23	1.09		
1	1/2	9	11	11	5	Average	15,910	.00873	29,380	.0424	.542	29	Average	11,120	.00358	24,140	.460	3,111	1.43	1.22	2	3
						Maximum	17,460	.01000	32,100	.0600			Maximum	12,360	.00424	26,360		3,552	1.57	1.33		
						Minimum	16,210	.0125	29,080	.0450			Minimum									
1	1	10	5	5	4	Average	17,360	.01402	29,850	.0475	.582	--	Average	--	--	--	--	--	--	--	--	2-1/2
						Maximum	18,450	.0169	30,460	.0500			Maximum									
						Minimum	13,510	.0069	--	--			Minimum	--	--	--		--	1.32	--		
1	1	11	6	6	1	Average	14,970	.00947	28,400	.0300	.527	1	Average	10,220	.00349	22,960	.445	2,927	1.47	1.24	2	--
						Maximum	15,850	.0109	--	--			Maximum	--	--	--		--	1.55	--		

[1] Column 8 divided by column 15.

[2] Column 10 divided by column 17.

[3] End margin for tensile loading determined by modified compressive loading.

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Table 4.--Bolt-bearing and compressive strength and related properties for laboratory-made, cross-banded, yellow birch compreg. Bolt-bearing tests were made under compressive and modified compressive loading, with the load at an angle of 90° to the grain of the face plies. Compression tests were made with the load parallel to the grain of the face plies.

Nominal bolt diameter	Nominal panel thickness	Panel number	Bolt bearing: Number of specimens: Total tested	Bolt bearing: Number of specimens: Tested for proportional limit	Bolt bearing: Number of specimens: Tested for ultimate load	Bolt bearing: Variation	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Ratio of proportional limit to ultimate	Compression: Number of specimens	Compression: Variation	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Ratio of proportional limit to ultimate	Compression: Modulus of elasticity	Ratio of bolt-bearing stress to average compressive stress: Proportional limit[1]	Ratio of bolt-bearing stress to average compressive stress: Ultimate[2]	Critical dimensions: Edge clearance	Critical dimensions: End margin[3]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
Inch	Inch						Psi.	Inch	Psi.	Inch				Psi.	Inch per inch	Psi.		1,000 psi.			Bolt diameters	Bolt diameters
						Minimum	23,020	0.00760	29,400	0.0200			Minimum	10,020	0.00338	22,390		2,867	2.11	1.14		
1/4	1/4	17	5	5	4	Average	24,430	.01024	31,340	.0244	0.780	14	Average	10,890	.00370	25,730	0.423	2,946	2.24	1.22	1-1/2	—
						Maximum	26,100	.01300	33,200	.0300			Maximum	11,330	.00388	27,220		3,051	2.40	1.29		
						Minimum	23,100	.00930	32,520	.0250			Minimum	8,740	.00347	19,780		2,332	2.13	1.42		
1/4	1/2	7	6	6	5	Average	24,330	.01057	34,710	.0280	.701	26	Average	10,840	.00385	22,900	.473	2,822	2.24	1.52	1-1/2	—
						Maximum	26,320	.01160	36,550	.0300			Maximum	12,760	.00440	24,900		3,160	2.43	1.60		
						Minimum	14,340	.00570	28,810	.0300			Minimum	10,020	.00338	22,390		2,867	1.32	1.12		
1/2	1/4	17	10	10	5	Average	17,630	.00701	31,470	.0300	.560	14	Average	10,890	.00370	25,730	.423	2,946	1.62	1.22	1-1/2	3
						Maximum	19,750	.00895	35,900	.0300			Maximum	11,330	.00388	27,220		3,051	1.81	1.40		
						Minimum	19,080	.00785	29,530	.0250			Minimum	9,600	.00368	19,580		2,310	1.82	1.40		
1/2	1/2	19	5	5	3	Average	19,580	.00870	30,660	.0300	.639	24	Average	10,490	.00409	21,450	.489	2,568	1.87	1.43	1-3/4	—
						Maximum	20,960	.00950	31,420	.0350			Maximum	12,230	.00485	23,290		2,824	2.00	1.47		
						Minimum	15,750	.00940	30,900	.0600			Minimum	7,130	.00258	19,120		2,520	1.96	1.51		
1/2	1	3	4	4	2	Average	16,630	.01241	31,030	.0650	.535	10	Average	8,040	.00310	20,480	.393	2,595	2.07	1.52	2	—
						Maximum	18,000	.01590	31,280	.0700			Maximum	8,840	.00350	22,840		2,764	2.24	1.53		
						Minimum	17,090	.01150	31,350	.0400			Minimum	9,700	.00336	22,680		2,749	1.68	1.36		
1/2	1	12	5	5	4	Average	19,380	.01328	34,040	.0413	.569	5	Average	10,200	.00354	23,070	.442	2,889	1.90	1.48	—	3
						Maximum	21,680	.01500	36,650	.0450			Maximum	10,650	.00388	23,850		3,019	2.13	1.59		
						Minimum	15,750	.01065	—	—			Minimum	8,990	.00301	22,100		2,686	1.55	—		
1	1/2	8	2	2	1	Average	16,360	.01090	27,380	.0400	.598	23	Average	10,170	.00355	23,430	.434	2,870	1.61	1.17	—	3
						Maximum	16,980	.01115	—	—			Maximum	11,160	.00397	25,110		3,073	1.67	—		
						Minimum	12,580	.01000					Minimum	9,380	.00290	22,420		2,639	1.13			
1	1/2	9	2	2	0	Average	13,100	.01070	—	—	—	29	Average	11,120	.00358	24,140	—	3,111	1.18	—	—	—
						Maximum	13,630	.01140					Maximum	12,360	.00424	26,360		3,552	1.23			
						Minimum	14,100	.00730	27,630	.0215			Minimum	9,600	.00368	19,580		2,310	1.34	1.29		
1	1/2	19	5	5	3	Average	15,650	.00792	27,850	.0252	.562	24	Average	10,490	.00409	21,450	.489	2,568	1.49	1.30	1-1/2	—
						Maximum	17,280	.00900	28,080	.0300			Maximum	12,230	.00485	23,290		2,824	1.65	1.31		
						Minimum	12,580	.00335	31,220	.0450			Minimum	9,700	.00336	22,680		2,749	1.23	1.35		
1	1	12	10	10	4	Average	13,960	.00628	31,520	.0487	.443	5	Average	10,200	.00354	23,070	.442	2,889	1.37	1.37	2	3
						Maximum	14,920	.00905	31,920	.0500			Maximum	10,650	.00388	23,850		3,019	1.46	1.38		

[1] Column 8 divided by column 15.

[2] Column 10 divided by column 17.

[3] End margin for tensile loading determined by modified compressive loading.

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Table 5.--Bolt-bearing and compressive strength and related properties for laboratory-made, cross-banded, yellow birch compreg. Bolt-bearing tests were made under tensile loading with load at angles of 0°, 45°, and 90° to the grain of the face plies. Compression tests were made parallel to the grain of the face plies.

Nominal bolt diameter	Nominal panel thickness	Panel number	Bolt-bearing: Number of specimens: Total tested	Bolt-bearing: Number of specimens: Tested for proportional limit	Bolt-bearing: Number of specimens: Tested for ultimate load	Bolt-bearing: Variation	Bolt-bearing: Proportional limit: Stress	Bolt-bearing: Proportional limit: Deformation	Bolt-bearing: Ultimate: Stress	Bolt-bearing: Ultimate: Deformation	Bolt-bearing: Ratio of proportional limit to ultimate	Compression: Number of specimens	Compression: Variation	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Ratio of proportional limit to ultimate	Compression: Modulus of elasticity	Ratio of bolt-bearing stress to average compressive stress: Proportional limit[1]	Ratio of bolt-bearing stress to average compressive stress: Ultimate[2]	Critical dimensions: Edge clearance	Critical dimensions: End margin
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
Inch	Inch						Psi.	Inch	Psi.	Inch				Psi.	Inch per inch	Psi.		1,000 psi.			Bolt diameters	Bolt diameters
									Bolt-bearing at 0°													
						Minimum	17,960	0.00485	30,850	0.0168			Minimum	10,400	0.00358	22,170		2,249	1.53	1.24		
1/4	1/4	4	10	8	7	Average	20,100	.00594	33,530	.0224	0.599	8	Average	11,770	.00431	24,800	0.474	2,775	1.71	1.35	2-1/2	4
						Maximum	23,000	.00814	36,940	.0330			Maximum	12,600	.00560	26,800		3,465	2.02	1.47		
						Minimum	13,980	.00695	35,930	.0463			Minimum	8,980	.00373	18,660		2,300	1.39	1.76		
1/4	1/2	2	5	5	2	Average	14,980	.00752	36,210	.0473	.403	25	Average	10,060	.00412	20,440	.492	2,445	1.49	1.77	--	5
						Maximum	15,150	.00780	36,490	.0484			Maximum	11,340	.00463	22,480		2,578	1.51	1.78		
						Minimum	15,440	.00800	32,280	.0329			Minimum	8,740	.00347	19,780		2,332	1.42	1.41		
1/4	1/2	7	6	6	4	Average	16,770	.00887	34,480	.0367	.486	26	Average	10,840	.00385	22,900	.473	2,822	1.55	1.51	3	--
						Maximum	18,750	.00995	36,700	.0395			Maximum	12,760	.00440	24,900		3,160	1.73	1.60		
						Minimum	13,980	.00320	26,800	.0115			Minimum	10,400	.00358	22,170		2,249	1.19	1.08		
1/2	1/4	4	10	10	6	Average	14,630	.00371	28,360	.0191	.516	8	Average	11,770	.00431	24,800	.474	2,775	1.24	1.14	2	3-1/2
						Maximum	16,310	.00427	29,750	.0257			Maximum	12,600	.00560	26,800		3,465	1.39	1.20		
						Minimum	14,900	.00480	28,960	.0237			Minimum	8,740	.00347	19,780		2,332	1.34	1.26		
1/2	1/2	7	10	10	7	Average	15,780	.00552	30,450	.0287	.518	26	Average	10,840	.00385	22,900	.473	2,822	1.46	1.33	2-1/2	3-1/2
						Maximum	18,040	.00690	32,800	.0322			Maximum	12,760	.00440	24,900		3,160	1.72	1.43		
									Bolt-bearing at 45°													
						Minimum	19,390	.00527	30,820	.0205			Minimum	10,860	.00367	21,680		2,648	1.64	1.34		
1/4	1/4	6	9	9	7	Average	20,430	.00672	32,840	.0260	.622	10	Average	11,810	.00388	22,920	.515	3,046	1.73	1.43	2-1/2	3
						Maximum	21,100	.00820	35,100	.0301			Maximum	12,500	.00410	23,920		3,224	1.79	1.53		
						Minimum	14,860	.00720	33,800	.0341			Minimum	8,860	.00322	19,990		2,271	1.47	1.51		
1/4	1/2	18	10	10	9	Average	16,330	.00892	36,300	.0450	.450	62	Average	10,140	.00377	21,900	.463	2,693	1.61	1.66	2-1/2	3
						Maximum	18,250	.01040	40,220	.0629			Maximum	11,320	.00476	23,500		3,003	1.80	1.84		
						Minimum	13,440	.00405	25,020	.0187			Minimum	10,860	.00367	21,680		2,648	1.14	1.09		
1/2	1/4	6	9	9	8	Average	14,780	.00466	28,120	.0247	.526	10	Average	11,810	.00388	22,920	.515	3,046	1.25	1.23	2-1/2	2-1/2
						Maximum	15,780	.00560	29,950	.0278			Maximum	12,500	.00410	23,920		3,224	1.34	1.31		
						Minimum	12,980	.00480	26,800	.0176			Minimum	8,860	.00322	19,990		2,271	1.28	1.22		
1/2	1/2	18	9	9	8	Average	13,880	.00530	29,700	.0277	.467	62	Average	10,140	.00377	21,900	.463	2,693	1.37	1.36	2-1/2	2-1/2
						Maximum	15,720	.00630	33,450	.0389			Maximum	11,320	.00476	23,500		3,003	1.55	1.53		
									Bolt-bearing at 90°													
						Minimum	15,570	.00475	29,420	.0139			Minimum	10,020	.00338	22,390		2,867	1.43	1.14		
1/4	1/4	17	10	10	5	Average	17,810	.00565	32,780	.0269	.543	14	Average	10,890	.00370	25,730	.423	2,946	1.64	1.27	3-1/2	3
						Maximum	21,610	.00727	37,280	.0327			Maximum	11,330	.00388	27,220		3,051	1.98	1.45		
						Minimum	14,700	.00740	34,080	.0359			Minimum	9,600	.00368	19,580		2,310	1.40	1.63		
1/4	1/2	19	10	10	5	Average	15,630	.00814	39,420	.0427	.396	24	Average	10,490	.00409	21,450	.489	2,568	1.49	1.84	4	4
						Maximum	16,580	.00980	43,360	.0516			Maximum	12,230	.00485	23,290		2,824	1.58	2.02		
						Minimum	11,590	.00265	25,740	.0138			Minimum	10,020	.00338	22,390		2,867	1.06	1.00		
1/2	1/4	17	8	6	3	Average	12,960	.00342	27,610	.0221	.469	14	Average	10,890	.00370	25,730	.423	2,946	1.19	1.07	3	4
						Maximum	15,080	.00406	29,900	.0278			Maximum	11,330	.00388	27,220		3,051	1.38	1.16		
						Minimum	13,420	.00415	--				Minimum	9,600	.00368	19,580		2,310	1.28	--		
1/2	1/2	19	7	7	[3]1	Average	14,150	.00495	[3]30,000	.0233	.473	24	Average	10,490	.00409	21,450	.489	2,568	1.35	1.40	4	--
						Maximum	14,870	.00555	--				Maximum	12,230	.00485	23,290		2,824	1.42	--		

[1]Column 8 divided by column 15.

[2]Column 10 divided by column 17.

[3]Widest specimen tested; failed in tension.

Z M 59357 F

Table 6.--Summary of critical dimensions for various grain angles

Diameter of bolt	Thickness of compreg	Edge clearance						End margin					
		Compressive loading			Tensile loading			Modified compressive loading			Tensile loading		
		Angle of grain of face plies to direction of load						Angle of grain of face plies to direction of load					
		0°	45°	90°	0°	45°	90°	0°	45°	90°	0°	45°	90°
Inch	Inch	Bolt diameters			Bolt diameters			Bolt diameters			Bolt diameters		
1/4	1/4	1-1/2	2	1-1/2	2-1/2	2-1/2	3-1/2	4	3	--	4	3	3
1/4	1/2	2	2	1-1/2	3	2-1/2	4	4	3	--	5	3	4
1/4	1	2	--	--	--	--	--	--	--	--	--	--	--
3/8	1	--	--	--	--	--	--	4	--	--	--	--	--
1/2	1/4	1-1/2	2	1-1/2	2	2-1/2	3	3	3	3	3-1/2	2-1/2	4
1/2	1/2	1-3/4	2	1-3/4	2-1/2	2-1/2	4	4	3	--	3-1/2	2-1/2	--
1/2	1	2	2	2	--	--	--	3	3	3	--	--	--
1	1/2	1-1/2	2	1-1/2	--	--	--	2-1/2	3	3	--	--	--
1	1	1-1/2	2	2	--	--	--	3	2-1/2	3	--	--	--

Table 7.--Summary of average bolt-bearing stresses at proportional limit and ultimate.

Diameter of bolt	Thickness of compreg	Stress at proportional limit						Stress at ultimate					
		Compressive loading[1]			Tensile loading			Compressive loading[1]			Tensile loading		
		Angle of grain of face plies to direction of load			Angle of grain of face plies to direction of load			Angle of grain of face plies to direction of load			Angle of grain of face plies to direction of load		
		0°	45°	90°	0°	45°	90°	0°	45°	90°	0°	45°	90°
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Inch	Inch	Psi.	Psi.	Psi.	Psi.	Psi.	Psi.	Psi.	Psi.	Psi.	Psi.	Psi.	Psi.
1/4	1/4	22,800	21,390	24,430	20,100	20,430	17,810	34,810	30,730	31,340	33,530	32,840	32,780
1/4	1/2	20,890	22,250	24,330	15,670	16,330	15,630	34,240	34,060	34,710	35,350	36,300	39,420
1/4	1	[2]13,420	--	--	--	--	--	[2]34,030	--	--	--	--	--
3/8	1	16,570	--	--	--	--	--	33,160	--	--	--	--	--
1/2	1/4	16,130	18,500	17,630	14,630	14,780	12,960	26,910	28,360	31,470	28,360	28,120	27,610
1/2	1/2	16,980	19,940	19,580	15,780	13,880	14,190	27,670	30,660	30,660	30,450	29,700	30,000
1/2	1	15,740	17,850	18,010	--	--	--	29,120	34,080	32,560	--	--	--
1	1/2	14,890	15,910	15,040	--	--	--	27,730	29,380	27,610	--	--	--
1	1	14,700	16,160	13,960	--	--	--	27,160	29,120	31,520	--	--	--

[1]Includes modified compressive loading.

[2]Bolt bent and sheared during test. High L/D ratio.

Table 8.--Summary of average bolt-bearing deformations at proportional limit and ultimate

Diameter of bolt	Thickness of compreg	Deformation at proportional limit						Deformation at ultimate					
		Compressive loading[1]			Tensile loading			Compressive loading[1]			Tensile loading		
		Angle of grain of face plies to direction of load						Angle of grain of face plies to direction of load					
		0°	45°	90°	0°	45°	90°	0°	45°	90°	0°	45°	90°
Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch
1/4	1/4	0.0070	0.0085	0.0102	0.0059	0.0067	0.0057	0.0257	0.0276	0.0244	0.0224	0.0260	0.0269
1/4	1/2	.0079	.0102	.0106	.0082	.0089	.0081	.0350	.0390	.0280	.0420	.0450	.0427
1/4	1	.0091	--	--	--	--	--	[2].0180	--	--	--	--	--
3/8	1	.0108	--	--	--	--	--	.0588	--	--	--	--	--
1/2	1/4	.0056	.0076	.0070	.0037	.0047	.0034	.0250	.0259	.0300	.0191	.0247	.0221
1/2	1/2	.0061	.0102	.0087	.0055	.0053	.0049	.0328	.0352	.0300	.0287	.0277	.0233
1/2	1	.0102	.0121	.0128	--	--	--	.0471	.0411	.0532	--	--	--
1	1/2	.0086	.0087	.0098	--	--	--	.0418	.0424	.0326	--	--	--
1	1	.0088	.0117	.0063	--	--	--	.0460	.0388	.0487	--	--	--

[1] Includes modified compressive loading.

[2] Bolt failed in double shear.

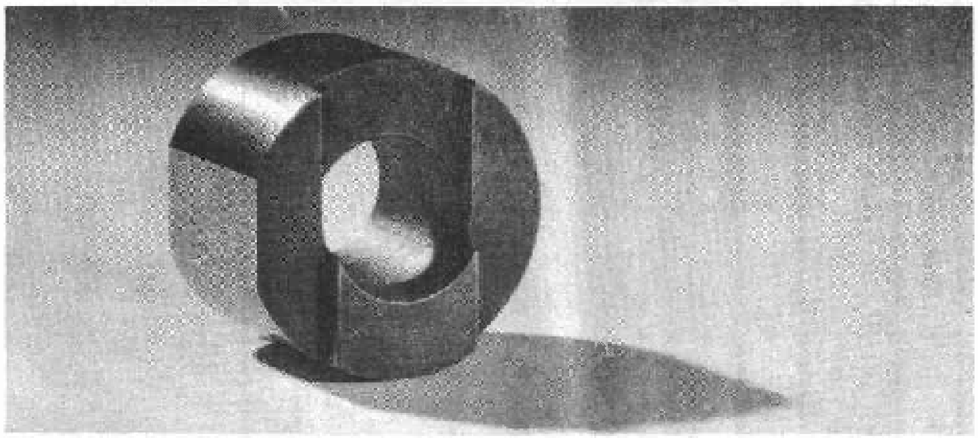

Figure 1.--Recessed, hardened steel bushing used in bolt-bearing tests of compreg.

Z M 56563 F

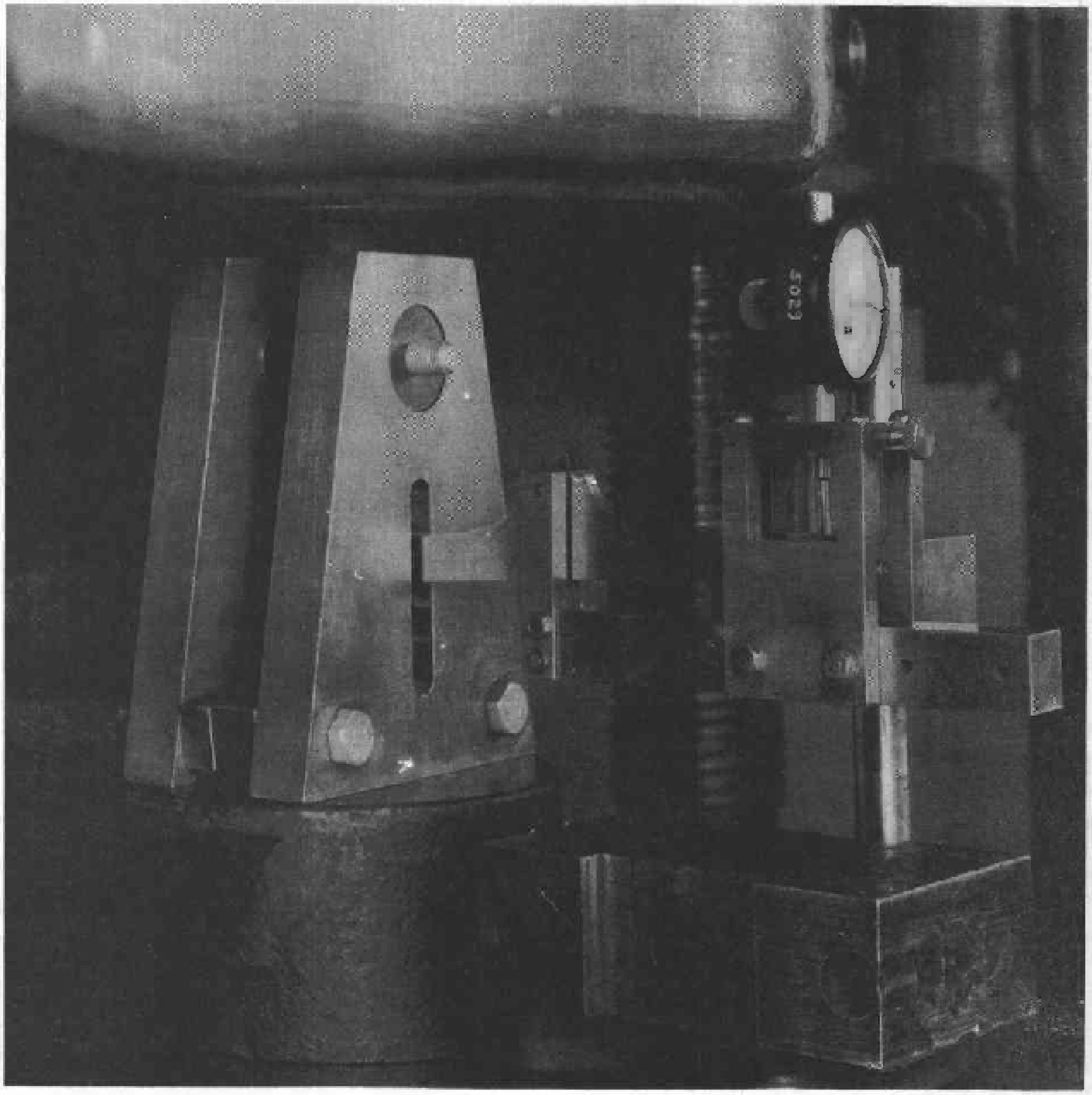

Figure 2.--Apparatus for bolt-bearing tests under compressive loading.

Z M 51671 F

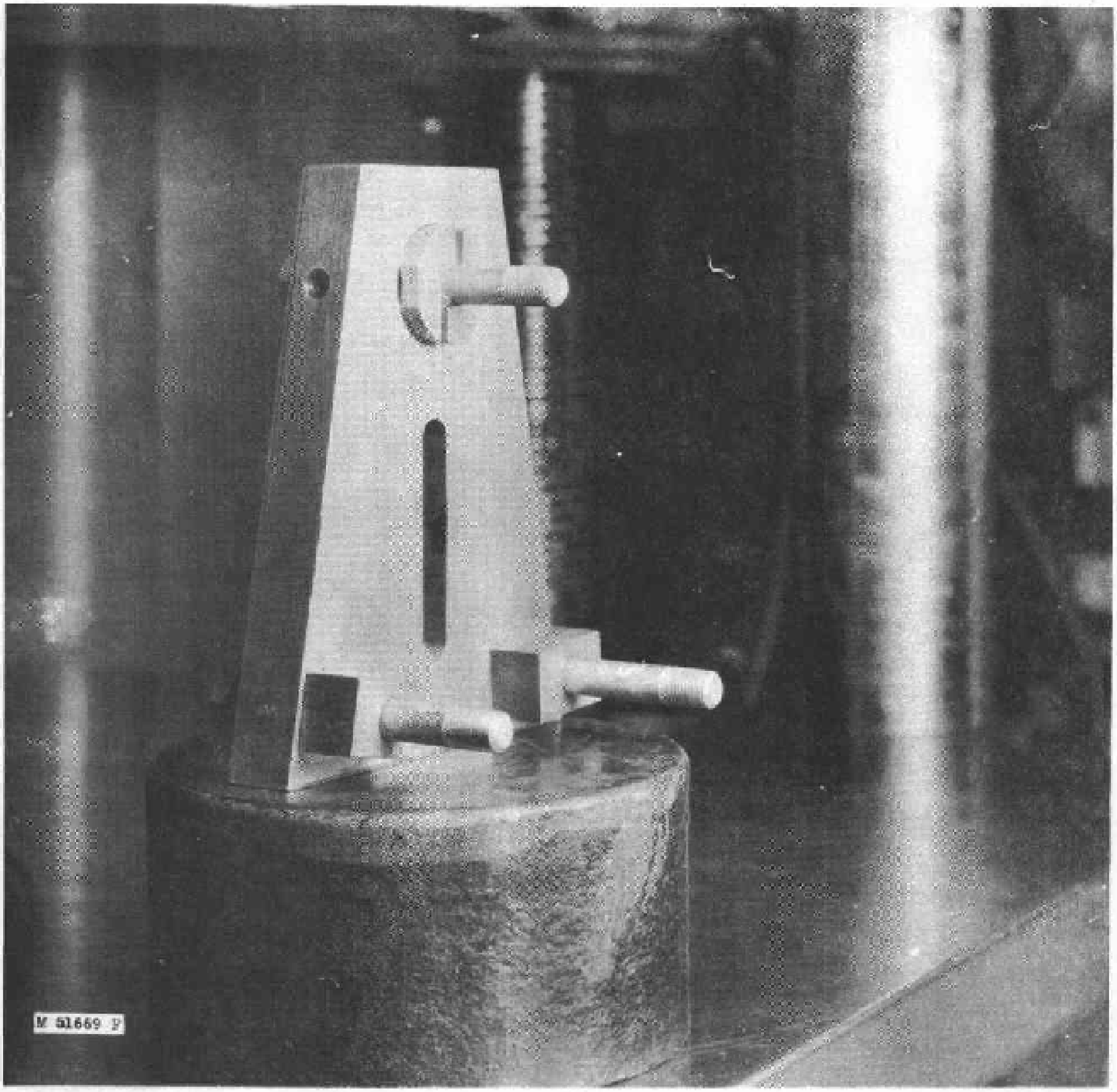

Figure 3.--Inside view of apparatus shown in figure 2 for bolt-bearing tests under compressive loading.

Z M 51669 F

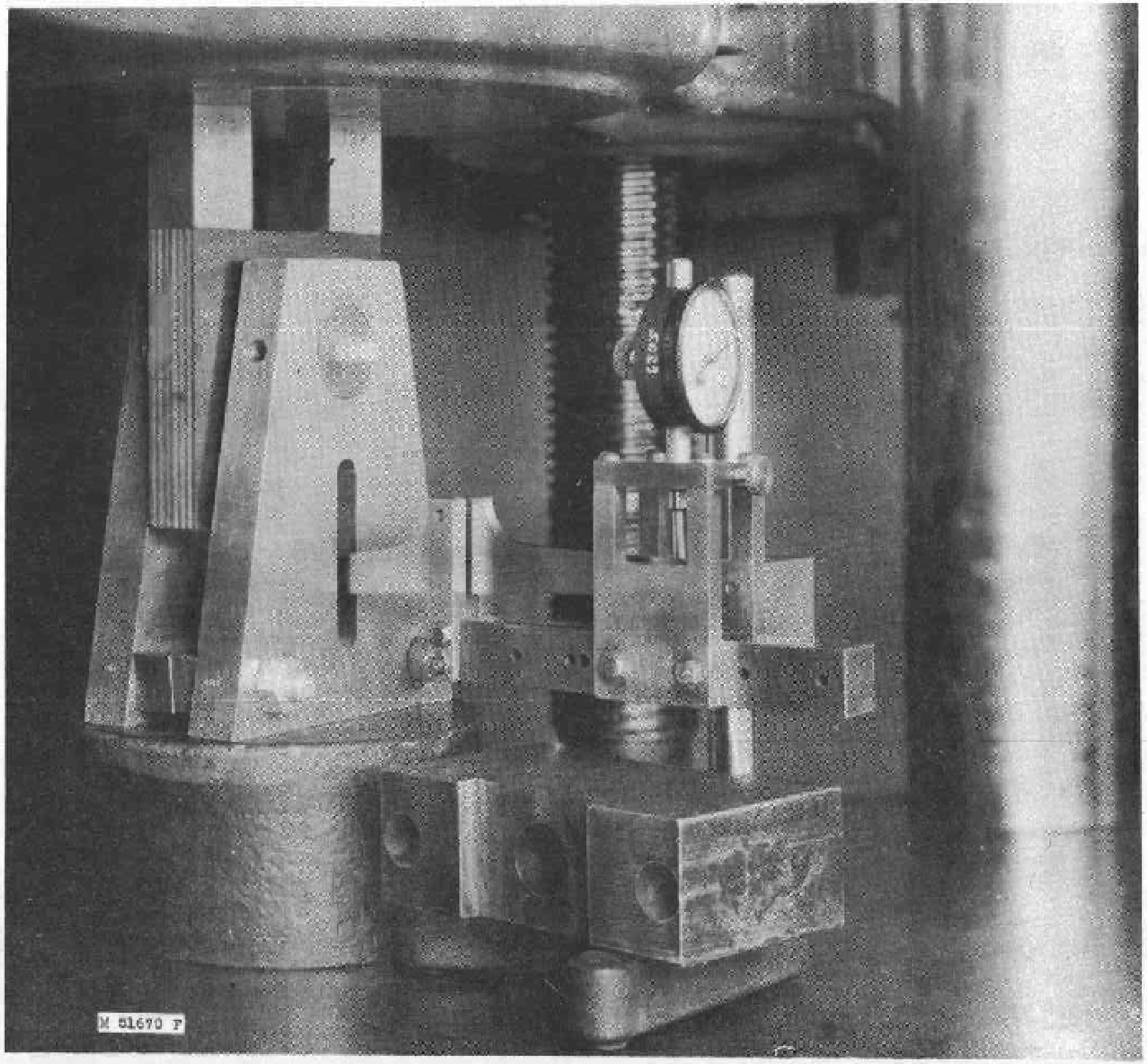

Figure 4.--Apparatus for bolt-bearing tests under modified compressive loading.

Z M 51670 F

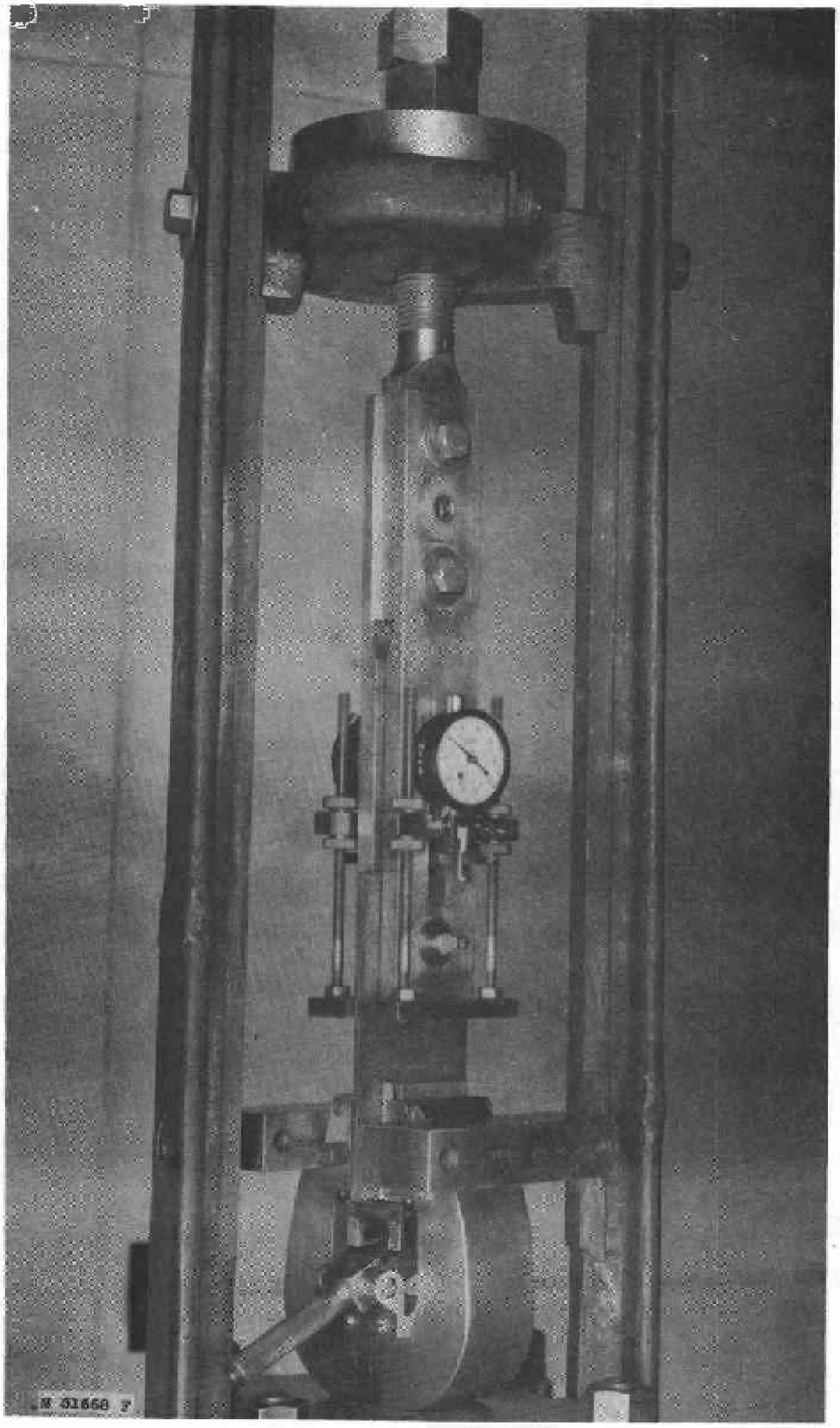

Figure 5.--Apparatus for bolt-bearing tests under tensile loading.

Z M 51668 F

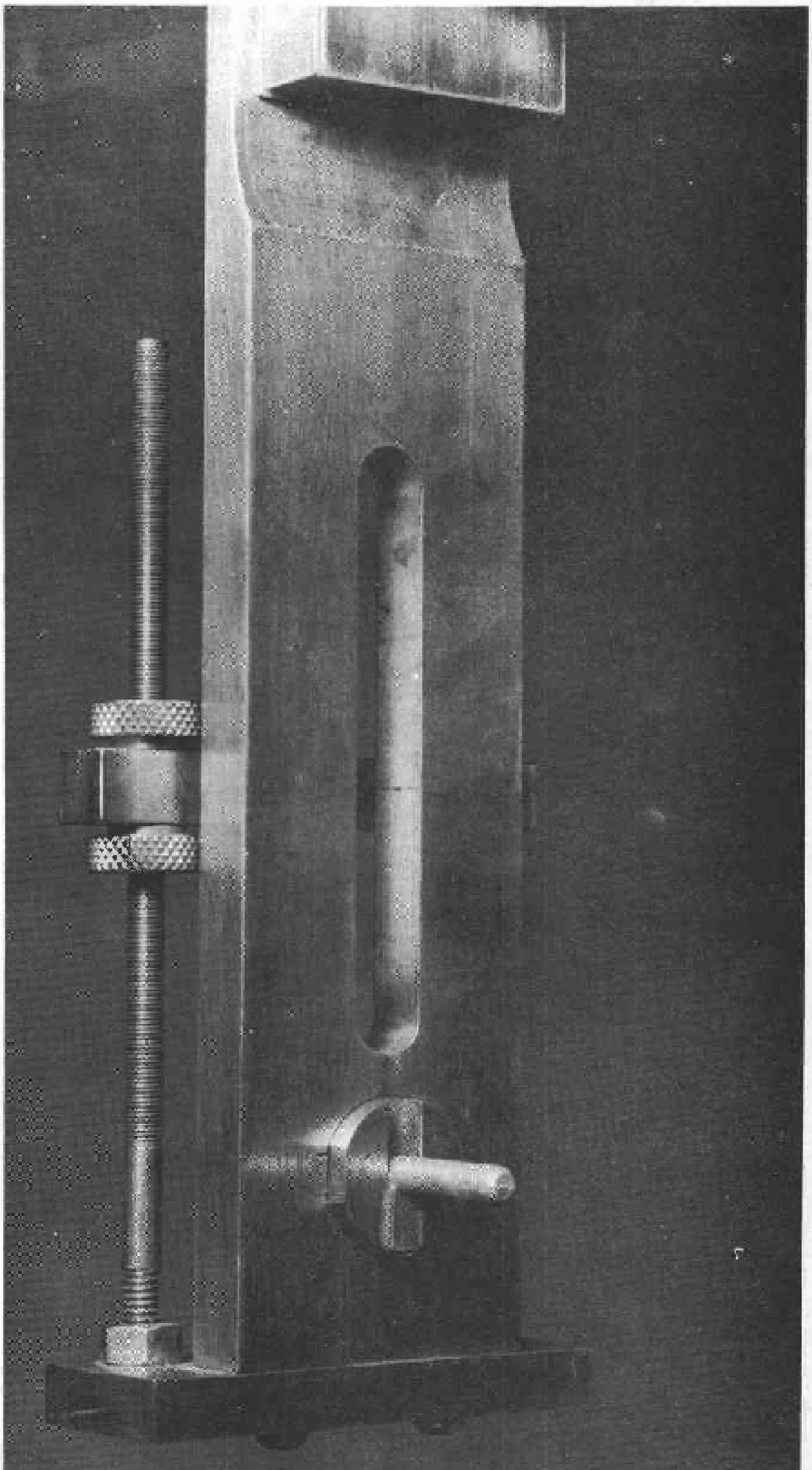

Figure 6.--Inside view of apparatus for bolt-bearing tests under tensile loading.

Z M 51662 F

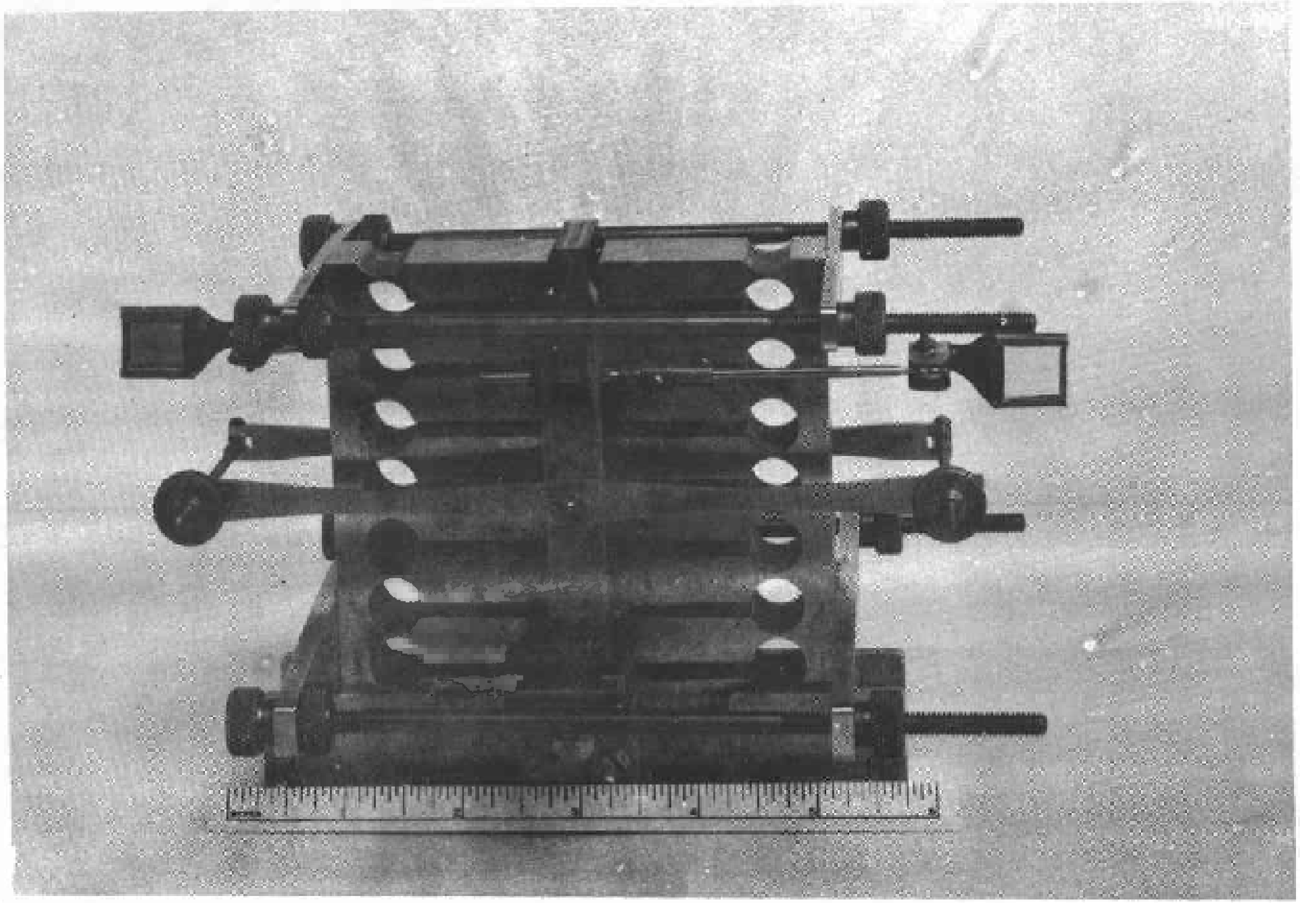

Figure 7.--Apparatus, including a 2-inch Martens' mirror compressometer, used in compression tests of laterally supported 1/4- by 1- by 4-inch specimens.

Z M 55342 F

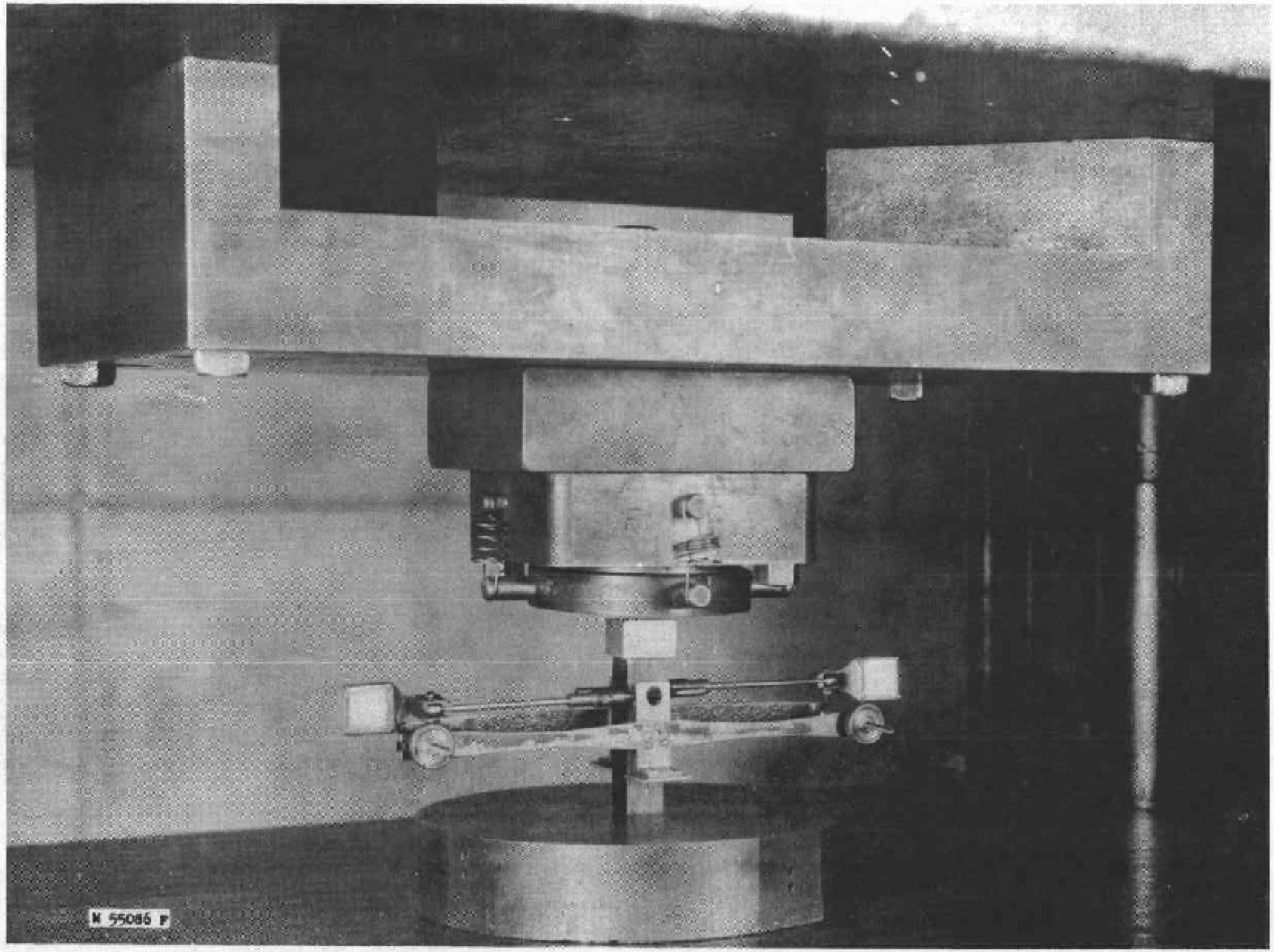

Figure 8.--Apparatus, including a 1-inch Martens' mirror compressometer, used for compression tests of 1/2- by 1/2- by 2-inch specimens.

Z M 55086 F

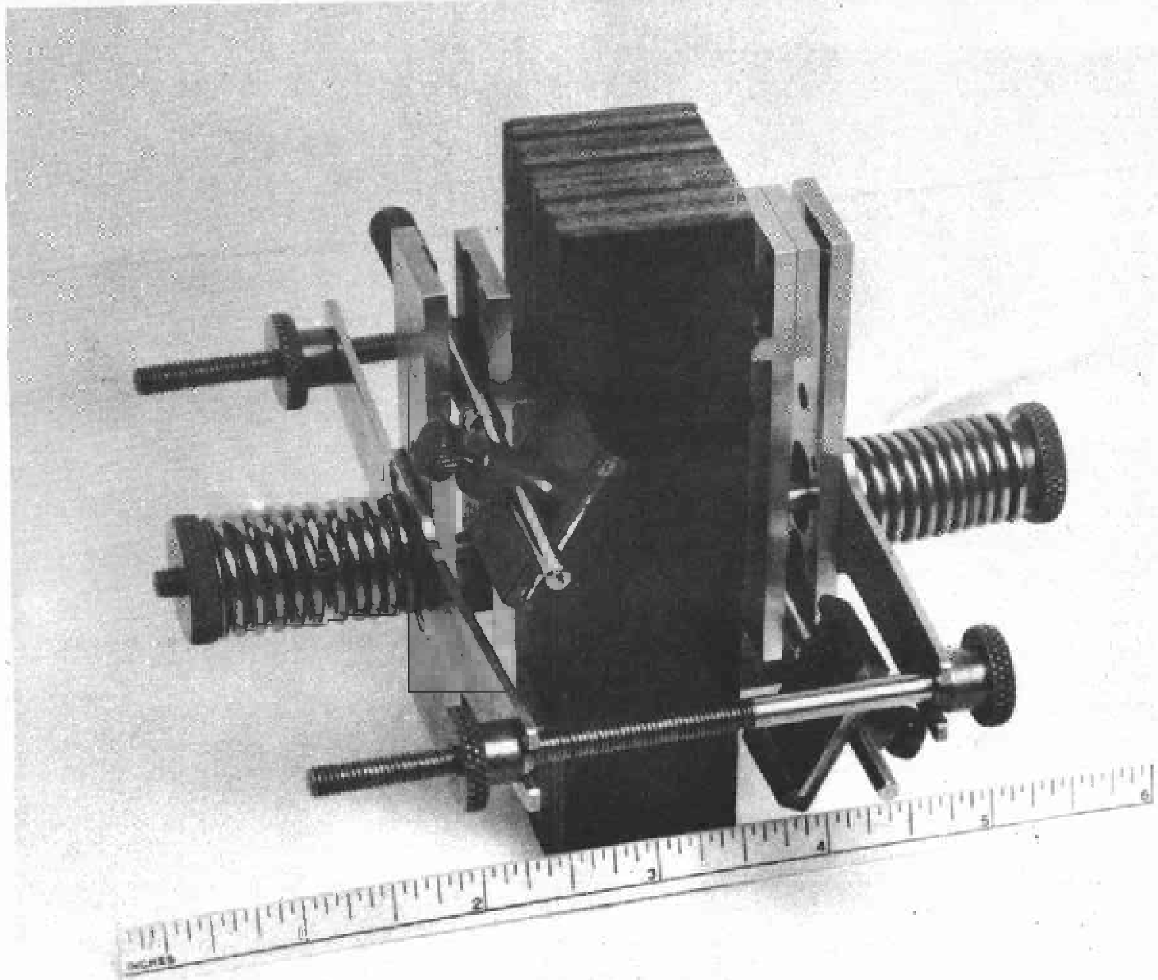

Figure 9.--Apparatus, including a roller type compressometer with averaging optical levers, used in compression tests of 1- by 1- by 4-inch specimens. Gage length = 2 inches.

Z M 55913 F

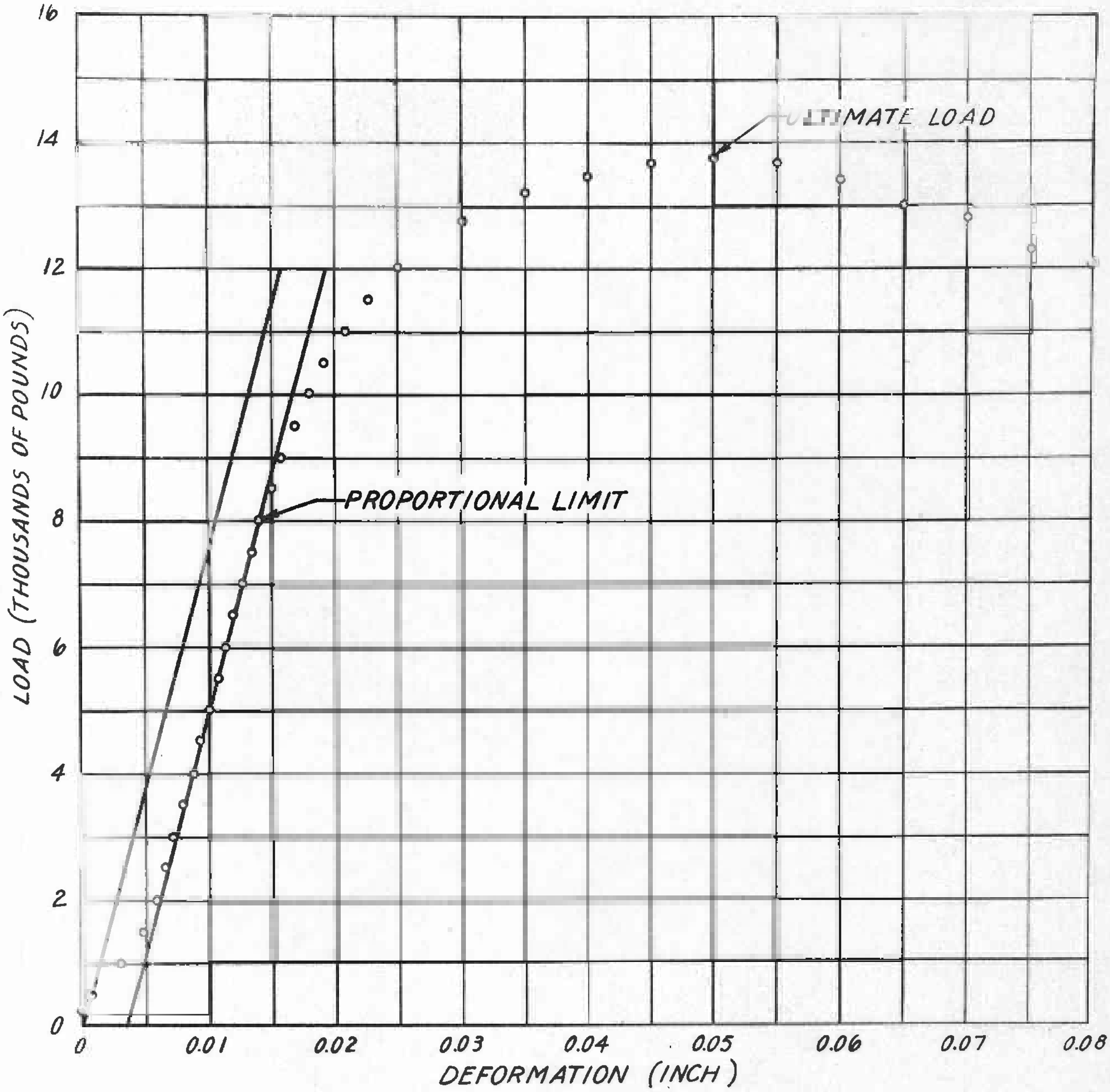

Figure 10.--Typical load-deformation curve for bolt-bearing test of 1-inch cross-banded compreg using 1/2-inch steel aircraft bolt under compressive loading parallel to the grain of the face plies.

Z M 59358 F

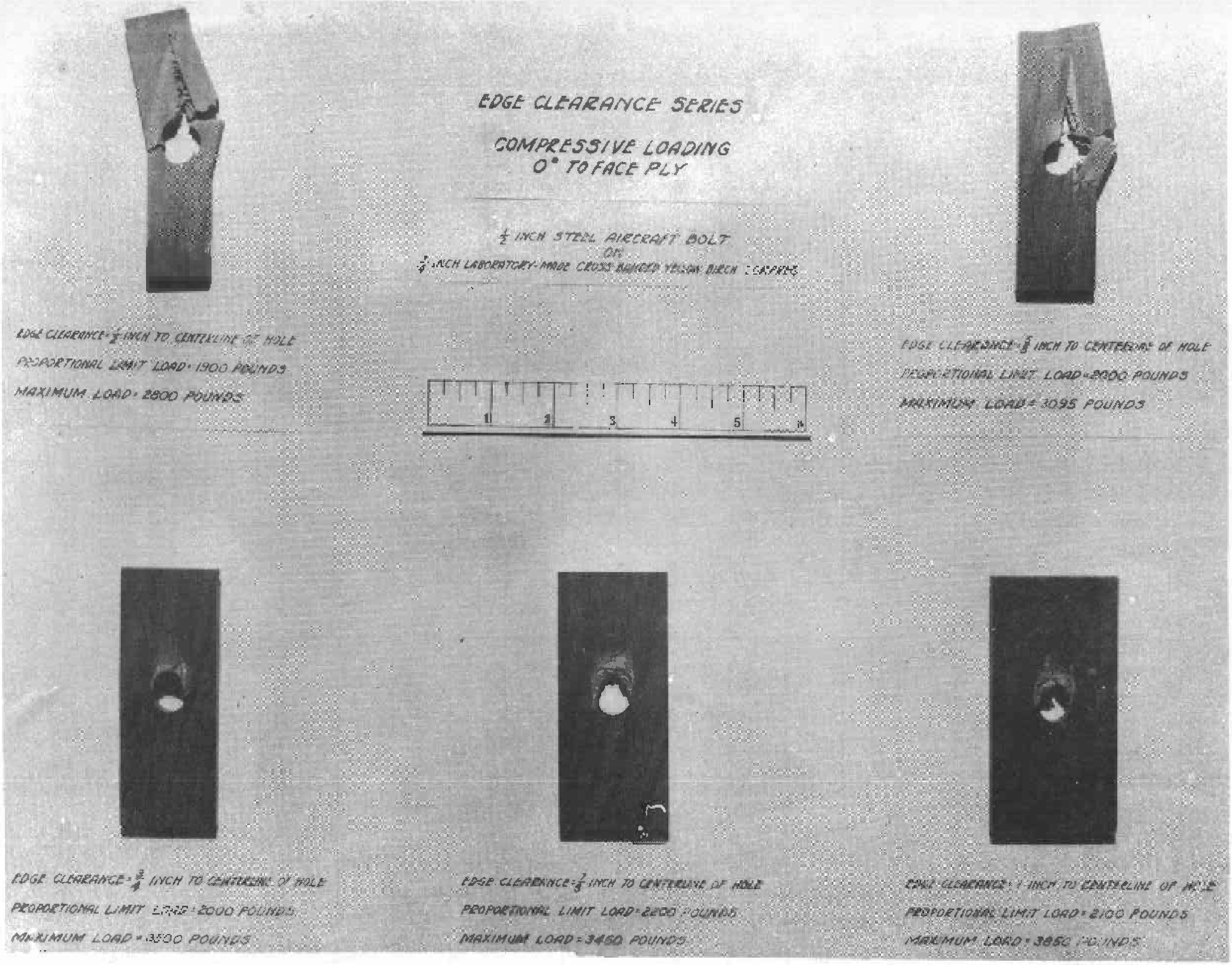

Figure 11.--Edge-clearance series tested under compressive loading parallel to grain of face ply. One-half inch steel aircraft bolt on 1/4-inch, Laboratory-made, cross-banded yellow birch compreg.

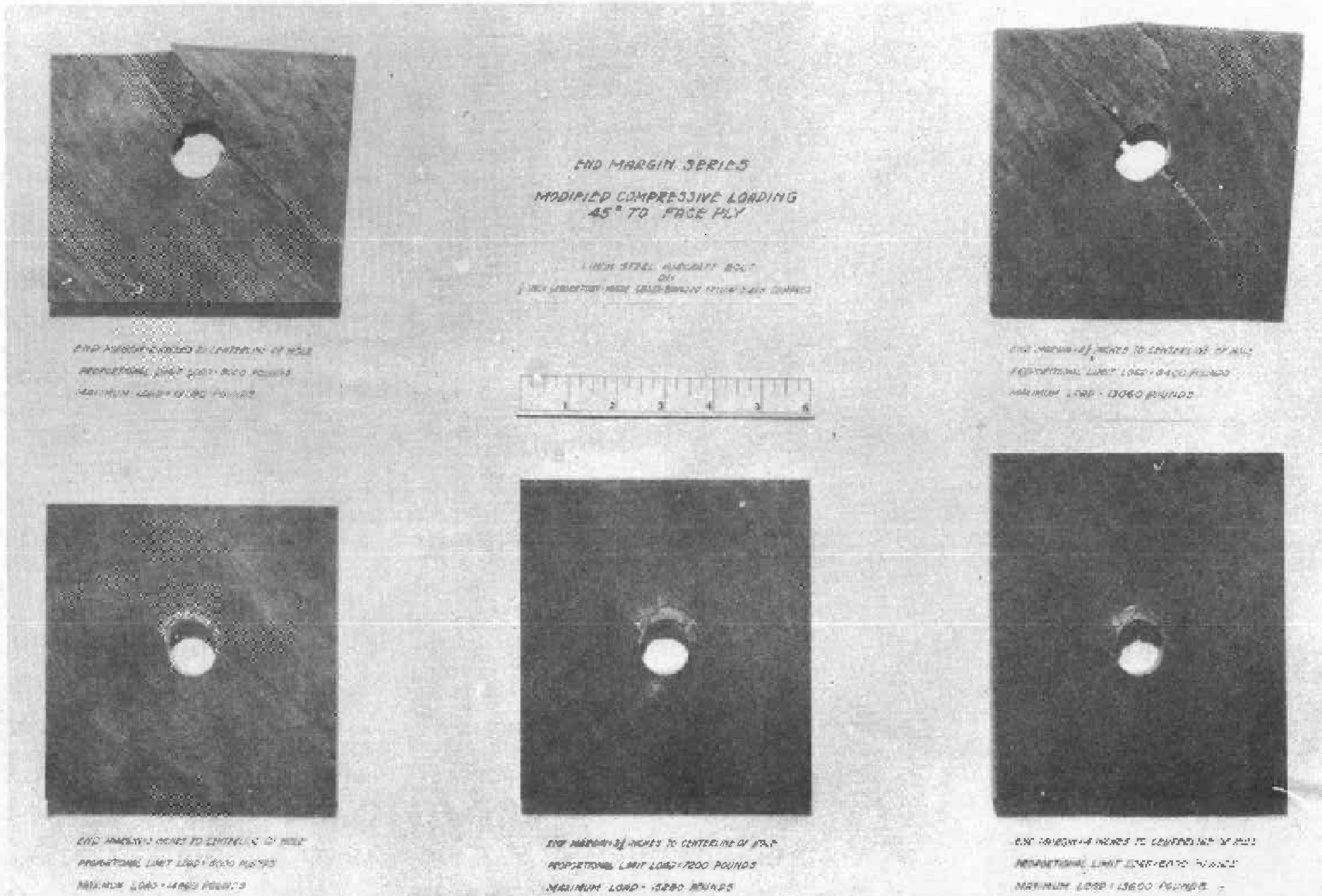

Figure 12.--End-margin series tested under modified compressive loading at an angle of 45° to the grain of the face ply. One-inch steel aircraft bolt on 1/2-inch, Laboratory-made, cross-banded yellow birch compreg.

Z M 56382 F

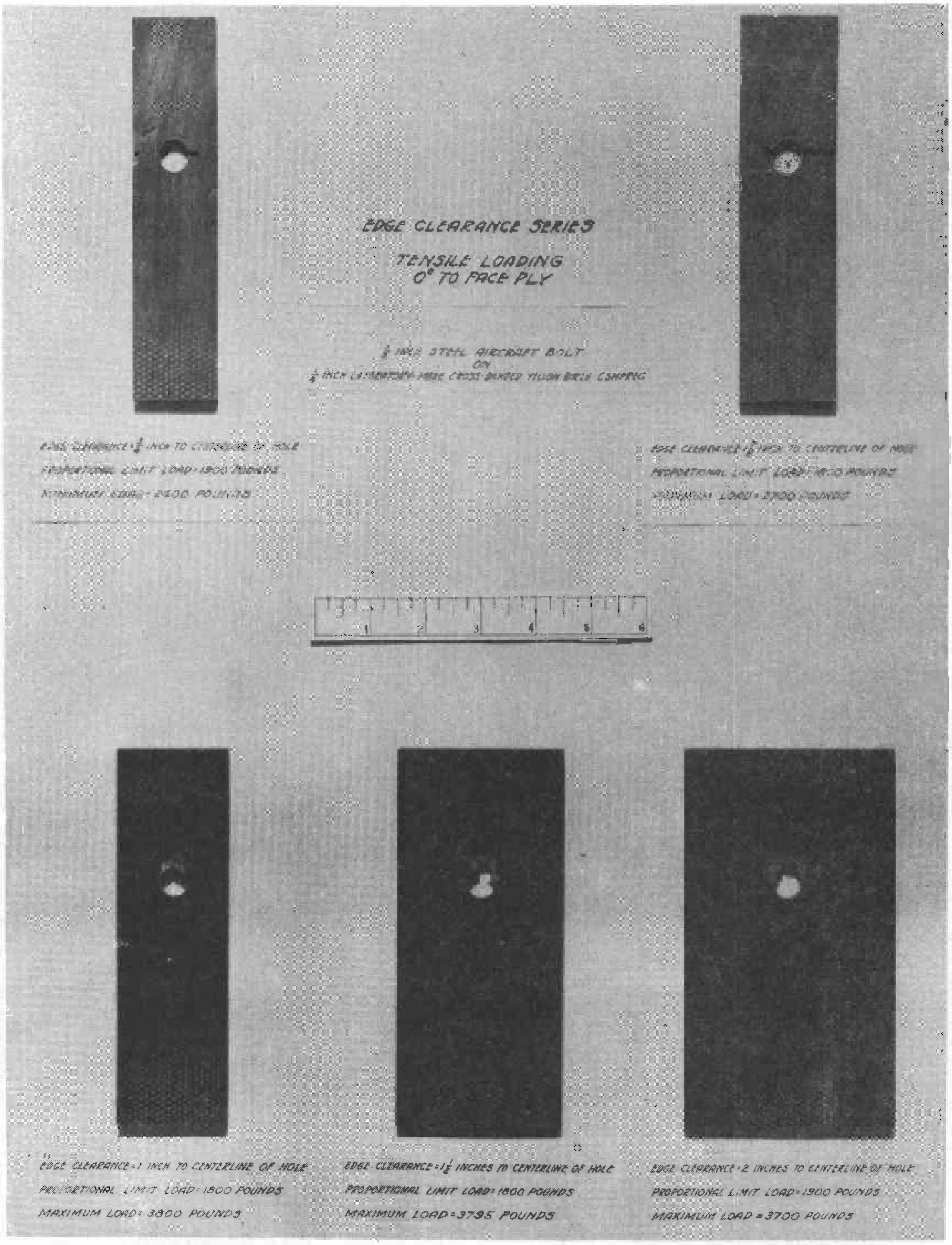

Figure 13.--Edge-clearance series tested under tensile loading parallel to the grain of the face ply. One-half-inch steel aircraft bolt on 1/4-inch, Laboratory-made, cross-banded yellow birch compreg.

Z M 56385 F

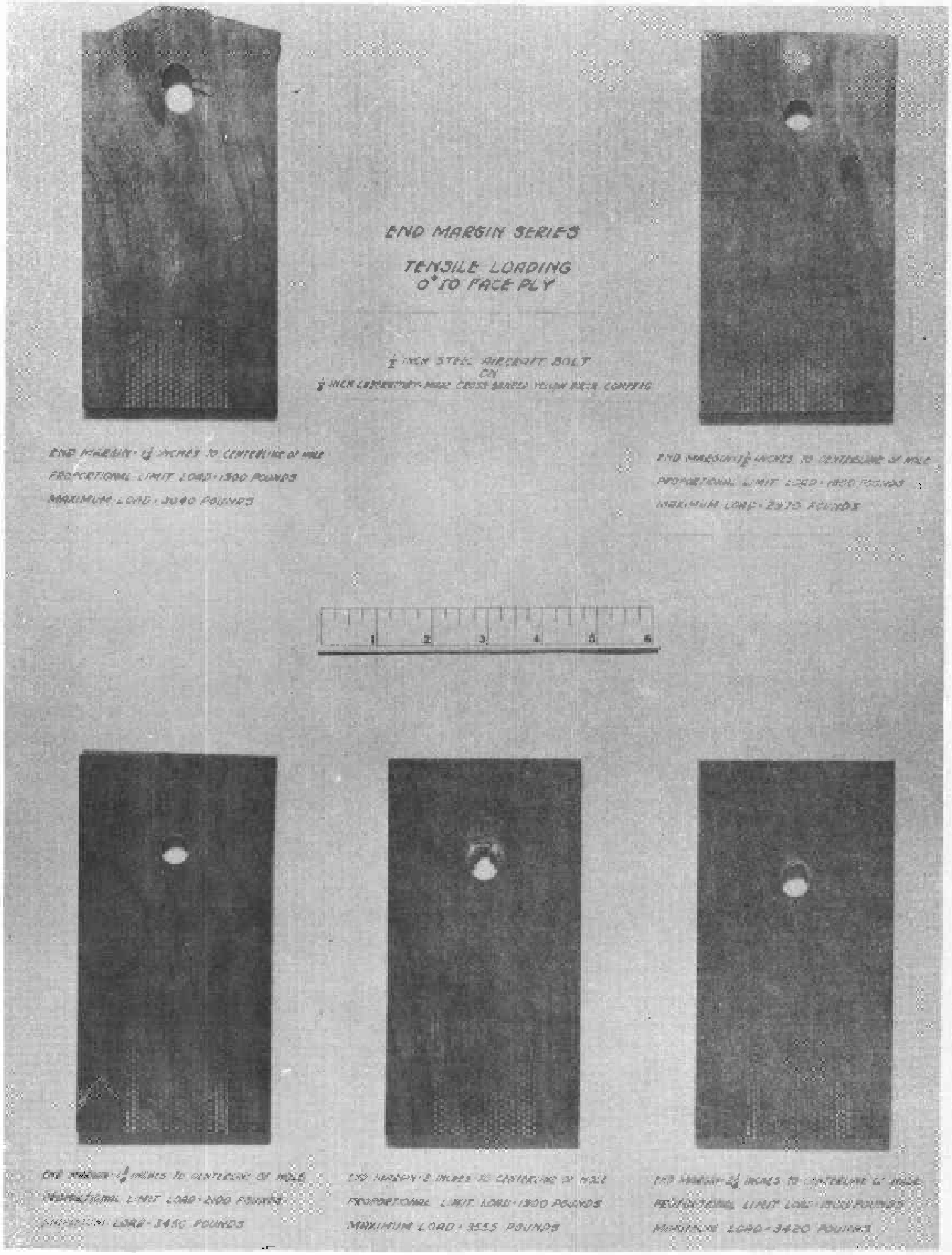

Figure 14.--End-margin series tested under tensile loading parallel to the grain of the face ply. One-half-inch steel aircraft bolt on 1/4-inch, Laboratory-made, cross-banded yellow birch compreg.

Z M 56384 F

Figure 15.--Steel aircraft bolt sheared during bolt-bearing test of 1-inch cross-banded compreg under compressive loading. Ultimate load, 7,480 pounds; bolt diameter, 0.246 inch; bearing length, .949 inch.

Z M 60750 F