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Aluminum Company of America

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INTRODUCTION

Although a number of investigations of the bearing strength of aluminum alloys have been made (see references 1 and 2), the problem remains one of considerable interest to the aircraft industry. For this reason it has seemed advisable to make additional tests of the commonly used aircraft alloys in an effort to establish a better basis for the selection of allowable bearing values. Current design practice does not recognize the effect of edge distance upon bearing strengths, and for this reason edge distance was one of the principal variables considered in this investigation. The increasing emphasis being placed upon permanent set limitations makes it essential that more information on bearing yield phenomena be obtained.

The object of this investigation was to determine bearing yield and ultimate strengths of the following aluminum alloy products: 17S-T, 24S-T, Alclad 24S-T, 24S-RT, 52S-O, 52S-1/2H, 52S-H, 53S-T, and 61S-T sheet; A51S-T and 14S-T forgings; and 24S-T, 53S-T and 61S-T extrusions. Ratios of these bearing properties to tensile properties were also determined.

MATERIAL

The sheet used for these tests was 0.064- by 10- by 20-inch. Bearing specimens were cut parallel to the 20-inch dimension, which was also parallel to the direction of rolling. The extruded material was obtained in the form of die No. K-22934. Figure 13 shows a sketch of this section and indicates the portion used for the bearing specimens. The forgings were obtained in the form of 1/4-

by 3- by 12-inch samples which were machined to a 1/8-inch thickness for test.

The tensile properties given in table I indicate that the material used was typical of commercial production. The ultimate strengths ranged from 7 to 17 percent higher than the guaranteed minimums (see reference 3); the yield strengths (with-grain for sheet) were from 11 to 30 percent higher than the latter. In only one case (53S-T sheet) was the elongation value (with-grain) less than that specified.

PROCEDURE

The bearing tests involved loading single thicknesses of material in bearing on a 0.250-inch-diameter steel pin, inserted in close-fitting drilled and reamed holes. All specimens were 2 inches wide and were tested in triplicate. The sheet specimens were loaded in the direction of the grain. The tests were conducted in the 40,000-pound capacity Amsler testing machine (type 20 ZBDA, serial no. 4318) using the loading fixture shown in figure 1.

The measurements of hole elongation under increasing loads were made with a filar micrometer microscope, reading directly to 0.01 millimeter and by estimation to 0.002 millimeter. These measurements were taken between two reference marks: one scribed on a shoulder on the underside of the pin, in the plane of the sheet; the other scribed on the specimen directly under the pin. Edge distances, defined as the distance from the edge of the specimen to the center of the hole in the direction of loading, were 1.5, 2, and 4 times the pin diameter. Tests at all three edge distances were made on each specimen by shearing or sawing off the damaged end after one test (about 3/4 in. below the center of the damage hole), and redrilling at a new edge distance.

RESULTS AND DISCUSSION

Table II gives the results of all the bearing tests. The bearing yield-strength values were obtained from the bearing stress-hole elongation curves shown in figures 2 to 15, using an offset from the initial straight-line portion of the curves equal to 2 percent of the pin diameter (0.005 in.). Table II also indicates the types of failure obtained. For edge distances of 1.5 and 2 times the pin diameter, failures occurred by shearing or tearing out a portion of the specimen in the margin above the pin. For edge distances of 4 times the pin diameter, failures occurred by upsetting and crushing the metal above the pin for all cases except the forgings, which failed in shear as for the smaller edge distances.

One of the primary objects of this investigation was to obtain information to aid in establishing typical ratios of bearing to tensile properties for the aluminum alloys commonly used in aircraft. Table III summarizes the average ratios obtained. These results have been arranged according to similarity of bearing-strength characteristics into two fairly well-defined groups: group 1, including the alloys having tensile strengths ranging from 64,500 to 77,900 pounds per square inch; and group 2, including the alloys having tensile strengths ranging from 28,600 to 47,300 pounds per square inch. Ratios of tensile yield to ultimate strength averaged 0.79 for the first group; 0.90 for the second, excluding 52S-O. As would be expected, there are a few border-line cases where the bearing-strength ratios might be placed in either group, but, in general, the highest ratios of bearing ultimate and yield strength to tensile strength for all edge distances were obtained for the alloys within the lower range of tensile strengths; the lowest ratios were obtained for the highest strength materials.

The relative importance of the various properties influencing bearing strengths is, of course, not known. It seems reasonable to assume that the highest ratios of bearing ultimate to tensile strength should be exhibited by materials having low ratios of tensile yield to ultimate strength, combined with ductility or the ability to withstand highly localized plastic deformations without fracture. Of the materials in group 2, showing the highest ratios of bearing ultimate to tensile strength, 52S-O is the only one meeting both of these requirements. The ratios of tensile yield to ultimate strength of the other materials in group 2 are, with one exception, higher than for group 1, yet the influence of this factor was apparently more than offset as far as ultimate bearing strengths were concerned by the greater ductility of the lower strength alloys. The superior forming characteristics of this group of materials are generally recognized.

Bearing-yield strengths, it appears, should be related in some way to the other yield-strength characteristics of a material. Although the state of stress developed by a pin or rivet in bearing is obviously complex, it is not surprising that the bearing-yield to tensile-strength ratios shown in table III increase with increasing ratios of tensile yield to tensile strength. From the approximately linear relationship observed between these ratios for both groups of materials, it follows that the ratios of bearing-yield to tensile-yield strength for any one edge distance should be fairly constant. The uniformity of these ratios suggests that they provide a simpler and perhaps a more rational basis for expressing bearing-yield characteristics than do ratios of bearing-yield strength to tensile strength which, as shown, may vary appreciably for different materials.

One of the interesting observations to be made from the results of these tests is that the increases in bearing-yield strengths for edge distances greater than 2 diameters were not as pronounced as in the case of the ultimate bearing strengths. This was particularly true of the materials in the lower tensile-strength group. At an edge distance of 2 diameters, moreover, the bearing-yield strengths averaged about two-thirds of the ultimate bearing strengths. According to present aircraft-design procedures, in which the stress at yielding generally controls design if it is less than two-thirds of the ultimate strength (ultimate factor of safety = 1.5), it appears that bearing yield rather than bearing ultimate strength will be the controlling factor in designs for edge distances greater than 2 diameters.

It should be emphasized in connection with any analysis of these data for design purposes that the bearing strengths given were all obtained from tests of 2-inch-wide specimens, 0.064 to 0.125 inch thick, loaded parallel to the direction of the grain through a 1/4-inch-diameter steel pin. Under other test conditions somewhat different bearing values would have been obtained. Table IV gives a few data from other tests relative to the effect of specimen proportions and direction of loading upon the bearing properties of 24S-T sheet. Of principal interest is the fact that the ratios of bearing-yield to tensile-yield strength were higher for the cross-grain direction (X) than for the with-grain direction (W). These cross-grain ratios may be approximated by multiplying the with-grain ratios by the ratios of the tensile yield strength with-grain to that across-grain.* Ratios of bearing ultimate strength to tensile strength for the cross-grain direction may likewise be estimated by multiplying the with-grain ratios by the ratio of the tensile strength with-grain to that across-grain. It is concluded from these observations that actual values of bearing yield and ultimate strength (not ratios to tensile properties) show no significant directional characteristics. This result is consistent with the indications of earlier bearing tests.

Table IV also indicates that the bearing-yield strengths obtained from specimens having a gross width equal to four times the pin diameter (W = 4D) were essentially the same as found for specimens having a width of 8D, which was the width proportion used for the tests of this investigation. The ultimate bearing strengths of the specimens having a width of 4D were about 5 percent less than obtained for the wider specimens.

Ratios of pin diameter to material thickness (D/t) apparently have little effect upon bearing strengths, provided D/t equals 4 or less. For relatively larger pin diameters, decreases in ultimate bearing strength may be expected as shown in table IV. Although not indicated in the table, bearing-yield strengths are not influenced by ratios of D/t provided the required yield strain (0.02D) can be produced before ultimate bearing failure occurs.

Table V gives a summary of the ratios selected from table III as a tentative basis for predicting nominal bearing values for the alloys and products considered. It should be emphasized that the ratios proposed for sheet materials are based on bearing and tensile tests made in the with-grain direction. Since bearing properties do not show marked directional characteristics it follows that ratios of bearing to tensile properties across-grain will be somewhat higher than shown in table III. The greatest difference will be found in the case of ratios of bearing yield to tensile yield strength, since the latter property for certain cases is normally higher in the with-grain direction than in the cross-grain direction.

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*See table I-1, ANC-5, 1942, for relations between with- and cross-grain properties of aluminum-alloy sheet.

The ratios given for 17S-T and plain and Alclad 24S-T sheet in table V are in substantial agreement with values obtained in previous bearing tests of these alloys in the form of sheet. The ratios given for the thin 24S-T extruded sections, however, are not necessarily representative of the behavior likely to be obtained in thicker extrusions. Table V includes, for example, a set of ratios recently obtained for $3\frac{3}{4}$-inch thick 24S-T extruded sections having a large percentage of unrecrystallized material with tensile strengths slightly over 80,000 pounds per square inch. The ratios of bearing to tensile properties for this 24S-T were appreciably lower than any obtained in the present tests. Comparative data for thick and thin forgings of A51S-T and 14S-T are not available.

It is quite evident from table V that one set of ratios of bearing to tensile properties cannot be given to cover adequately all the wrought-aluminum alloys in their various commercial forms. The ratio of bearing ultimate strength to tensile strength of approximately 1.4 currently used for most alloys in aircraft design (see reference 4) is satisfactory for edge distances of 1.5 diameters but appears unduly conservative for edge distances of 2 diameters or greater. It is believed that the influence of edge distance should be recognized in the selection of allowable bearing values.

CONCLUSIONS

The results of this investigation of the bearing-strength characteristics of a number of aluminum alloys in the form of sheet, thin extrusions, and thin forgings, loaded in bearing through a steel pin, 1/4 inch in diameter, seem to warrant the following conclusions:

1. The bearing-strength data presented were obtained from materials representative of commercial production. Table I gives a summary of tensile properties.

2. Table II gives bearing yield and ultimate strengths for all materials for edge distances of 1.5, 2 and 4 times the diameter of the pin. Although the highest bearing values were obtained for the largest edge distance, the increases in bearing-yield strengths for edge distances greater than 2D were not as pronounced as in the case of the ultimate strengths.

3. Bearing-yield strengths are apparently related to the other yield characteristics of a material and therefore tend to approach an upper limiting value as edge distances are increased. Bearing ultimate strengths, however, reflect the ability of a material to withstand highly localized plastic deformations without fracture. Because of the upsetting that may occur ahead of the pin, accompanied by an increase in effective bearing area, extremely high values of ultimate bearing strength may be obtained for large edge distances in ductile materials.

4. All specimens with edge distances of 1.5 and 2 times the diameter of the pin failed by shearing or tearing out a portion of the specimen in the margin above the pin. Specimens with edge distances of 4 diameters failed in bearing by crushing or upsetting the metal above the pin, except in the case of the forgings which failed in shear, as for the smaller edge distances.

5. The ratios of bearing yield and ultimate strength to tensile strength given in table III indicate that all the materials tested may be placed in two rather well defined groups: one including the alloys having tensile strengths ranging from 64,500 to 77,900 pounds per square inch; the other including the alloys having tensile strengths ranging from 28,600 to 47,300 pounds per square inch. The highest ratios of bearing to tensile strength were found for the materials in the lower tensile-strength range.

6. Ratios of bearing yield to tensile ultimate strength varied almost linearily with ratios of tensile yield to ultimate strength. Ratios of bearing-yield to tensile-yield strength, however, were practically constant for all materials, particularly for edge distances of 1.5D and 2D. Tensile-yield strengths therefore appear to provide a simpler and perhaps a more rational basis for expressing bearing-yield characteristics than do tensile ultimate strengths.

7. From a limited number of tests of 24S-T sheet, summarized in table IV, and the results of an earlier investigation, it appears that bearing yield and ultimate strengths do not exhibit marked directional characteristics. In view of the difference which exists in some cases between tensile-yield strengths in the with- and cross-grain directions, ratios of bearing-yield to tensile-yield strengths in the cross-grain direction may be higher than shown in table III for the with-grain direction.

8. Bearing-yield strengths determined from auxiliary specimens having a gross width of only four times the pin diameter were essentially the same as determined from specimens having a width of 8 diameters, the proportion used in these tests. Ultimate bearing strengths for specimens having a width of 4D were about 5 percent less than for a width of 8D. Ratios of pin diameter to material thickness (D/t) had little effect upon either bearing yield or ultimate strengths for values of D/t equal to 4 or less. For higher D/t ratios, decreases in bearing ultimate strengths must be expected, as shown in table IV.

9. Table V presents the ratios of bearing-to-tensile properties proposed from these tests as a tentative basis for predicting nominal bearing values for the aluminum alloys and products considered.

10. Edge distance is a sufficiently important factor to be recognized in the selection of allowable bearing values. It is believed that consideration of this factor will permit some increase in bearing values over those currently used in design.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Pa., April 20, 1943.

REFERENCES

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2. Miller, Roy A.: The Bearing Strength of Steel and Aluminum Alloy Sheet in Riveted or Bolted Joints. Jour. Aero. Sci., vol. 5, 1937.

3. Alcoa Aluminum and Its Alloys. Aluminum Co. of America, 1943.

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TABLE I

TENSILE PROPERTIES OF ALUMINUM ALLOY SHEET, FORGINGS, AND EXTRUSIONS, USED FOR BEARING TESTS

(P. T. No. 040642-C)

Alloy and Temper	Form of Material	Nominal Thickness of Specimen,† in.	Ultimate Strength, psi	Yield Strength (Offset=0.2%), psi	Elongation in 2 in., per cent
17S-T	Sheet	0.064	64 600	47 100	20.5
24S-T	Sheet	0.064	73 000	55 000	18.0
Alc. 24S-T*	Sheet	0.064	65 400	50 400	19.5
24S-RT	Sheet	0.064	77 900	64 200	12.0
52S-0	Sheet	0.064	28 600	12 500	22.0
52S-1/2H	Sheet	0.064	37 800	31 600	9.0
52S-H	Sheet	0.064	39 200	34 700	9.8
53S-T	Sheet	0.064	40 400	36 000	12.5
61S-T	Sheet	0.064	45 200	41 600	11.5
14S-T	Forging	0.125	70 700	63 200	10.8
A51S-T	Forging	0.125	47 300	44 200	12.3
24S-T	Extrusion	0.070	64 500	50 800	21.5
53S-T	Extrusion	0.070	36 700	33 800	11.0
61S-T	Extrusion	0.070	41 700	38 800	11.5

The above values are the average of two tests (with-grain) of sheet and extrusions and three tests of the forgings. Standard tension test specimens for sheet metals used, see Fig. 2 of Tentative Methods of Tension Testing of Metallic Materials (E8-40T), 1940 Supplement to Book of A.S.T.M. Standards, Part I, p. 454.

* 5 per cent Alclad coating on each side.

† Original thicknesses of material except for 14S-T and A51S-T, in which cases specimens were machined from 1/4 x 3 x 12-in. forged stock.

TABLE III

RATIOS OF AVERAGE BEARING PROPERTIES TO TENSILE PROPERTIES

(P. T. No. 040642-C)

Alloy and Temper	Form of Material	TS, psi	TYS, psi	TYS/TS	Edge distance = 1.5xpin diameter			Edge distance = 2xpin diameter			Edge distance = 4xpin diameter		
					BS/TS	BYS/TS	BYS/TYS	BS/TS	BYS/TS	BYS/TYS	BS/TS	BYS/TS	BYS/TYS
					Group 1								
17S-T	Sheet	64 600	47 100	0.73	1.49	1.03	1.41	1.96	1.19	1.64	2.59	1.31	1.80
24S-T	Sheet	73 000	55 000	0.75	1.52	1.06	1.41	1.98	1.23	1.64	2.37	1.35	1.80
Alc.24S-T*	Sheet	65 400	50 400	0.77	1.53	1.06	1.37	2.00	1.20	1.56	2.35	1.31	1.70
24S-RT	Sheet	77 900	64 200	0.82	1.45	1.15	1.40	1.83	1.27	1.54	2.32	1.41	1.71
24S-T	Thin ext.	64 500	50 800	0.79	1.54	1.12	1.42	1.91	1.33	1.69	2.45	1.49	1.89
14S-T	Thin forgings	70 700	63 200	0.90	1.46	1.21	1.35	1.97	1.44	1.63	2.65	1.45	1.62
					Group 2								
52S-0	Sheet	28 600	12 500	0.44	1.68	0.91	2.07	2.23	1.10	2.51	3.33	1.15	2.63
52S-H	Sheet	39 200	34 700	0.89	1.61	1.31	1.48	2.08	1.43	1.61	2.84	1.46	1.65
52S-1/2H	Sheet	37 800	31 600	0.84	1.50	1.23	1.47	2.06	1.39	1.67	3.13	1.42	1.70
53S-T	Sheet	40 400	36 000	0.89	1.65	1.31	1.47	2.28	1.44	1.62	3.20	1.48	1.66
61S-T	Sheet	45 200	41 600	0.92	1.59	1.27	1.38	2.18	1.50	1.63	3.23	1.53	1.66
53S-T	Thin ext.	36 700	33 800	0.92	1.62	1.32	1.43	2.19	1.46	1.59	3.10	1.47	1.60
61S-T	Thin ext.	41 700	38 800	0.93	1.64	1.33	1.43	2.21	1.47	1.58	3.35	1.51	1.62
A51S-T	Thin forgings	47 300	44 200	0.93	1.57	1.31	1.41	2.36	1.53	1.64	3.28	1.52	1.63

All bearing tests on 1/4-in. diameter steel pin (D/t = 4 or less). Specimens 2 in. wide loaded parallel to direction of grain.

BS - Bearing strength
BYS - Bearing yield strength (offset = 0.02 x pin diameter = 0.005 in.)
TS - Tensile strength (with-grain)
TYS - Tensile yield strength (offset = 0.2 per cent) (with-grain)

* 5 per cent Alclad coating on each side.

TABLE II.- BEARING STRENGTHS OF ALUMINUM ALLOY SHEET, FORGINGS, AND EXTRUSIONS
(P. T. No. 040642-C)

Alloy and Temper	Form of material	Nominal[a] thickness (in.)	Test number	BEARING STRENGTHS, (psi): Edge distance = 1.5 × pin diam. Ultimate	Edge distance = 1.5 × pin diam. Yield*	Type of failure†	Edge distance = 2 × pin diam. Ultimate	Edge distance = 2 × pin diam. Yield*	Type of failure†	Edge distance = 4 × pin diam. Ultimate	Edge distance = 4 × pin diam. Yield*	Type of failure†
17S-T	Sheet	0.064	1	95,810	67,500	S	126,130	78,500	S	168,060	83,500	B
	Sheet	.064	2	96,450	66,000	S	126,770	76,500	S	167,420	85,500	B
	Sheet	.064	3	96,450	65,500	S	126,450	76,500	S	166,130	85,000	B
			Av.	96,240	66,350	S	126,450	77,150	S	167,205	84,650	B
24S-T	Sheet	0.064	1	111,200	78,500	S	144,800	90,000	S	176,970	100,000	B
	Sheet	.064	2	110,000	77,000	S	142,900	90,000	S	172,120	97,500	B
	Sheet	.064	3	112,100	77,500	S	144,800	90,000	S	169,700	99,000	B
			Av.	111,100	77,650		144,165	90,000		172,930	98,850	
Alc.24S-T[b]	Sheet	0.064	1	98,500	69,000	S	128,000	78,000	S	145,570	83,500	B
	Sheet	.064	2	98,800	67,500	S	134,400	79,000	S	150,630	87,500	B
	Sheet	.064	3	103,000	70,500	S	129,100	79,000	S	163,920	86,000	B
			Av.	100,100	69,000		130,500	78,650		153,375	85,650	
24S-RT	Sheet	0.064	1	112,420	90,000	S	143,870	99,500	S	183,000	110,000	B
	Sheet	.064	2	113,400	90,000	S	141,410	97,500	S	182,030	110,000	B
	Sheet	.064	3	112,580	90,000	S	142,640	99,500	S	177,480	110,000	B
			Av.	112,800	90,000		142,640	98,850		180,835	110,000	
52S-0	Sheet	0.064	1	51,200	25,500	S	63,300	31,700	S	96,100	31,500	B
	Sheet	.064	2	46,800	25,600	S	60,700	31,500	S	99,700	32,800	B
	Sheet	.064	3	46,600	26,500	S	67,300	31,000	S	90,300	34,500	B
			Av.	48,200	25,900		63,800	31,400		95,400	32,900	
52S-1/2H	Sheet	0.064	1	57,000	45,800	S	78,300	52,500	S	119,430	54,000	B
	Sheet	.064	2	55,800	46,000	S	77,200	52,500	S	117,400	53,500	B
	Sheet	.064	3	57,800	47,200	S	78,000	53,300	S	118,240	53,500	B
			Av.	56,870	46,350		77,835	52,750		118,355	53,650	
52S-H	Sheet	0.064	1	63,500	52,100	S	83,000	57,200	S	113,400	57,000	B
	Sheet	.064	2	63,800	52,000	S	81,200	56,700	S	111,200	58,000	B
	Sheet	.064	3	62,800	50,500	S	80,000	54,200	S	108,800	57,000	B
			Av.	63,400	51,500		81,400	56,000		111,100	57,300	
53S-T	Sheet	0.064	1	65,500	52,800	S	92,300	58,000	S	128,200	60,200	B
	Sheet	.064	2	66,000	52,200	S	91,000	58,300	S	121,800	59,200	B
	Sheet	.064	3	67,800	53,700	S	92,300	58,300	S	137,800	59,500	B
			Av.	66,430	52,900		91,865	58,200		129,265	59,650	
61S-T	Sheet	0.064	1	70,800	58,000	S	98,200	67,000	S	144,790	69,000	B
	Sheet	.064	2	70,400	58,300	S	98,200	66,800	S	146,630	69,000	B
	Sheet	.064	3	74,000	60,500	S	98,800	69,500	S	145,710	69,000	B
			Av.	71,730	57,250		98,400	67,750		145,710	69,000	
14S-T	Forging	0.125	1	103,480	87,000	S	140,030	103,000	S	191,455	99,000	S
	Forging	.125	2	103,180	83,500	S	135,870	102,000	S	177,140	104,000	S
	Forging	.125	3	102,200	85,500	S	142,450	101,000	S	194,030	105,000	S
			Av.	102,950	85,550		139,450	102,000		187,575	102,650	
A51S-T	Forging	0.125	1	73,900	58,500	S	112,740	75,500	S	159,120	70,000	S
	Forging	.125	2	73,410	62,000	S	112,740	71,000	S	158,600	71,500	S
	Forging	.125	3	75,560	66,000	S	109,210	71,000	S	147,460	74,500	S
			Av.	74,290	62,150		111,565	72,500		155,060	72,000	
24S-T	Extrusion	0.070	1	98,890	71,000	S	121,390	83,000	S	154,720	96,000	B
	Extrusion	.070	2	98,890	71,500	S	123,340	85,000	S	157,780	96,500	B
	Extrusion	.070	3	100,000	74,000	S	125,000	89,000	S	160,560	95,000	B
			Av.	99,260	72,150		123,245	85,650	S	157,685	95,850	
53S-T	Extrusion	0.070	1	60,880	49,500	S	83,820	56,000	S	117,060	55,500	B
	Extrusion	.070	2	58,820	48,500	S	79,120	53,500	S	116,760	55,000	B
	Extrusion	.070	3	58,290	47,500	S	77,720	51,500	S	107,710	51,500	B
			Av.	59,330	48,500		80,220	53,650		113,845	54,000	
61S-T	Extrusion	0.070	1	68,820	56,000	S	93,240	61,000	S	139,710	64,000	B
	Extrusion	.070	2	68,410	55,000	S	91,590	60,500	S	138,550	62,000	B
	Extrusion	.070	3	68,240	56,000	S	91,180	62,000	S	140,590	62,500	B
			Av.	68,490	55,650		92,005	61,150		139,620	62,850	

Note - All tests on 1/4-in. diam. steel pin (D/t, 4 or less). Specimens 2 in. wide, loaded parallel to direction of grain. [a]Original thicknesses of material except for 14S-T and A51S-T, in which cases specimens were machined from 1/4- by 3- by 12-in. forged stock. [b]Five percent alclad coating on each side. *Stress corresponding to offset of 2 percent of hole diam. from initial straight line portion of load-hole elongation curves shown in figs. 2 to 15. (0.005 in. offset for 1/4-in. diam. pin) †Type of failure (B) Bearing, (S) Shear.

TABLE IV

EFFECT OF SPECIMEN PROPORTIONS AND DIRECTIONS OF LOADING UPON RATIOS OF BEARING TO TENSILE PROPERTIES OF 24S-T SHEET

Pin Diam./Thickness (D/t)	Spec. Width/Pin Diam. (W/D)	Direction of Loading*	TS psi	TYS psi	Edge distance= 1.5 x pin diam.			Edge distance= 2 x pin diam.			Edge distance= 4 x pin diam.		
					BS/TS	BYS/TS	BYS/TYS	BS/TS	BYS/TS	BYS/TYS	BS/TS	BYS/TS	BYS/TYS
4	4	W	71 500	51 600	1.45	1.04	1.44	1.85	1.21	1.68	2.27	1.36	1.89
4	4	X	69 400	44 800	1.46	1.02	1.57	1.90	1.22	1.89	2.36	1.40	2.17
4	8	W	73 000	55 000	1.52	1.06	1.41	1.98	1.23	1.64	2.37	1.35	1.80
4	8	X	69 900	47 800	----	----	----	2.05	1.29	1.89	----	----	----
2	4	X	70 000	45 900	1.49	----	----	1.91	----	----	----	----	----
2	8	X	70 000	45 900	----	----	----	2.03	----	----	----	----	----
3	6	W	71 200	54 200	1.56	----	----	1.92	----	----	2.48	----	----
4	4	X	69 900	47 800	1.48	----	----	1.93	----	----	----	----	----
4	6	W	71 200	54 200	1.56	----	----	1.92	----	----	2.23	----	----
4	8	X	69 900	47 800	----	----	----	2.05	1.29	1.89	----	----	----
6	4	X	70 000	45 900	----	----	----	1.53	----	----	----	----	----
8	4	X	69 900	47 800	1.36	----	----	1.41	----	----	----	----	----
12	4	X	69 900	47 800	----	----	----	1.03	----	----	----	----	----

* X - cross-grain, W - with-grain.

TABLE V

SUGGESTED TYPICAL RATIOS OF BEARING TO TENSILE PROPERTIES

(P. T. No. 040642-C)

Product	Edge distance = 1.5 x pin diameter		Edge distance = 2 x pin diameter		Edge distance = 4 x pin diameter	
	BS/TS	BYS/TYS	BS/TS	BYS/TYS	BS/TS	BYS/TYS
17S-T sheet 24S-T sheet Alc. 24S-T* sheet 24S-RT sheet	1.5	1.4	1.9	1.6	2.3	1.7
52S-O sheet 52S-1/2H sheet 52S-H sheet 53S-T sheet 61S-T sheet	1.6	1.4	2.1	1.6	3.0	1.6
24S-T thin extrusions	1.5	1.4	1.9	1.6	2.3	1.7
24S-T thick extrusions	1.2	1.2	1.5	1.4	2.1	1.6
53S-T thin extrusions 61S-T thin extrusions	1.6	1.4	2.1	1.6	3.0	1.6
14S-T thin forgings	1.5	1.4	1.9	1.6	2.3	1.7
A51S-T thin forgings	1.6	1.4	2.1	1.6	3.0	1.6

Above ratios are based on tests of 2-in. wide specimens, loaded parallel to direction of grain on 1/4-in. diameter steel pin. (D/t = 4 or less). Corresponding ratios for sheet across grain are higher by ratio of tensile yield or ultimate strength with-grain to that across-grain.
Ratios for "thin" extrusions are based on tests of specimens from section 0.070 in. thick (Die No. K-22934).
Ratios for "thick" extrusions are based on tests of specimens from section approximately 3-3/4 in. thick (Die No. K-27768).
Ratios for "thin" forgings are based on tests of specimens from forged plates, 1/4 x 3 x 12 in.

* 5 per cent Alclad coating on each side.

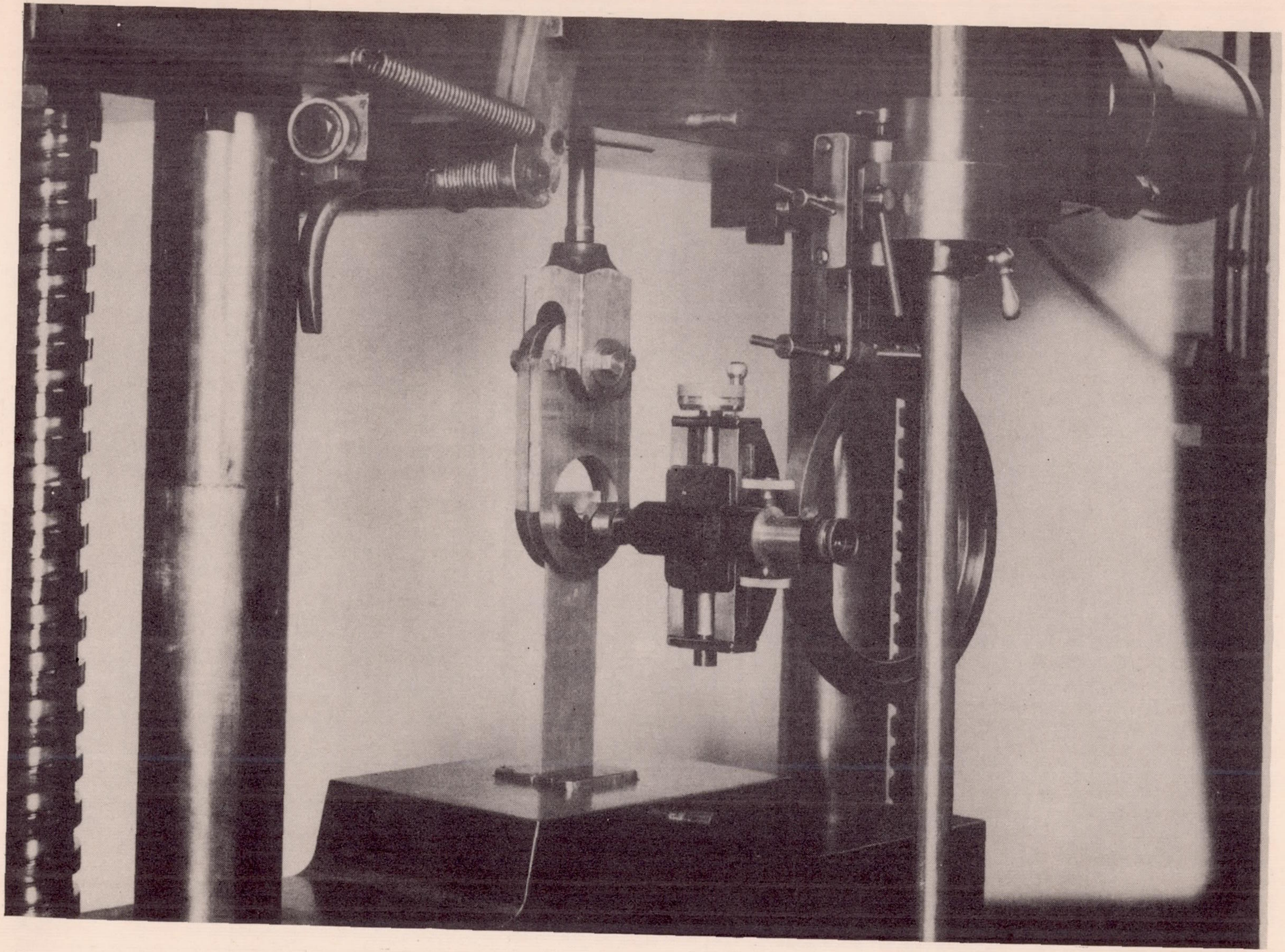
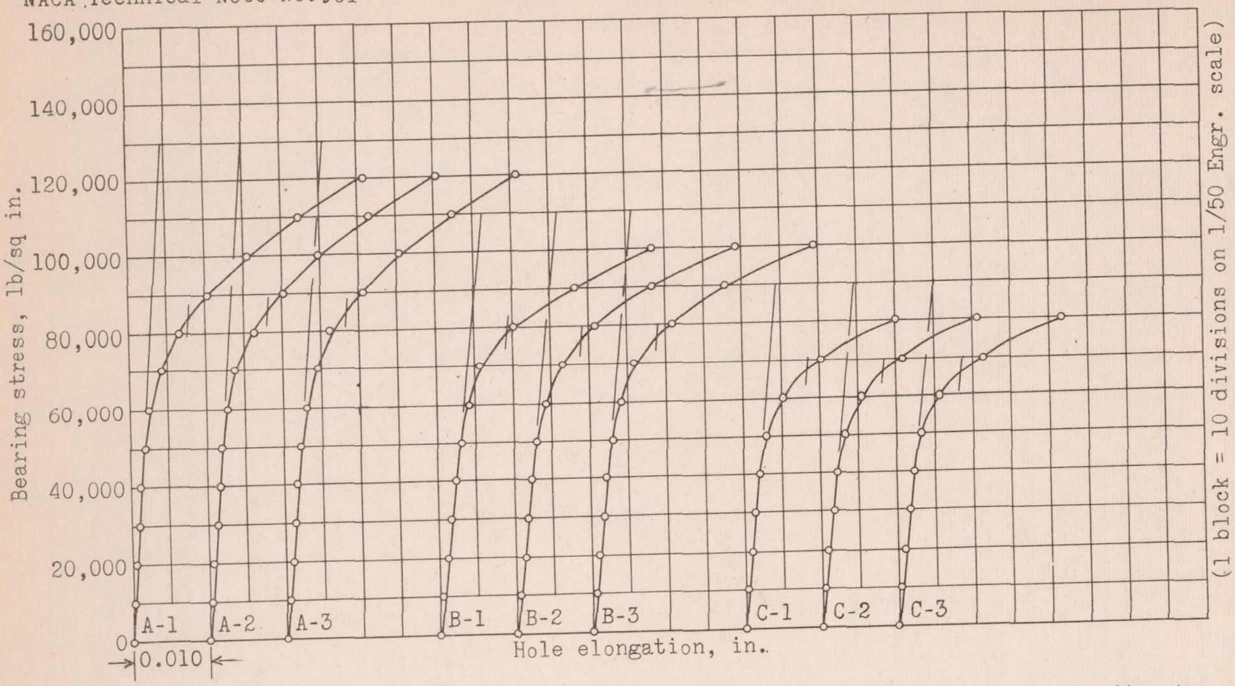


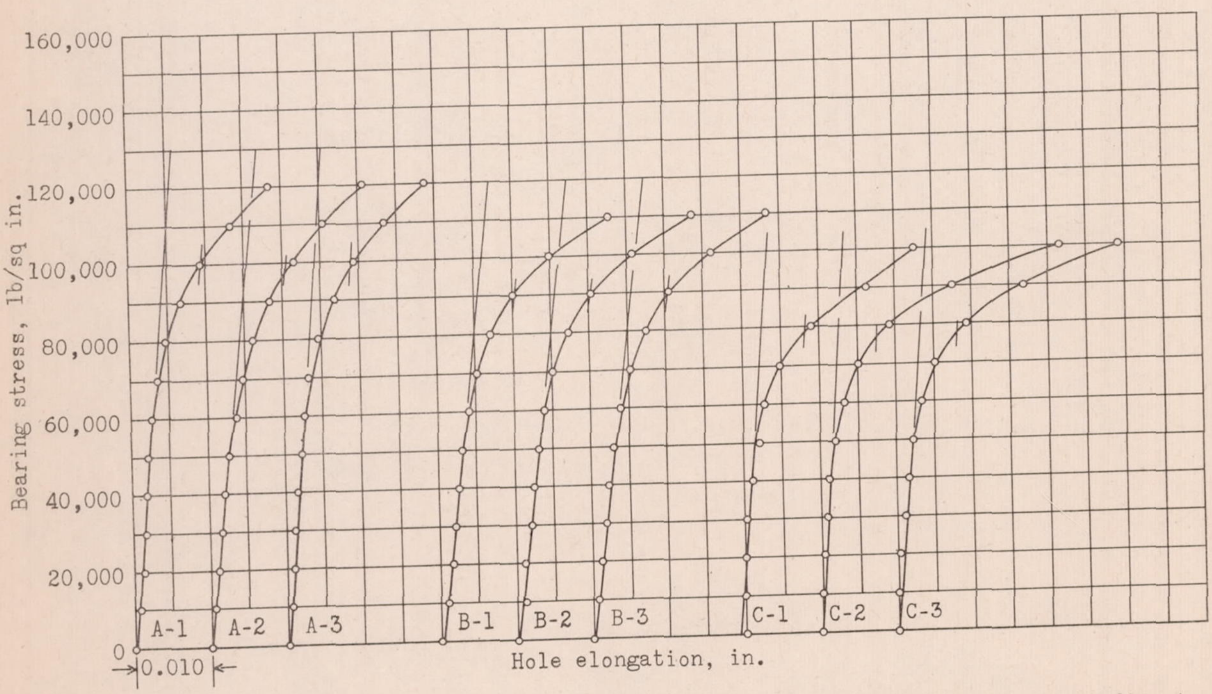
Figure 1.- Arrangement for bearing tests using filar micrometer microscope for measurements of hole elongation.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

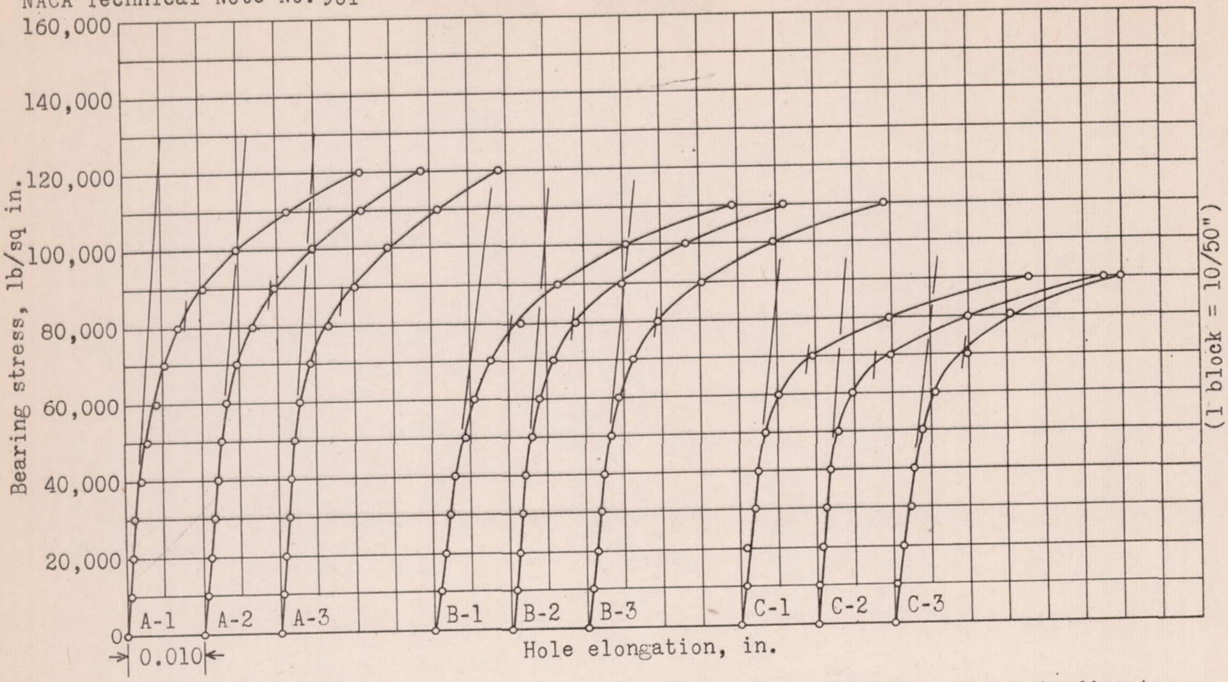
Figure 2.- Bearing stress-hole elongation curves for aluminum alloy sheet, 17S-T.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

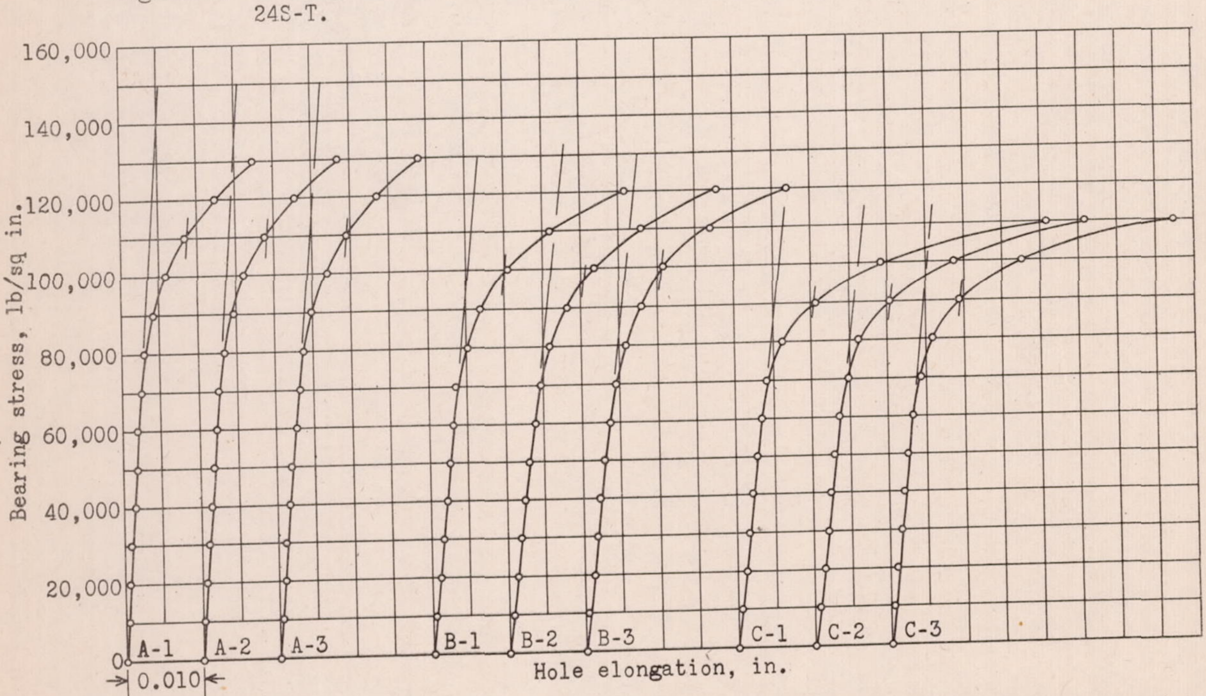
Figure 3.- Bearing stress-hole elongation curves for aluminum alloy sheet, 24S-T.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

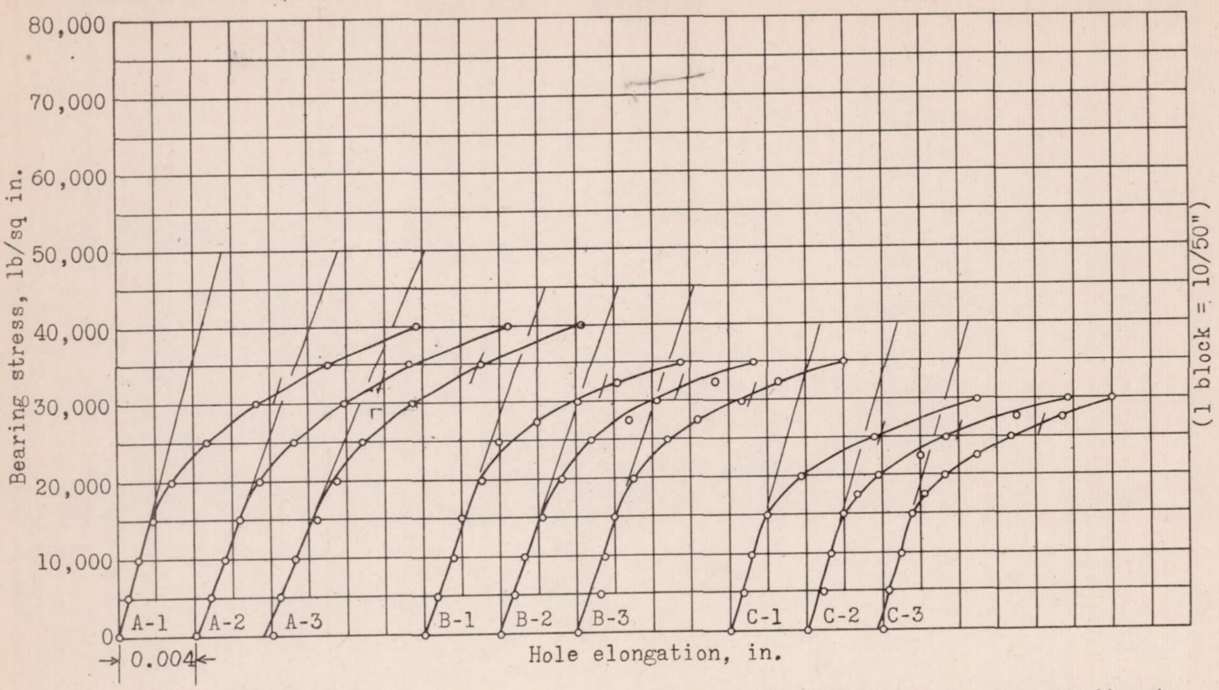
Figure 4.- Bearing stress-hole elongation curves for aluminum alloy sheet, alclad 24S-T.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

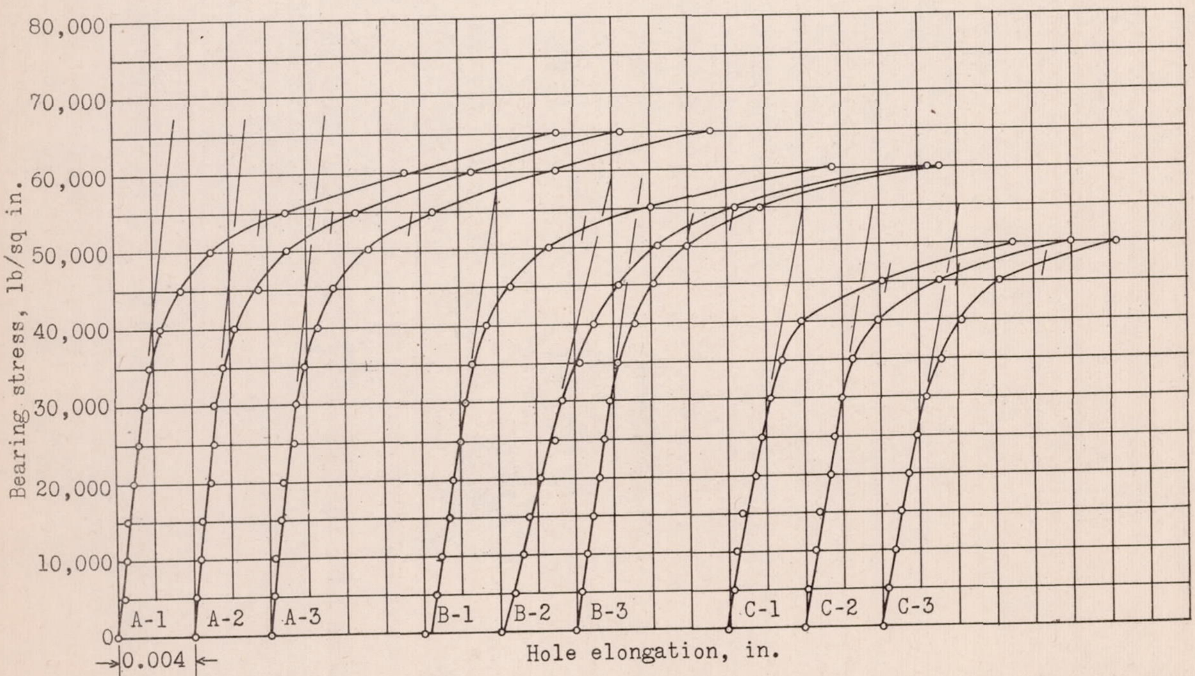
Figure 5.- Bearing stress-hole elongation curves for aluminum alloy sheet, 24S-RT.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

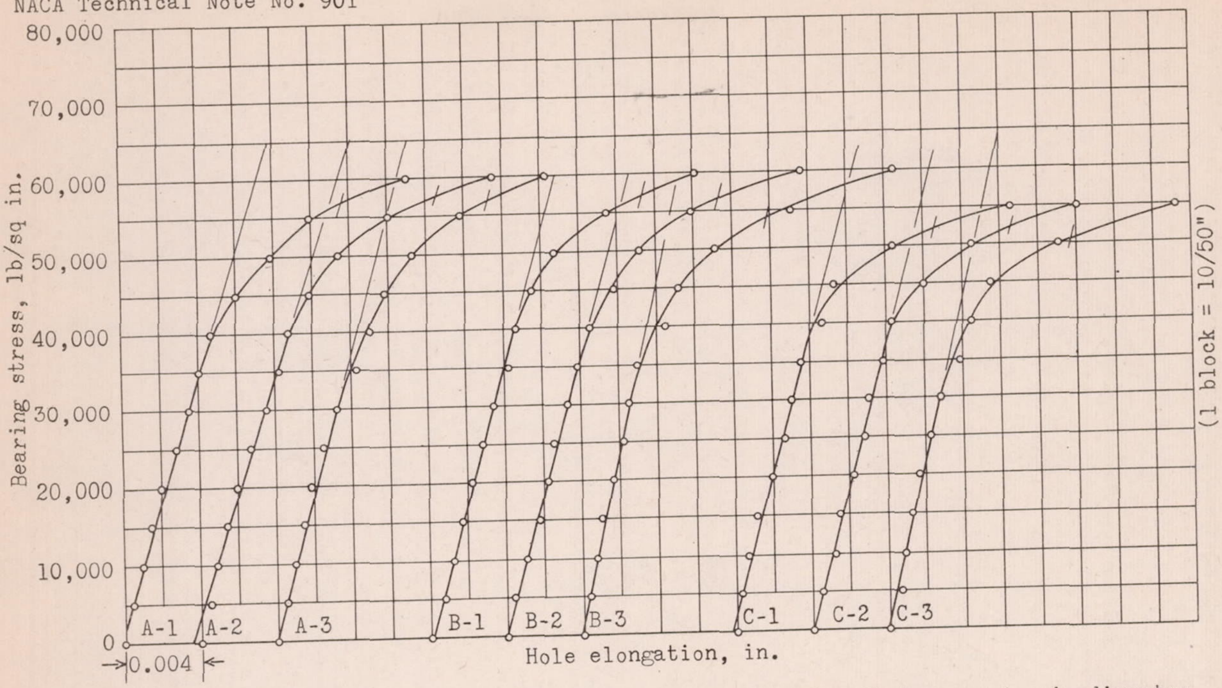
Figure 6.- Bearing stress-hole elongation curves for aluminum alloy sheet, 52S-0.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

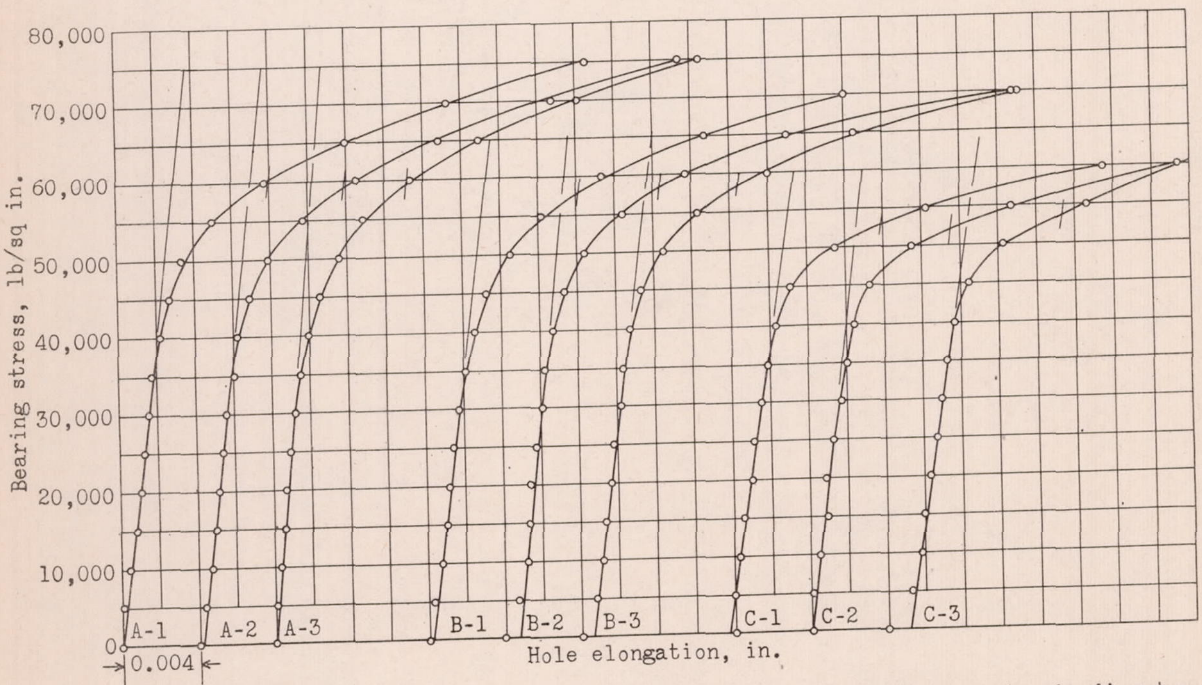
Figure 7.- Bearing stress-hole elongation curves for aluminum alloy sheet, 52S-1/2H.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1,A-2 and A-3: edge distance = 4 × pin diameter
B-1,B-2 and B-3: edge distance = 2 × pin diameter
C-1,C-2 and C-3: edge distance = 1.5 × pin diameter

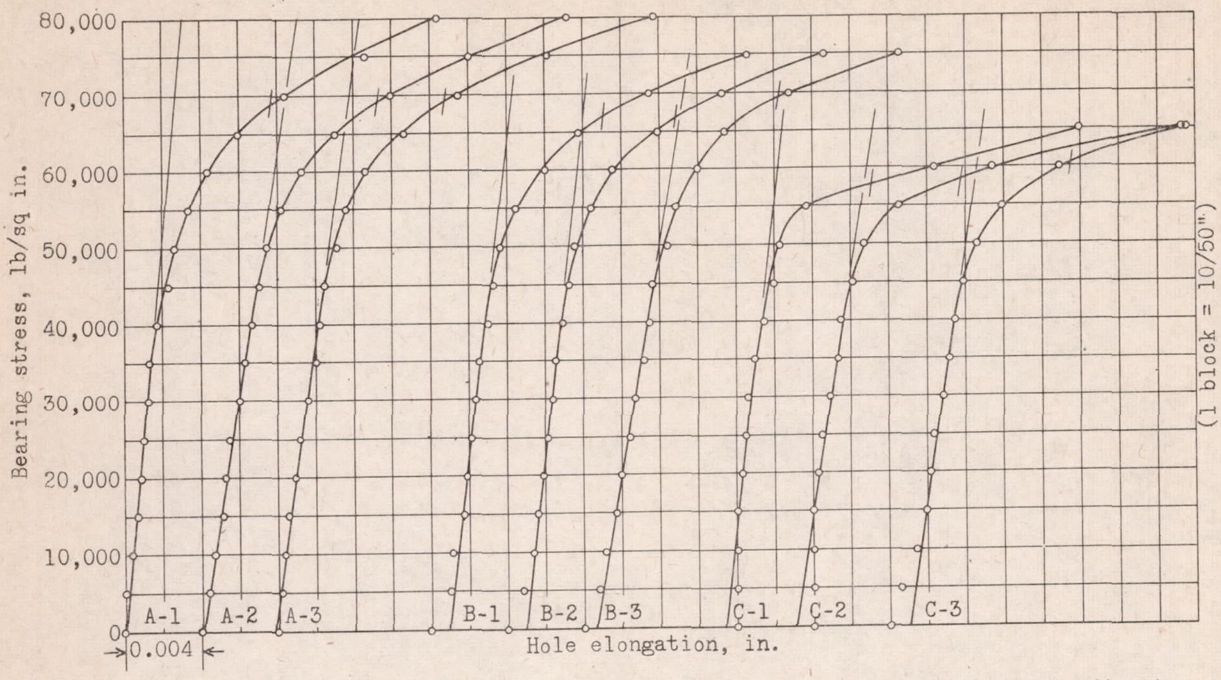
Figure 8.- Bearing stress-hole elongation curves for aluminum alloy sheet, 52S-H.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1,A-2 and A-3: edge distance = 4 × pin diameter
B-1,B-2 and B-3: edge distance = 2 × pin diameter
C-1,C-2 and C-3: edge distance = 1.5 × pin diameter

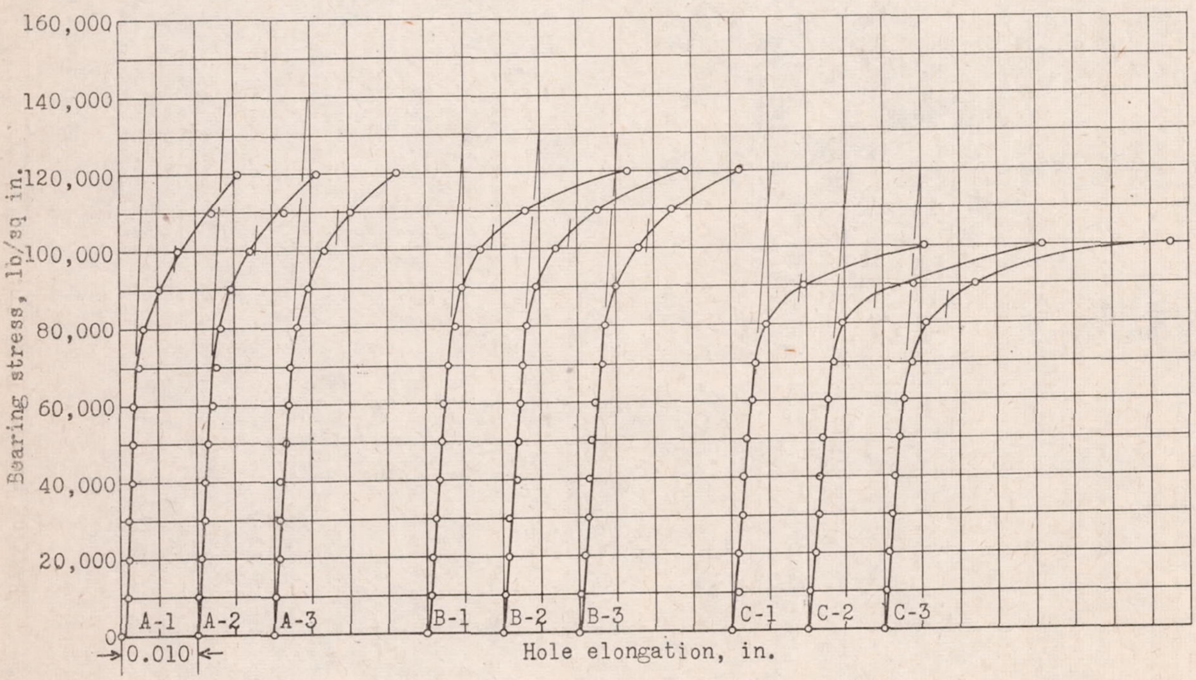
Figure 9.- Bearing stress-hole elongation curves for aluminum alloy sheet, 53S-T.



Pin diameter = 1/4 in.
Sheet thickness = 0.064 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

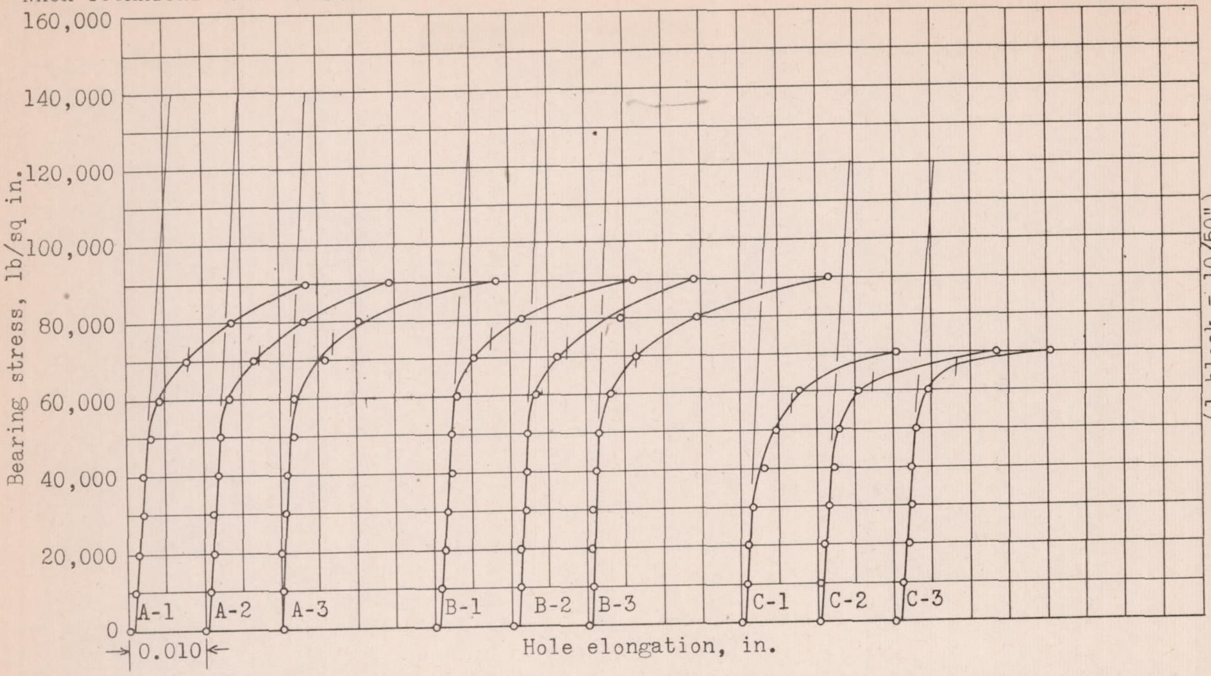
Figure 10.- Bearing stress-hole elongation curves for aluminum alloy sheet, 61S-T.



Pin diameter = 1/4 in.
Sheet thickness = 0.125 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

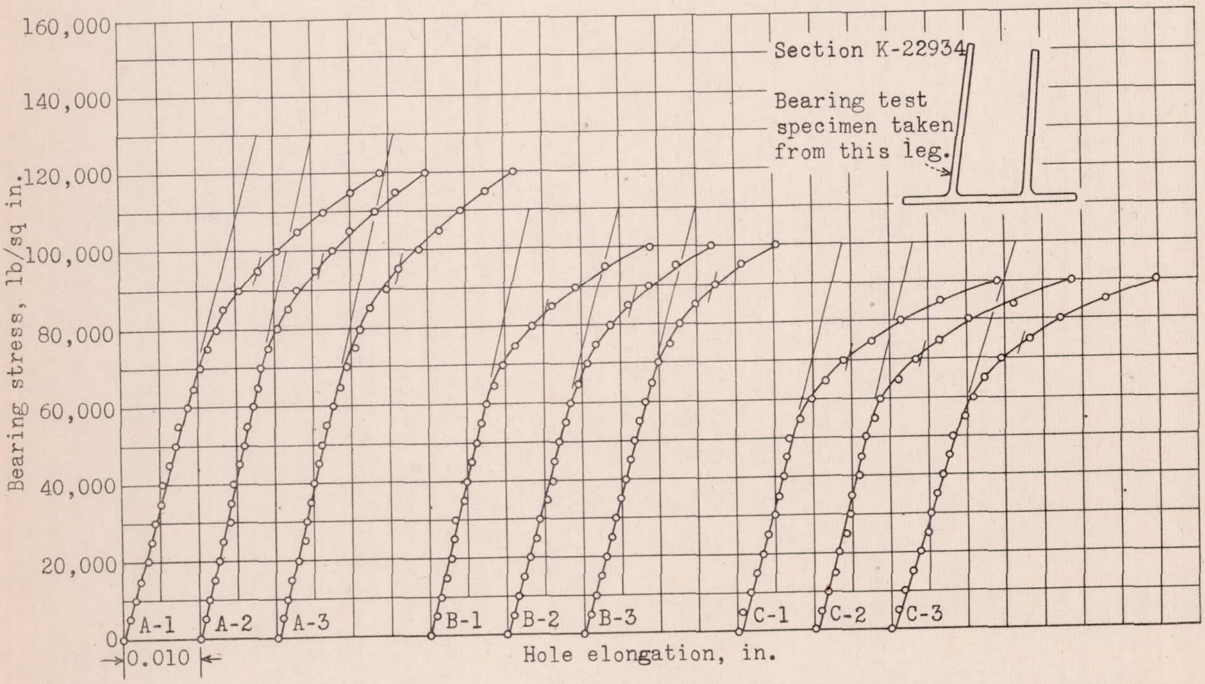
Figure 11.- Bearing stress-hole elongation curves for aluminum alloy forging, 14S-T.



Pin diameter = 1/4 in.
Specimen thickness = 0.125 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

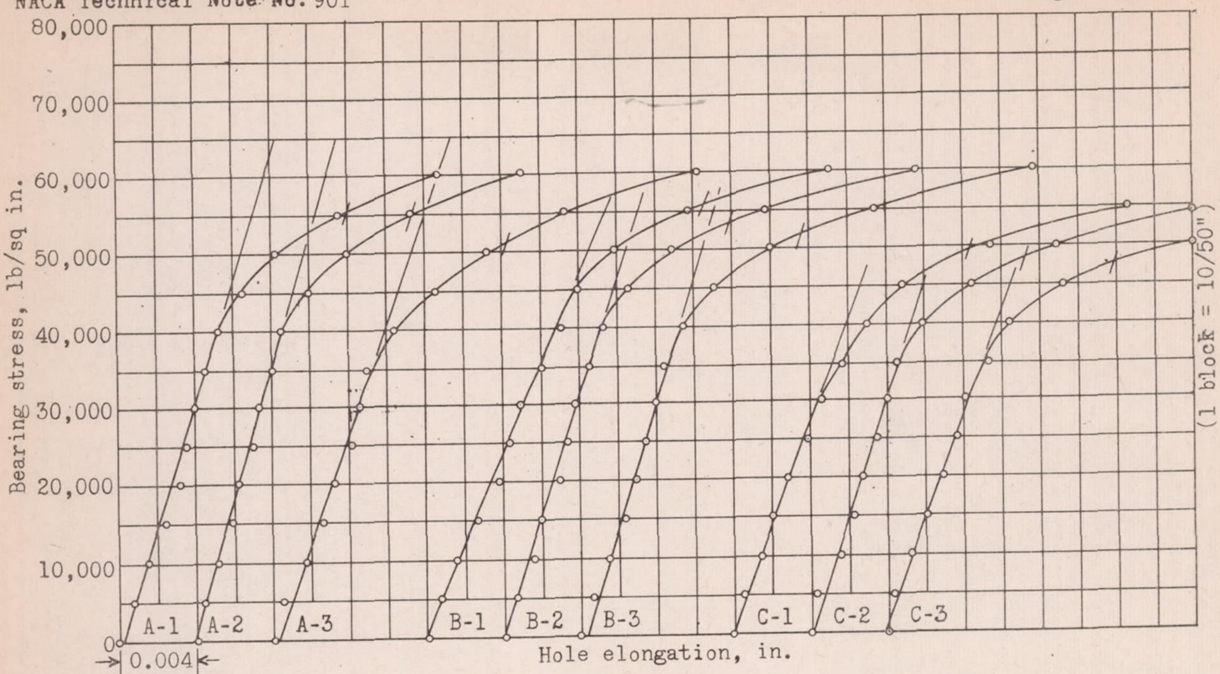
Figure 12.- Bearing stress-hole elongation curves for aluminum alloy forging, A51S-T.



Pin diameter = 1/4 in.
Specimen thickness = 0.070 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

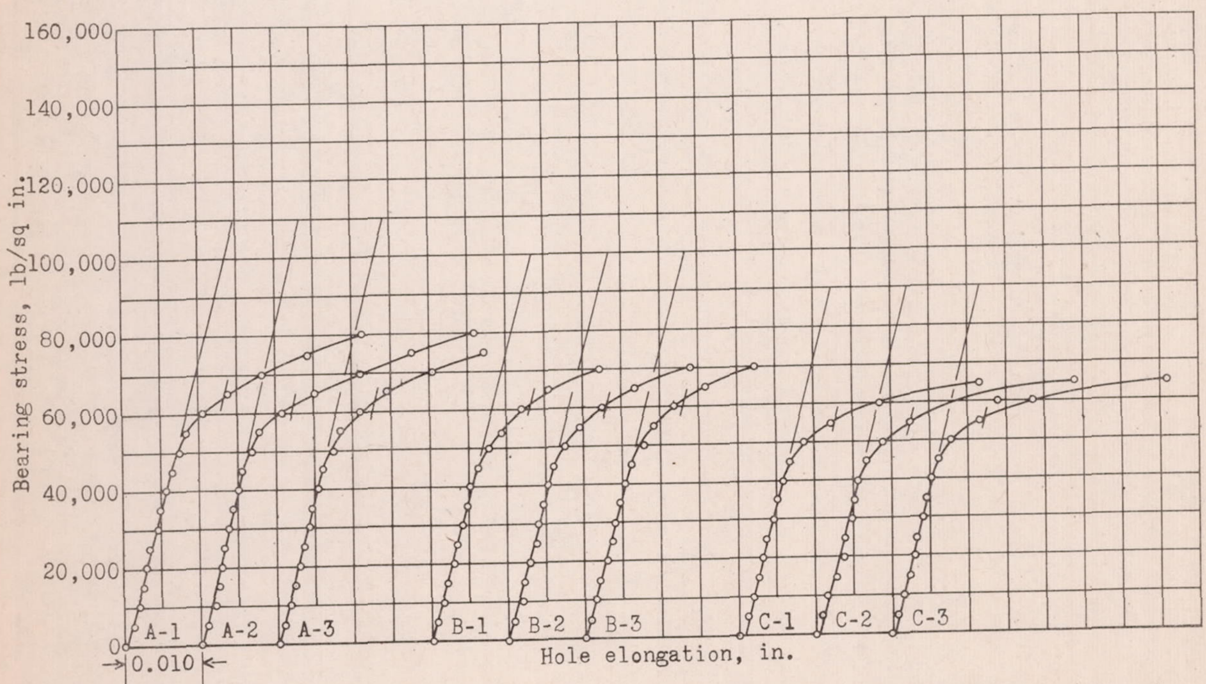
Figure 13.- Bearing stress-hole elongation curves for aluminum alloy extrusion, 24S-T.



Pin diameter = 1/4 in.
Specimen thickness = 0.070 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

Figure 14.- Bearing stress-hole elongation curves for aluminum alloy extrusion, 53S-T.



Pin diameter = 1/4 in.
Specimen thickness = 0.070 in.
Specimen width = 2 in.

A-1, A-2 and A-3: edge distance = 4 × pin diameter
B-1, B-2 and B-3: edge distance = 2 × pin diameter
C-1, C-2 and C-3: edge distance = 1.5 × pin diameter

Figure 15.- Bearing stress-hole elongation curves for aluminum alloy extrusion, 61S-T.