NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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EFFECT OF OPEN CIRCULAR HOLES ON TENSILE STRENGTH AND ELONGATION OF SHEET SPECIMENS OF SOME ALUMINUM ALLOYS

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SUMMARY

Tests were made to determine the relative effect of various patterns of open circular holes on the tensile strength and elongation of 24S-T3 (24S-T),[1] 24S-T81, 24S-T86, 24S-0, Alclad 75S-T6 (Alclad 75S-T),[1] Alclad 14S-T6 (Alclad 14S-T),[1] and Alclad 14S-T3 (Alclad 14S-W)[1] aluminum-alloy sheet specimens having a ratio of hole diameter to thickness of sheet of 3.

In practical cases, the reduction in strength resulting from open circular holes in sheet subjected to tension will not exceed about 5 percent for Alclad 14S-T6, Alclad 75S-T6, 24S-T81, and 24S-T86. In the case of 24S-T3, 24S-0, and Alclad 14S-T3, however, strength reductions may be slightly greater than 10 percent.

INTRODUCTION

The presence of a section discontinuity, such as an open circular hole, in a member stressed in the elastic range gives rise to stress concentrations which are functions solely of geometry and not related to the material involved. The degree of concentration of elastic stress is dependent upon the size and spacing of the holes. In the plastic range, however, these stress concentrations are alleviated by a redistribution of stress, the amount being a function of the plastic properties of the material. The greater the ductility the greater the stress redistribution will be. In a brittle material the high stress concentration remains right up to the point of breaking, producing a considerable weakening as shown by a reduction in the ultimate strength. In a ductile material, yielding in the vicinity of the perforations permits the stress in the rest of the section to build up before failure occurs.

[1] Old designation.

It is probable that, for ductile materials such as the aluminum alloys covered by this investigation, there will always be a certain amount of stress concentration present in the proximity of the discontinuity. Consequently the material near to the perforation, having a higher stress, will arrive at the ultimate strength before the adjoining material. Failure will begin at the edge of the perforation and this tends to produce a reduction in strength, resulting from the concentration of stress (references 1, 2, 3, and 4).

The static efficiency of a perforated tension member may be defined as the ratio of the ultimate load divided by the net area to the tensile strength of the material. This efficiency is not only affected by the stress distribution in the vicinity of the discontinuity but is influenced also by the ratio of initial to final area of the tension member and the shape of the stress-strain curve for the material. The effectiveness of the discontinuity, dependent upon its geometry, in resisting reduction in area of the critical section may increase the static efficiency of the member, since the original area may be substantially maintained while the stress distribution is made more uniform. It has been shown that in some cases the presence of an open circular hole will result in net section efficiencies of over 100 percent. In most aluminum alloys, however, a reduction in static efficiency is produced by such a discontinuity (references 5 and 6).

The presence of a hole in a tension member produces a concentration of strain on the net section and thus the over-all elongation of the member at failure is drastically reduced by such discontinuities. This reduction in elongation in turn lowers the impact strength of the member and also affects the performance of parts acting in combination (reference 3).

Concentrations of stress are of particular importance to the design engineer in determining the fatigue strength of such elements as riveted and bolted joints, since progressive cracks are likely to start at such points where the stress is far above the average. Stress concentration does not affect the static strength to such a great extent but nevertheless the effect must be considered in some instances, particularly in aircraft applications where small margins of safety are used and perforations such as rivet and bolt holes are present which affect the ultimate tensile strength.

Multiple staggered holes, such as frequently used in rivet patterns, cause a decrease in tensile strength of a tension member over that caused by a single row of holes even though failure does not occur through both rows of holes. The sections in line with the holes in the extra row are apparently unable to assume their full share of the load, thus causing an irregular distribution of stress across the section.

The purpose of this investigation was to study the relative effect of open circular holes on the tensile strength and elongation of the following aluminum alloys in sheet form: 24S-T3, 24S-T81, 24S-T86, 24S-O, Alclad 75S-T6, Alclad 14S-T6, and Alclad 14S-T3. Tests were made to study the effects of the relative proportion of the hole and the specimen and also the effect of spacing and arrangement of the holes for each of the above-listed alloys. The effect of open circular holes on specimens such as those tested in this investigation will not be the same as in riveted or bolted joints but nevertheless will serve to indicate the importance of strength reduction arising from such discontinuities.

DESCRIPTION OF SPECIMENS

All specimens were cut from 0.032-inch sheet. All specimens were cut across grain. The holes were subdrilled and reamed with a No. 41 drill (0.096-in. diameter). These dimensions were arbitrarily chosen to give a ratio of hole diameter to sheet thickness of 3, which is within the practical range as far as aircraft construction is concerned. Descriptive dimensions of the various types of specimens are contained in table I.

TESTING PROCEDURE

Dimensions of the specimens were accurately measured before testing. Width and thickness measurements were made with a micrometer caliper which was read to 0.0001 inch. Hole diameters were determined with plug gages. Average measured dimensions are listed in table II for each type of specimen. The maximum variation of any width or thickness measurement from the average was less than 1 percent. The maximum in the case of the hole-diameter measurement was about 4 percent but the average variation was less than $\frac{1}{2}$ percent. Variations in this measurement have a minor effect upon the calculated net area.

Net areas were obtained by multiplying the least net width by the thickness of the specimen. For specimens containing staggered holes, the net width was obtained by deducting from the gross width the sum of the diameters of all of the holes in the chain, and adding for each gage space in the chain, the quantity

$$\frac{s^2}{4g}$$

where

s longitudinal spacing (pitch) of any two successive holes (measured in the direction of stress), in.

g transverse spacing (gage) of the same two holes (measured normal to the direction of stress), in.

This method of determining net width is quite commonly used in engineering design and is given in many structural-design specifications. Nominal values of pitch and gage were used in calculating net areas.

All types of specimens were tested in triplicate and one solid tensile specimen was tested for each group of three perforated specimens. The tensile strengths determined for all of the solid specimens for each alloy were averaged and the result was used as the tensile strength for that alloy. Specimens were tested in a 40,000-pound-capacity Amsler testing machine.[2]

Elongations on various gage lengths were measured on solid specimens and specimens containing a single central hole. These elongations were obtained by the use of the photogrid method, a 0.1-inch grid being printed on one surface of the specimen (reference 7). The changes in distance between adjacent lines in the grid were measured with a 42-power micrometer microscope. Readings were taken along the center line of the specimen. For the perforated specimens, the broken pieces were matched together and clamped in position. Measurement was then made of the gap at the edges of the hole and this distance subtracted from the measured distance between the nearest two transverse lines. The results, therefore, represent the elongation occurring on the longitudinal center line of the specimen.

RESULTS OF TESTS AND DISCUSSION

Tensile Properties of Materials

Tensile properties determined from the sheets of 24S-T3, 24S-T81, 24S-T86, 24S-O, Alclad 75S-T6, Alclad 14S-T6, and Alclad 14S-T3 from which the specimens were cut are listed in table III along with specified minimum values (reference 8). Average values are given for the tensile strength of the alloys. The maximum variation from average for any alloy was less than 2.5 percent. The tensile properties

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[2]Type 20 ZBDA, Serial No. 4318.

determined for the materials are within the specifications for the commercial aluminum-alloy sheets except for the yield strength of Alclad 14S-T6 which is slightly below the specified minimum value.

Specimens with Single Central Hole

Specimens with a single central hole are those comprising series I in table I. The variable studied in these tests was the ratio of hole dimater to width of specimen. Variations in this ratio were obtained by varying the width of specimens, the hole diameter and the thickness of material remaining constant. A summary of the results of the tests in this group of specimens is given in tables IV and V. The efficiency values given in table IV for the various alloys tested have been plotted in figure 1 against ratio of hole diameter to width of specimen $\frac{d}{b}$. Alloys 24S-T3, Alclad 75S-T6, Alclad 14S-T6, and Alclad 14S-T3 show a definite trend toward better efficiencies with increased d/b ratio, whereas 24S-O, 24S-T86, and 24S-T81 apparently are not so sensitive to a change in this ratio. The relative sensitivity of the different alloys to reduction in strength varies with the d/b ratio. Based on the maximum amount of reduction, however, the alloys may be divided into two groups; one group, in which the reduction in strength does not exceed about 5 percent, included Alclad 14S-T6, Alclad 75S-T6, 24S-T86, 24S-T81, and 24S-O. In the other group, which included 24S-T3 and Alclad 14S-T3, the reduction in strength exceeds 10 percent.

It was expected that reduction in strength for different alloys might vary about inversely as the ductility. While there is no accepted simple measure of the ductility of a material, three values which are commonly considered related to the ductility are the elongation, reduction in area, and ratio of yield strength to tensile strength. The higher the value of elongation or reduction in area and the lower the ratio of yield strength to tensile strength, the more ductile the material is generally considered to be. It is therefore somewhat surprising to find that, with the exception of 24S-O, all of the alloys in the group showing the least reduction in strength are those which would be considered to be the least ductile on the basis of elongation or yield to tensile ratio values. Because of the cross section of the sheet specimens tested in this investigation, it was not possible to measure reductions in area. It is known, however, from tests on round specimens that of the alloys involved 24S-O typically has the greatest reduction in area and the high-strength alloys of the first group have the least reduction in area. It seems that the susceptibility of a perforated specimen to strength reduction cannot be explained on the basis of commonly accepted measures of ductility.

Figure 2 shows the elongation of a standard tensile specimen over various gage lengths for each of the alloys tested. These curves indicate the manner in which percent elongation decreased with an increase in gage length (reference 9). The effect of a single central hole on the elongation of a tensile specimen for each of the alloys tested is shown by figures 3(a) to 3(g). It can be seen from these curves that the presence of a hole greatly decreases the over-all elongation of the member at failure. In table VI are shown the elongation values for each of the alloys tested, for both solid and perforated specimens 1/2 inch wide, and for gage lengths of 0.2 inch, 1 inch, and 2 inches. Ratios of the elongation of the perforated specimen to that for the solid specimen are also given. These values are plotted in figure 4. The curves of figure 4 indicate that, contrary to the relations for the reductions in strength, in general the reductions in elongation are greatest for the least ductile materials, although there is no strict relation between ductility and reduction in elongation. The relative reduction in elongation of the different alloys is influenced to some extent by the d/b ratio. Figures 5(a) to 5(g) illustrate the elongations over varying gage lengths for the different alloys tested as they are affected by the ratio of hole diameter to sheet width. It is seen that an increase in d/b ratio results in a decrease in percent elongation in all cases.

While the reduction in strength produced by a single central hole was not very great (generally not exceeding about 10 percent), the reduction in elongation is extreme. In the case of Alclad 75S-T6 alloy, the elongation measured over 2 inches of the perforated specimen was only about 4 percent of the value for a solid specimen.

Specimens Containing Two Staggered Holes

The specimens, included in series II of table I, contain two holes, each located with the same eccentricity on opposite sides of the longitudinal center line and with varying spacing in the direction of stress. The variable studied in these tests was the pitch of the holes.

The results of the tests on this series of specimens are summarized in tables VII and VIII. For all of the alloys investigated, when the pitch became equal to the eccentricity (type 25) the fracture did not occur on the net section corresponding to that for which the net area was calculated. Calculations of the least net section indicated that the least net width would follow a staggered pattern. Failure, however, was straight across the specimen through one hole.

The efficiency values for the specimens of this type are plotted in figure 6 against the ratio of pitch to gage s/2e. The nature of the failure is also indicated in this figure. These curves indicate in general for all of the alloys tested that, for a given gage, the efficiency decreases with increase in pitch as long as the least net width results in a staggered line. For failures that occur straight across, however, the ratio of pitch to gage has little effect on the efficiency. Each alloy has a curve of the same common shape but is displaced vertically. The alloys fall into the same groups as for the single-hole specimens with the exception that in this case 24S-O is in the group with 24S-T3 and Alclad 14S-T3 which have the greatest reduction in strength. The efficiency of this type of specimen is considerably lower than that with a single hole. The lowest efficiencies, based on the least net width, occurred for all of the alloys with a pitch-to-gage ratio of 1 (type 26) and the values ranged from 75 percent for 24S-T3 to 89 percent for Alclad 75S-T6.

Specimens with Four-Hole Pattern

The specimens, listed under series III of table I, contain four holes arranged in a symmetrical pattern. All of the specimens were of the same width and the holes had a constant gage. As with the two-hole staggered pattern, the variable studied was the pitch of the holes. Results of the tests on specimens in this group are summarized in tables IX and X and the efficiencies of the different types of specimens are plotted in figure 7 against the ratio of pitch to gage. These curves indicate that in general for a fracture occurring on a staggered line the efficiency decreases for an increase in pitch (to a ratio of pitch to gage of 1) while, for specimens which fracture straight across, the efficiency increases to a ratio of pitch to gage of 2, and beyond this the ratio of pitch to gage has little effect. The curves have the same general shape for the various alloys investigated but vary in their vertical position. Again, as with the two-hole staggered pattern, the alloys with a high yield-to-tensile ratio and low elongation (24S-T81, 24S-T86, Alclad 75S-T6, and Alclad 14S-T6) indicate higher relative efficiencies than those with a low yield-to-tensile ratio and high elongation (24S-O, 24S-T3, and Alclad 14S-T3).

In this group of specimens, the lowest efficiencies, based on the least net width, for each of the alloys tested occurred with specimens of type 37 which has a pitch-to-gage ratio of 1. Values ranged from 85 percent for 24S-T3 to 98 percent for Alclad 75S-T6. The efficiency values obtained on specimens in this group were higher than those for the two-hole staggered pattern and suggest higher efficiencies if the two-hole staggered pattern were repeated in wide specimens. This has been shown to be the case by a supplementary investigation where the two-hole pattern repeated in wide specimens of 24S-T3 indicated a reduction of strength of not over 5 percent.

SUMMARY OF RESULTS

The results of tests to determine the relative effect of various patterns of open circular holes on the tensile strength and elongation of 24S–T3, 24S–T81, 24S–T86, 24S–O, Alclad 75S–T6, Alclad 14S–T6, and Alclad 14S–T3 aluminum-alloy sheet specimens having a ratio of hole diameter to thickness of sheet of 3, may be summarized as follows:

1. Tensile properties of the materials used were within the specifications for commercial aluminum-alloy sheets, except for the yield strength of Alclad 14S–T6 which was about 1/2 percent below the specified minimum value.

Specimens with single central hole:

2. The hole produced a reduction in the ultimate tensile stress on the net section of the specimen, except for a few instances of high d/b ratios.

3. For alloys 24S–O, 24S–T81, 24S–T86, Alclad 14S–T6, and Alclad 75S–T6 the reduction in strength, for d/b ratios between 0.1 and 0.4, did not exceed about 5 percent.

4. The reduction in strength for 24S–T3 and Alclad 14S–T3 was about 10 percent or slightly greater, at d/b ratios between 0.1 and 0.2, but did not exceed 2 percent at a d/b ratio of 0.4.

5. The elongation values for the perforated specimens were greatly reduced over those for solid specimens of the same width. The reductions were greatest for the longer gage lengths and for the least ductile materials. The reduction in elongation in a 2-inch gage length was about 97 percent for Alclad 75S–T6 and about 81 percent for 24S–O. In a 0.2-inch gage length, the reductions in elongation ranged between 85 percent for Alclad 75S–T6 and 64 percent for 24S–O.

Specimens containing two staggered holes:

6. The holes produced a reduction in ultimate tensile strength on the net section which increased with an increasing ratio of pitch to gage, to a ratio value of 1, beyond which the reduction was practically constant for a given alloy.

7. The reductions in strength were greatest for specimens of 24S–O, 24S–T3, and Alclad 14S–T3, the maximum reduction in strength being about 25 percent for 24S–T3.

8. The maximum reduction in strength for the specimens of Alclad 75S–T6, Alclad 14S–T6, 24S–T81, and 24S–T86 was about 12 to 15 percent.

9. The results of a previous supplementary investigation showed that when the staggered two–hole pattern was repeated in a wide specimen, the reduction in strength for 24S–T3 did not exceed about 5 percent.

Specimens with four–hole pattern:

10. In the specimens containing four holes in a symmetrical diamond pattern and in which the pitch of the holes was varied, the reduction in strength increased with increasing ratio of pitch to gage to a ratio value of 1 and then decreased until a ratio value of 2 was reached. Beyond this value, the reduction for a given alloy is practically constant.

11. The reduction in strength was greatest for the specimens of 24S–O, 24S–T3, and Alclad 14S–T3, the maximum reduction in strength being about 15 percent for 24S–T3.

12. The maximum strength reduction for the 24S–T81 and 24S–T86 specimens was about 6 to 7 percent while the maximum reduction for the Alclad 75S–T6 and Alclad 14S–T6 specimens was only about $2\frac{1}{2}$ percent.

General:

13. Excluding 24S–O from consideration, the greatest reduction in strength occurred in the most ductile materials (24S–T3 and Alclad 14S–T3) that is, the materials having the greatest elongation and the lowest ratio of yield strength to tensile strength.

14. The effect of the properties of the material on the amount of strength reduction seems to depend somewhat on the type of specimen. In two types of specimen, 24S–O ranked with 24S–T3 and Alclad 14S–T3 but, in the specimens containing a single central hole, 24S–O ranked with the less ductile metals.

15. In practical cases, the reduction in strength resulting from open circular holes in sheet subjected to tension will not exceed about 5 percent for Alclad 14S–T6, Alclad 75S–T6, 24S–T81, and 24S–T86. In the case of 24S–T3, 24S–O, and Alclad 14S–T3, however, strength reductions may be slightly greater than 10 percent.

16. The reductions in elongation caused by open circular holes in sheet specimens are greatest for the least ductile materials, the percent reduction in elongation being greatest for Alclad 75S-T6 and least for 24S-O.

Aluminum Research Laboratories
Aluminum Company of America
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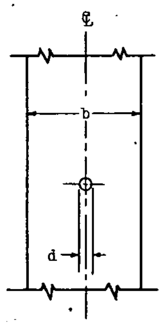
TABLE I

NOMINAL DIMENSIONS OF PERFORATED SPECIMENS

[t = 0.032 in. (20 gage); d = 0.0960 in. (No. 41 drill); d/t = 3]

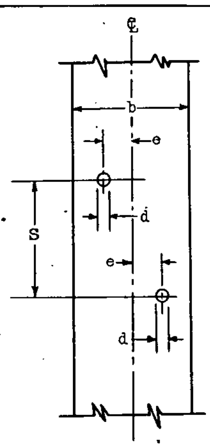
Series I



Type	b (in.)	d/b
1	0.960	0.10
2	.480	.20
3	.240	.40

Series II

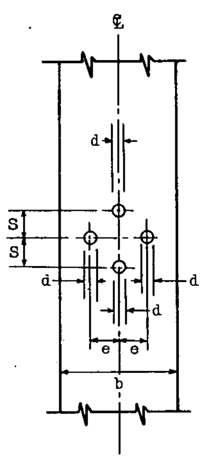
$\left(b = 0.960 \text{ in.};\ e = 0.360 \text{ in.};\ e/d = 3\frac{3}{4}\right)$



Type	s	s/e
23	0	0
24	0.180	1/2
25	.360	1
26	.720	2
27	1.440	4
28	2.880	8

Series III

$\left(b = 0.960 \text{ in.};\ e = 0.240 \text{ in.};\ e/d = 2\frac{1}{2}\right)$



Type	s	s/e
35	0	0
36	0.120	1/2
37	.240	1
38	.480	2
39	.960	4

TABLE II

MEASURED DIMENSIONS OF PERFORATED SPECIMENS

Alloy	Dimension measured (in.) \ Specimen type	1	2	3	23	24	25	26	27	28	35	36	37	38	39
		Average measurement[1]													
24S-T3	b[2]	0.9617	0.4720	0.2431	0.9627	0.9631	0.9622	0.9621	0.9625	0.9623	0.9624	0.9624	0.9621	0.9619	0.9616
	t[3]	.0325	.0330	.0330	.0321	.0321	.0321	.0328	.0326	.0326	.0329	.0331	.0325	.0327	.0328
	d[4]	.098	.097	.097	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096
24S-T81	b	.9604	.4795	.2383	.9603	.9602	.9601	.9598	.9602	.9599	.9599	.9597	.9593	.9591	.9590
	t	.0309	.0310	.0310	.0308	.0308	.0316	.0317	.0317	.0317	.0318	.0318	.0318	.0318	.0317
	d	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096
24S-T86	b	.9605	.4798	.2370	.9607	.9607	.9603	.9602	.9601	.9601	.9601	.9599	.9597	.9596	.9595
	t	.0312	.0312	.0311	.0312	.0300	.0301	.0300	.0300	.0300	.0306	.0307	.0307	.0310	.0310
	d	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096
24S-O	b	.9581	.4735	.2300	.9596	.9592	.9588	.9594	.9593	.9592	.9589	.9593	.9590	.9590	.9589
	t	.0321	.0323	.0325	.0322	.0323	.0323	.0324	.0325	.0327	.0318	.0317	.0315	.0315	.0316
	d	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096
Alclad 75S-T6	b	.9613	.4807	.2353	.9617	.9617	.9618	.9615	.9612	.9613	.9610	.9610	.9613	.9615	.9617
	t	.0315	.0317	.0320	.0317	.0320	.0320	.0318	.0320	.0315	.0318	.0315	.0317	.0315	.0317
	d	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096	.096
Alclad 14S-T6	b	.9577	.4832	.2433	.9580	.9582	.9587	.9603	.9610	.9587	.9597	.9597	.9603	.9607	.9610
	t	.0320	.0320	.0318	.0318	.0315	.0317	.0317	.0315	.0317	.0317	.0317	.0315	.0315	.0320
	d	.099	.098	.099	.099	.099	.098	.099	.097	.099	.097	.098	.098	.098	.098
Alclad 14S-T3	b	.9573	.4803	.4803	.9583	.9583	.9593	.9603	.9603	.9593	.9600	.9603	.9603	.9617	.9620
	t	.0320	.0323	.0328	.0325	.0325	.0322	.0323	.0325	.0320	.0320	.0320	.0320	.0320	.0320
	d	.099	.099	.099	.099	.100	.100	.100	.099	.099	.096	.096	.096	.096	.097

[1]Average of triplicate specimens for each type of specimen.
[2]b, width of specimen.
[3]t, thickness of specimen.
[4]d, hole diameter.

TABLE III

TENSILE PROPERTIES OF MATERIALS USED IN TESTS

Alloy and temper	Actual mechanical properties[a]				Specified mechanical properties[b]		
	Average tensile strength (psi)	Maximum variation from average (percent)	Tensile yield[c] strength[d] (psi)	Elongation in 2 in.[d] (percent)	Tensile strength, minimum (psi)	Yield[c] strength, minimum (psi)	Elongation in 2 in., minimum (percent)
24S–T3	69,760	2.35	46,470	19.4	64,000	42,000	15
24S–T81	72,370	1.97	64,100	6.5	[e]67,000	[e]58,000	[e]5
24S–T86	75,400	.53	70,300	5.5	[e]71,000	[e]67,000	[e]3
24S–O	30,620	2.31	13,200	16.0	[f]35,000	------	12
Alclad 75S–T6	77,570	2.29	66,200	13.0	70,000	60,000	7
Alclad 14S–T6	63,900	1.17	55,700	8.0	63,000	56,000	7
Alclad 14S–T3	61,030	1.92	39,600	18.5	55,000	35,000	14

[a]All properties cross grain.

[b]Values taken from reference 8.

[c]Stress at 0.2-percent offset.

[d]Determined from standard tensile specimen.

[e]Estimated from specified minimum values for Alclad 24S–T81 and Alclad 24S–T86.

[f]Maximum. So specified to insure satisfactory anneal.

TABLE IV

RESULTS OF TESTS ON SPECIMENS WITH SINGLE CENTRAL HOLE

[Series I]

Type of specimen[1]	d/b (2)	Specimen \ Alloy	24S-T3	24S-T81	24S-T86	24S-0	Alclad 75S-T6	Alclad 14S-T6	Alclad 14S-T3
			Efficiency[3]						
1	0.1	A	87	98	96	96	96	95	90
		B	90	98	96	96	95	95	88
		C	90	98	98	98	96	94	92
		Av.	89	98	97	97	96	95	90
2	.2	A	92	95	98	96	97	99	95
		B	92	95	98	96	97	100	95
		C	90	94	98	96	98	99	96
		Av.	91	95	98	96	97	99	95
3	.4	A	97	99	98	97	101	100	97
		B	98	94	98	97	100	101	99
		C	98	96	97	96	100	101	99
		Av.	98	96	98	97	100	101	98

[1]See table I for description of specimens.

[2]Ratio of hole diameter to width of specimen.

[3]Efficiency = $\frac{\text{Tensile strength based on net area}}{\text{Tensile strength of material}} \times 100.$

TABLE V

ULTIMATE-LOAD VALUES FOR SPECIMENS WITH SINGLE CENTRAL HOLE

[Series I]

Type	Specimen \ Alloy	24S-T3	24S-T81	24S-T86	24S-O	Alclad 75S-T6	Alclad 14S-T6	Alclad 14S-T3
		Ultimate load (lb)						
1	A	1720	1895	1965	810	2030	1665	1516
	B	1775	1885	1955	815	2010	1668	1471
	C	1788	1900	2000	825	2030	1660	1538
	Av.	1761	1893	1973	817	2023	1664	1508
2	A	800	820	885	365	929	788	708
	B	800	820	885	360	928	783	708
	C	780	810	880	365	921	777	713
	Av.	793	817	883	363	926	783	710
3	A	330	315	325	130	348	297	278
	B	335	300	325	125	349	295	279
	C	338	305	320	120	349	292	280
	Av.	334	307	323	125	349	295	279

TABLE VI

ELONGATION OVER VARIOUS GAGE LENGTHS FOR SOLID AND PERFORATED SPECIMENS[1]

Alloy and temper	Elongation in 2 in., gage length		Ratio of elongation, Perforated/Solid	Elongation in 1 in., gage length		Ratio of elongation, Perforated/Solid	Elongation in 0.2 in., gage length		Ratio of elongation, Perforated/Solid
	Solid	Perforated		Solid	Perforated		Solid	Perforated	
24S-T3	18.50	1.63	8.8×10^{-2}	20.50	2.25	11.0×10^{-2}	27.75	10.00	36.0×10^{-2}
24S-T81	5.41	.29	5.4	7.30	.59	8.1	16.25	2.60	16.0
24S-T86	5.17	.34	6.6	6.75	.72	10.7	14.29	3.46	24.2
24S-O	16.0	3.00	18.8	19.50	3.60	18.5	33.00	12.00	36.4
Alclad 75S-T6	12.34	.44	3.6	14.60	.85	5.8	29.00	4.28	14.8
Alclad 14S-T6	7.84	.39	5.0	9.89	.77	7.8	19.00	3.86	20.3
Alclad 14S-T3	18.35	1.23	6.7	22.50	1.81	8.0	38.00	7.84	20.6

[1]Solid specimens are standard tensile specimens while perforated specimens are of type 2 as described in table I.

TABLE VII

RESULTS OF TESTS ON SPECIMENS WITH TWO STAGGERED HOLES

[Series II]

Type of specimen[a]	$\frac{s}{2e} = \frac{s}{g}$ (b)	Specimen \ Alloy	24S-T3	24S-T81	24S-T86	24S-0	Alclad 75S-T6	Alclad 14S-T6	Alclad 14S-T3
			Efficiency[c]						
23	0	A	91	101	99	95	101	100	92
		B	91	101	99	96	103	99	90
		C	88	102	97	92	102	101	92
		Av.	90	101	98	94	102	100	91
24	.25	A	88	98	96	88	97	98	90
		B	89	98	98	88	95	97	90
		C	87	97	97	86	97	98	90
		Av.	88	98	97	87	96	98	90
25	.50	A	79 [d]75	93 [d]87	87 [d]82	84 ---	93 ---	93 ---	82 [d]77
		B	81 [d]76	92 [d]87	91 [d]86	83 ---	94 ---	93 ---	83 [d]78
		C	78 [d]74	92 [d]87	89 [d]86	83 [d]78	92 [d]87	91 [d]86	84 [d]79
		Av.	79 [d]75	92 [d]87	89 [d]85	83 [d]78	93 [d]87	92 [d]86	83 [d]78
26	1	A	75	88	85	77	88	86	77
		B	75	87	85	76	89	88	79
		C	76	86	85	76	87	88	77
		Av.	75	87	85	76	88	87	78
27	2	A	77	89	85	80	88	88	79
		B	75	89	86	80	89	89	79
		C	77	86	87	78	89	88	79
		Av.	76	88	86	79	89	88	79
28	4	A	78	88	84	78	91	90	79
		B	76	89	87	80	89	88	79
		C	73	90	86	79	87	86	79
		Av.	76	89	86	79	89	88	79

[a]See table I for description of specimens.

[b]Ratio of pitch to gage.

[c]Efficiency = $\frac{\text{Tensile strength based on net area}}{\text{Tensile strength of material}} \times 100$.

[d]Based on area of fracture.

TABLE VIII

ULTIMATE-LOAD VALUES FOR SPECIMENS WITH TWO STAGGERED HOLES

[Series II]

Type	Specimen \ Alloy	24S-T3	24S-T81	24S-T86	24S-O	Alclad 75S-T6	Alclad 14S-T6	Alclad 14S-T3
		Ultimate load (lb)						
23	A	1540	1730	1795	720	1930	1547	1390
	B	1535	1740	1795	723	1930	1541	1375
	C	1500	1750	1760	695	1920	1553	1387
	Av.	1525	1740	1783	713	1927	1547	1384
24	A	1520	1705	1705	675	1880	1520	1377
	B	1550	1700	1720	675	1840	1511	1378
	C	1530	1690	1715	665	1880	1514	1376
	Av.	1533	1698	1713	672	1867	1515	1377
25	A	1440	1720	1605	675	1880	1500	1316
	B	1465	1710	1685	670	1895	1506	1307
	C	1425	1710	1680	670	1865	1508	1319
	Av.	1443	1713	1657	672	1880	1505	1314
26	A	1470	1725	1665	655	1900	1512	1320
	B	1495	1710	1665	650	1890	1525	1326
	C	1500	1700	1650	650	1870	1520	1311
	Av.	1488	1712	1660	652	1887	1519	1319
27	A	1515	1755	1675	690	1895	1535	1351
	B	1460	1755	1685	690	1905	1540	1356
	C	1515	1690	1690	670	1905	1531	1356
	Av.	1497	1733	1683	683	1902	1535	1354
28	A	1540	1735	1650	675	1915	1564	1326
	B	1500	1770	1690	690	1880	1518	1327
	C	1435	1785	1680	680	1835	1500	1326
	Av.	1492	1763	1673	682	1877	1527	1326

TABLE IX

RESULTS OF TESTS ON SPECIMENS WITH FOUR HOLES

[Series III]

Type of specimen[a]	$\frac{s}{2e} = \frac{s}{g}$ (b)	Specimen \ Alloy	24S-T3	24S-T81	24S-T86	24S-O	Alclad 75S-T6	Alclad 14S-T6	Alclad 14S-T3
			Efficiency[c]						
35	0	A	86	96	98	96	99	101	95
		B	91	97	97	95	101	101	95
		C	85	97	97	96	102	100	97
		Av.	87	97	97	96	101	101	96
36	.5	A	88	97	96	94	101 ---	99	93 [d]85
		B	86	95	95	92	101 [d]93	100	94 [d]86
		C	91	96	97	91	100 [d]92	100	93 [d]85
		Av.	88	96	96	92	101 [d]93	100	93 [d]85
37	1	A	87	93	93	90 [d]87	99	98	90
		B	86	93	94	90 [d]87	98	97	91
		C	83	94	95	90 [d]87	96	97	90
		Av.	85	93	94	90 [d]87	98	97	90
38	2	A	92	97	98	92	102	101	95
		B	92	98	99	92	102	102	95
		C	91	98	99	91	101	102	91
		Av.	92	98	99	92	102	102	94
39	4	A	91	98	100	92	102	102	93
		B	90	98	100	92	101	101	93
		C	--	99	100	92	101	100	93
		Av.	91	98	100	92	101	101	93

[a]See table I for description of specimens.

[b]Ratio of pitch to gage.

[c]$\text{Efficiency} = \frac{\text{Tensile strength based on net area}}{\text{Tensile strength of material}} \times 100.$

[d]Based on area of fracture.

TABLE X

ULTIMATE-LOAD VALUES FOR SPECIMENS WITH FOUR HOLES

[Series III]

Type	Specimen	24S-T3	24S-T81	24S-T86	24S-O	Alclad 75S-T6	Alclad 14S-T6	Alclad 14S-T3
		Ultimate load (lb)						
35	A	1330	1480	1520	715	1660	1360	1251
	B	1415	1500	1510	715	1690	1367	1252
	C	1325	1500	1515	715	1675	1368	1265
	Av.	1357	1493	1515	715	1675	1365	1256
36	A	1415	1565	1560	635	1730	1403	1272
	B	1385	1535	1550	625	1740	1406	1285
	C	1450	1550	1570	615	1720	1413	1272
	Av.	1417	1550	1560	625	1730	1407	1276
37	A	1535	1650	1650	665	1865	1494	1352
	B	1500	1650	1660	665	1850	1487	1364
	C	1450	1660	1685	665	1846	1495	1351
	Av.	1495	1653	1665	665	1852	1492	1356
38	A	1620	1720	1755	680	1920	1557	1433
	B	1625	1720	1775	685	1920	1566	1435
	C	1610	1735	1780	675	1900	1582	1366
	Av.	1618	1725	1770	680	1913	1568	1411
39	A	1610	1725	1785	680	1915	1592	1402
	B	1600	1730	1800	685	1905	1588	1402
	C	----	1730	1795	680	1880	1577	1393
	Av.	1605	1728	1793	682	1900	1586	1399

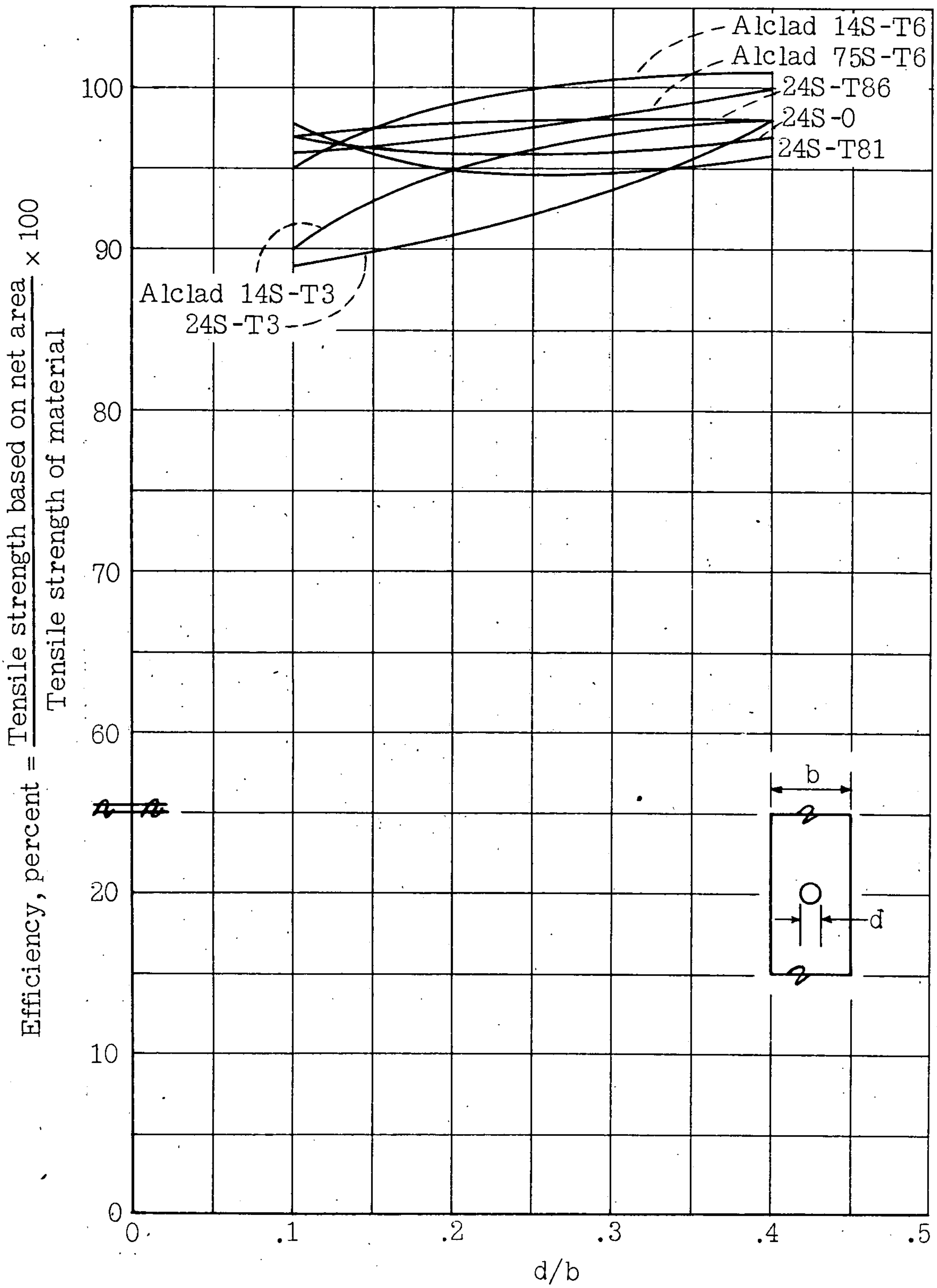


Figure 1.- Effect of central circular hole on tensile strength. Various aluminum alloys.

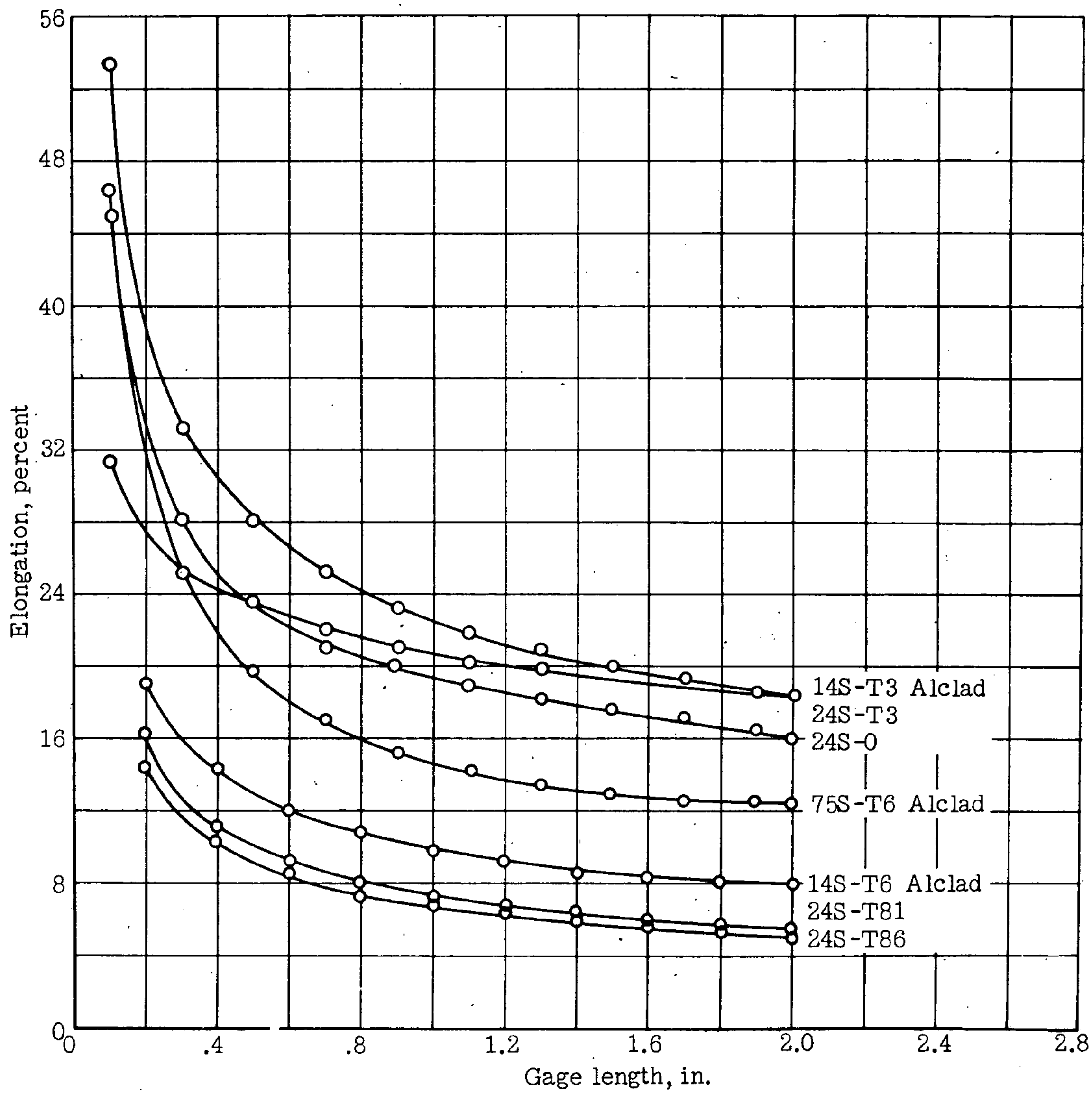
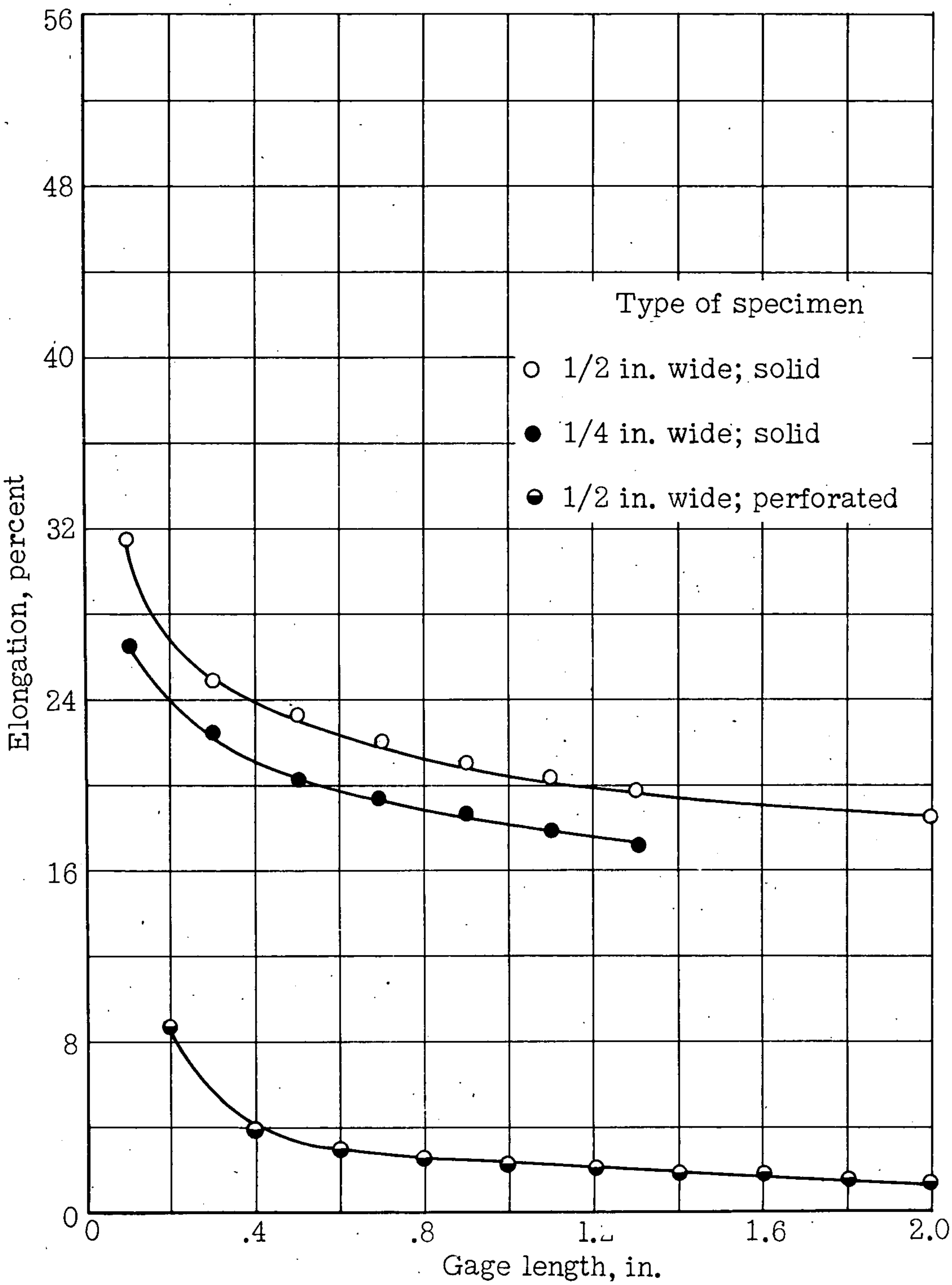
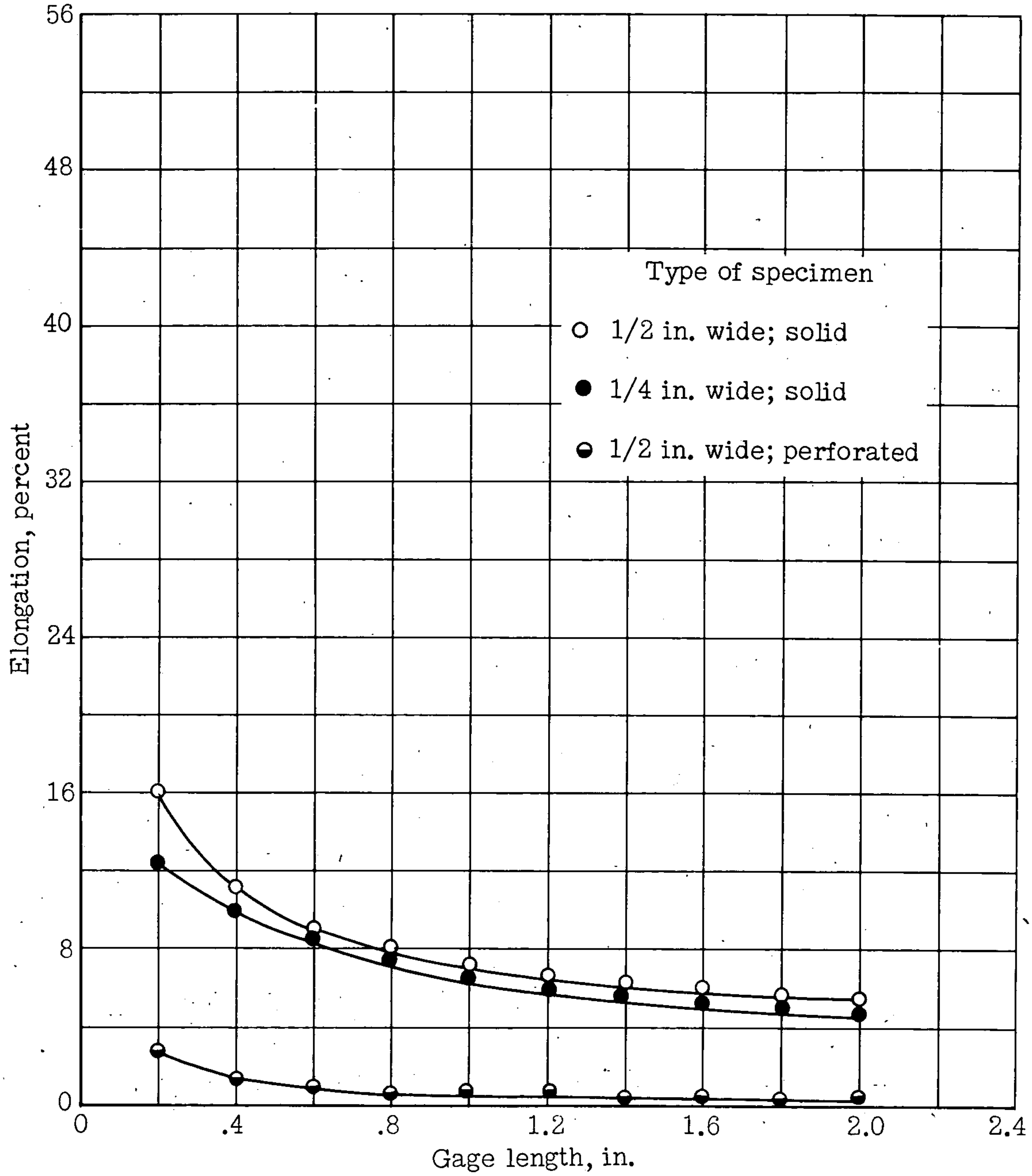


Figure 2.- Variation of elongation with gage length. Solid specimen 1/2 inch wide. Various aluminum alloys.



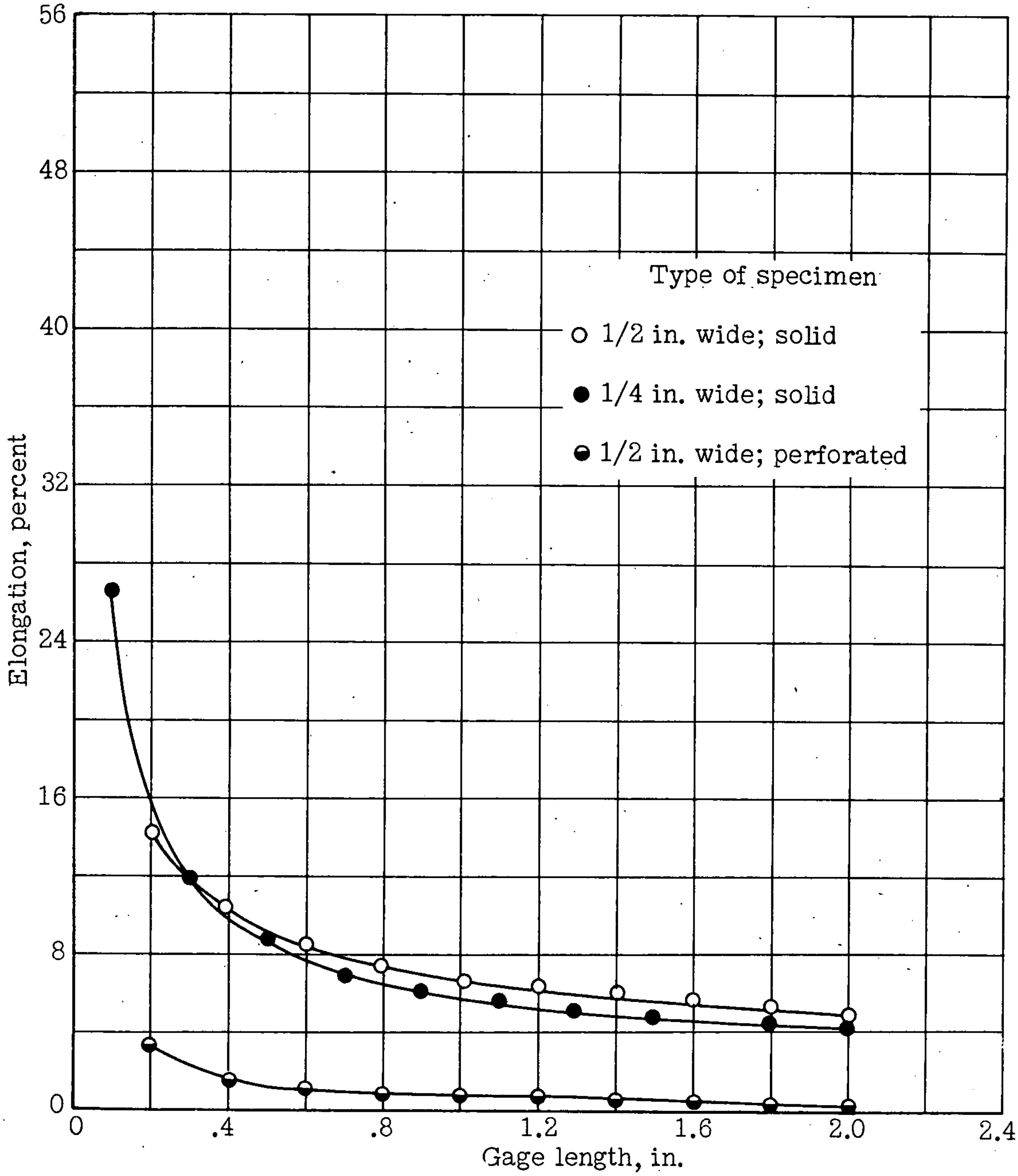
(a) 24S-T3 aluminum alloy.

Figure 3.- Variation of elongation with gage length. Solid and perforated specimens.



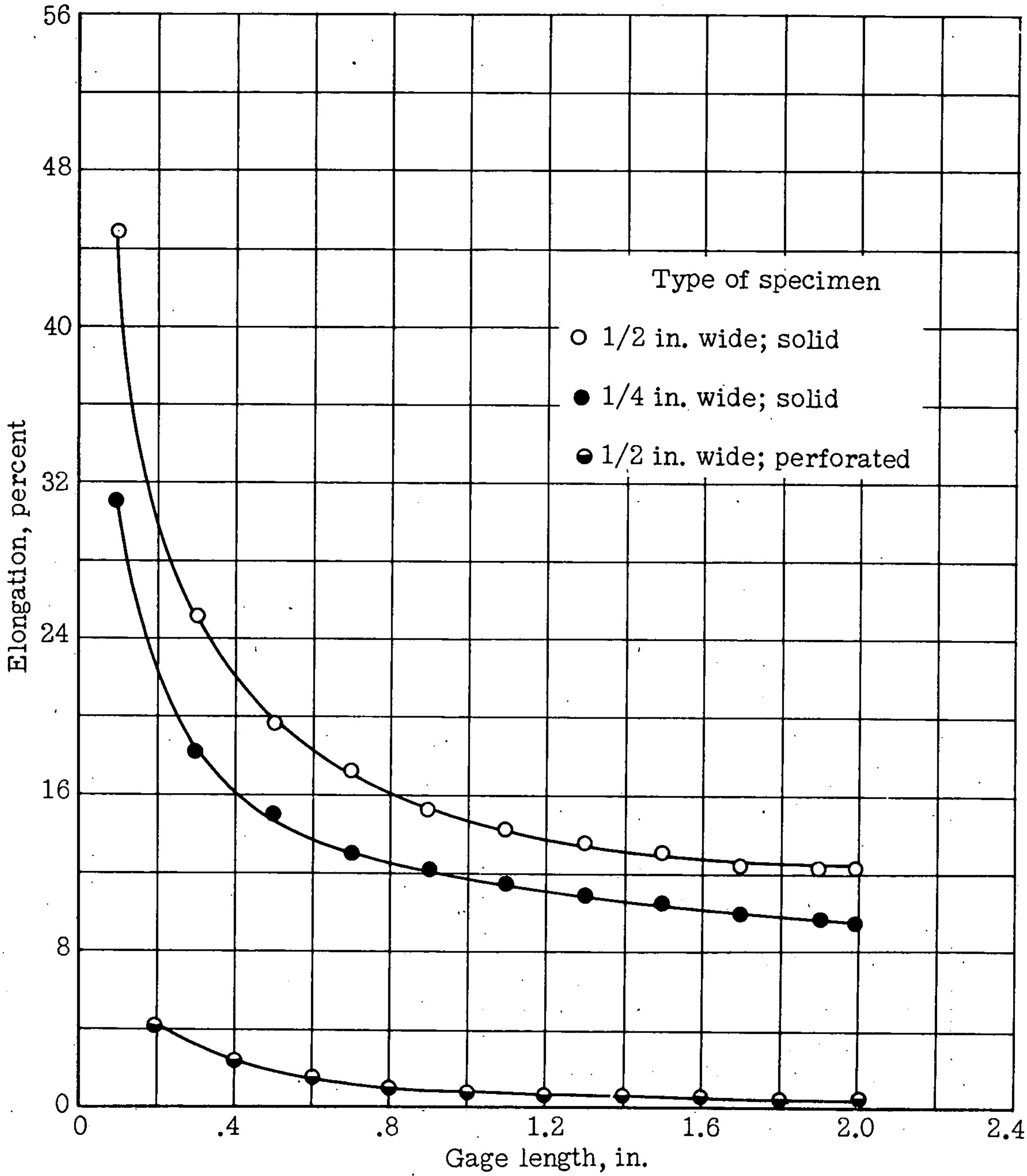
(b) 24S-T81 aluminum alloy.

Figure 3.- Continued.



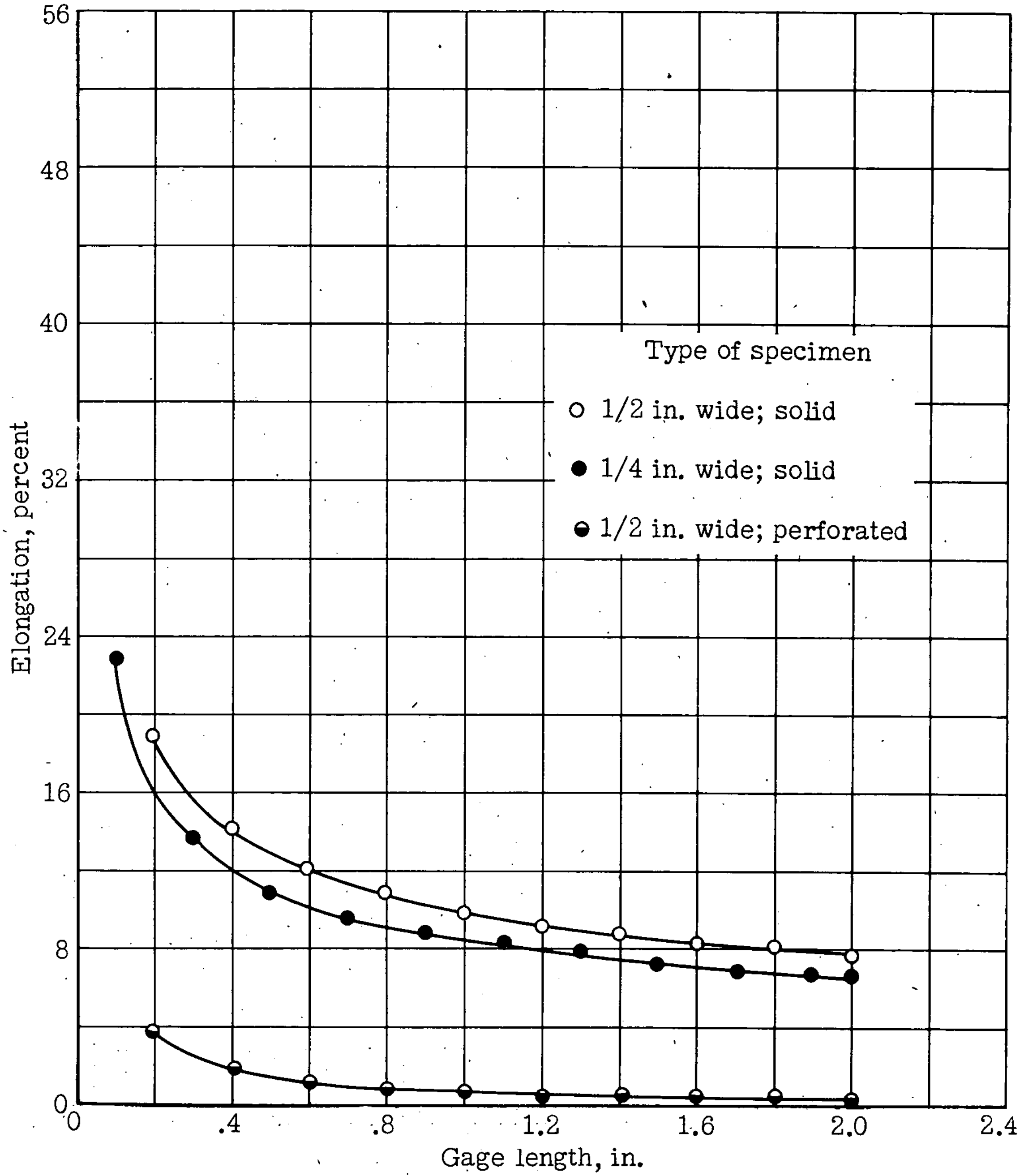
(c) 24S-T86 aluminum alloy.

Figure 3.- Continued.



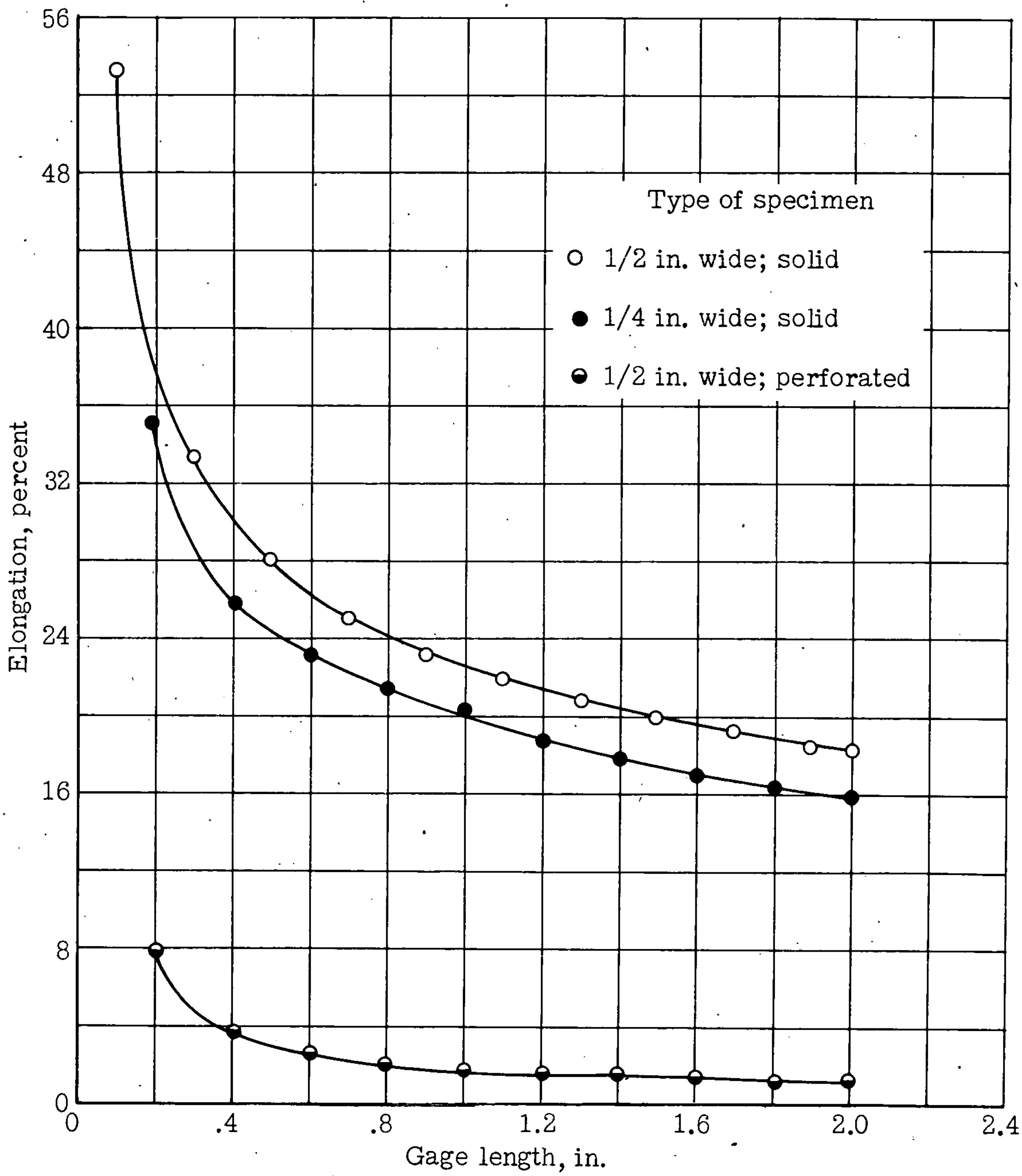
(d) 75S-T6 Alclad aluminum alloy.

Figure 3.- Continued.



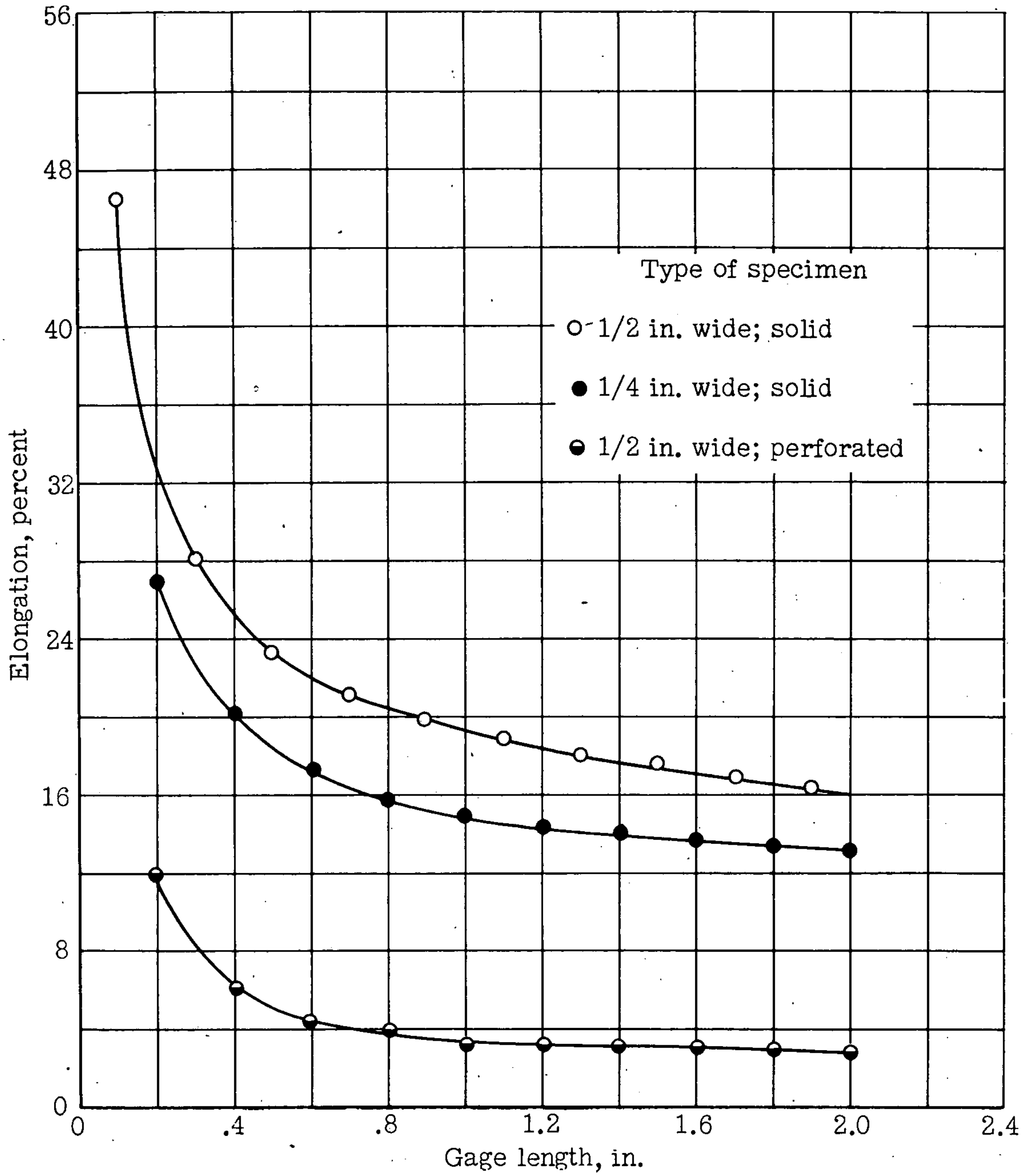
(e) 14S-T6 Alclad aluminum alloy.

Figure 3.- Continued.



(f) 14S-T3 Alclad aluminum alloy.

Figure 3.- Continued.



(g) 24S-0 aluminum alloy.

Figure 3.- Concluded.

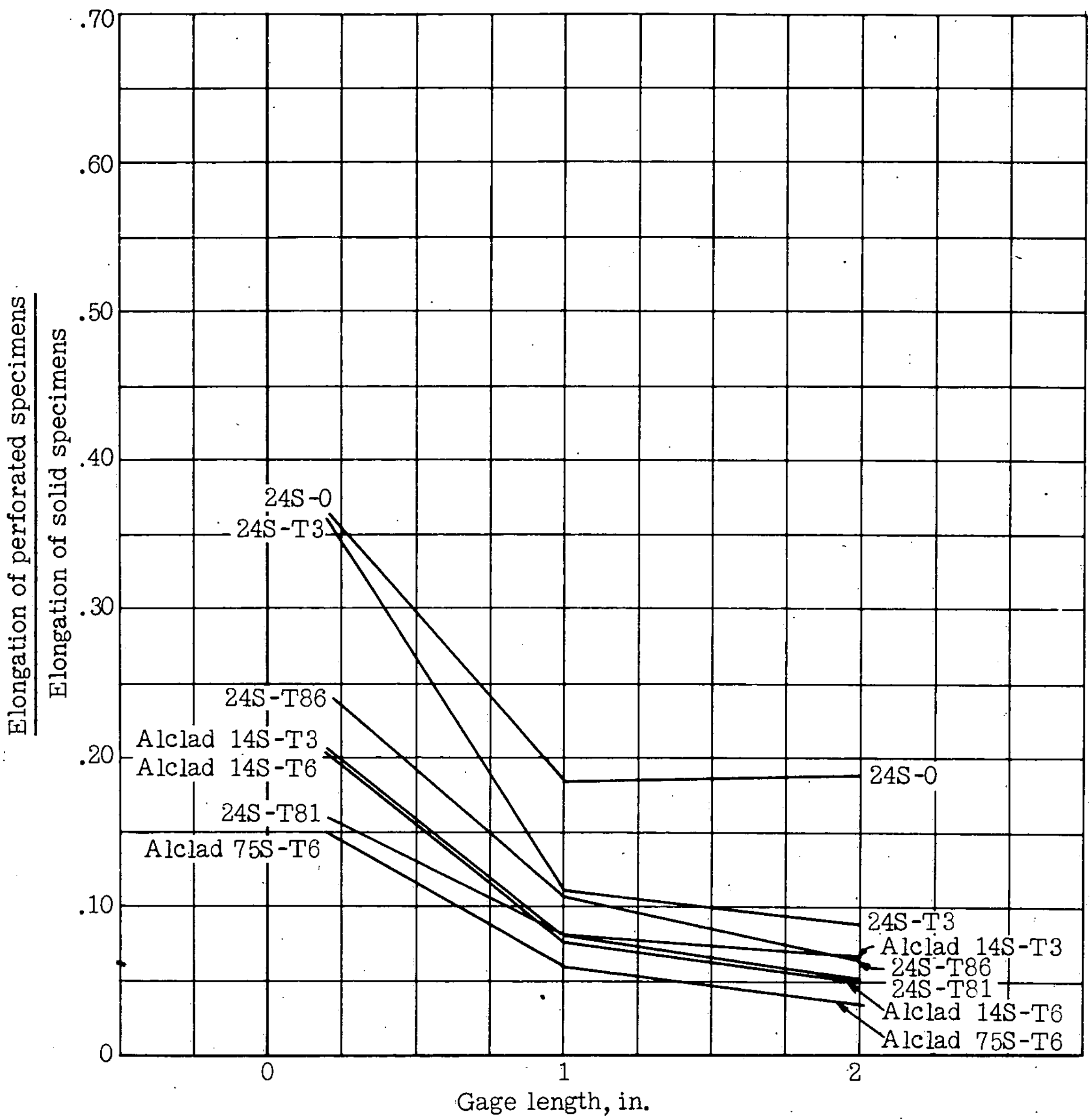
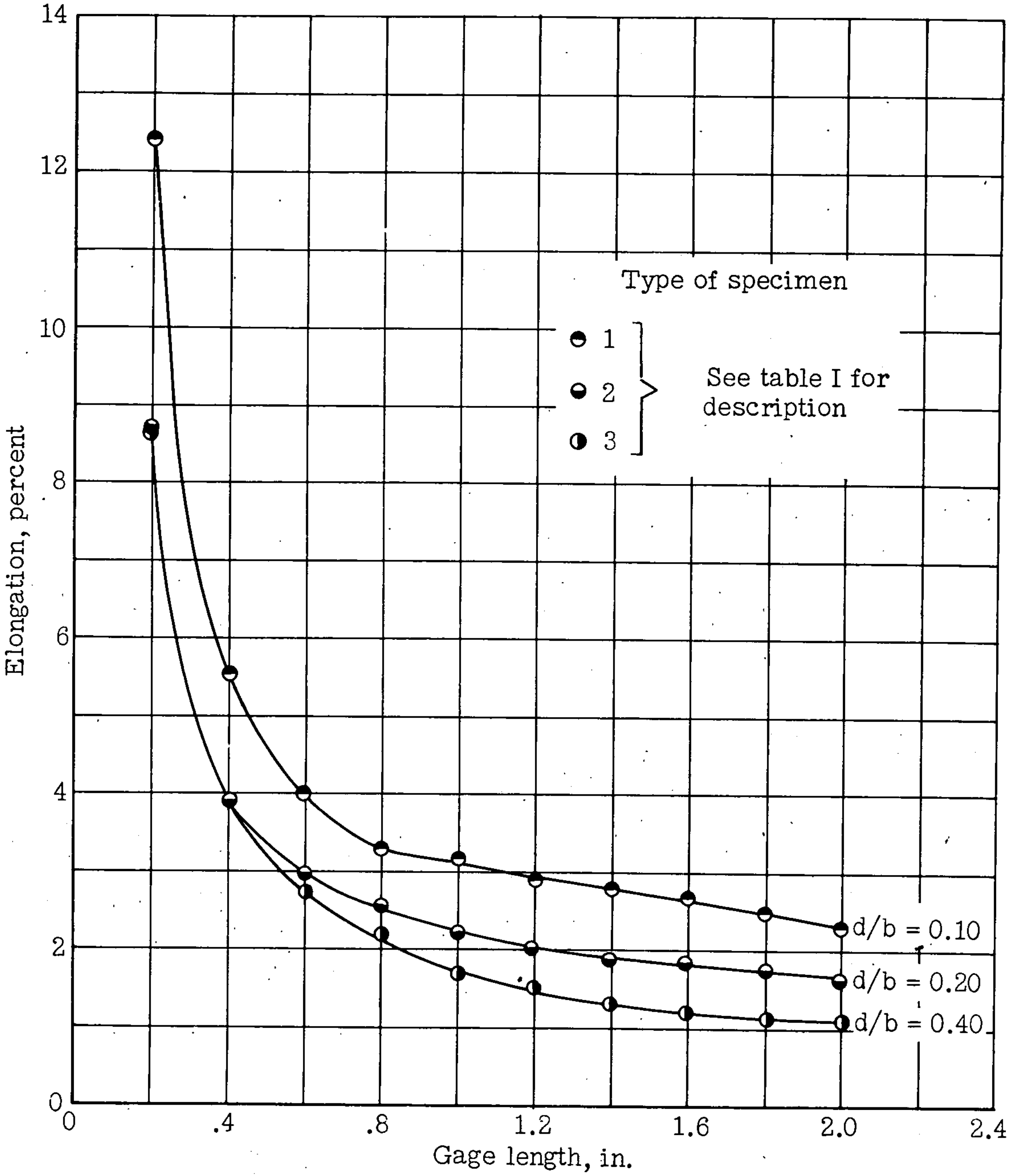
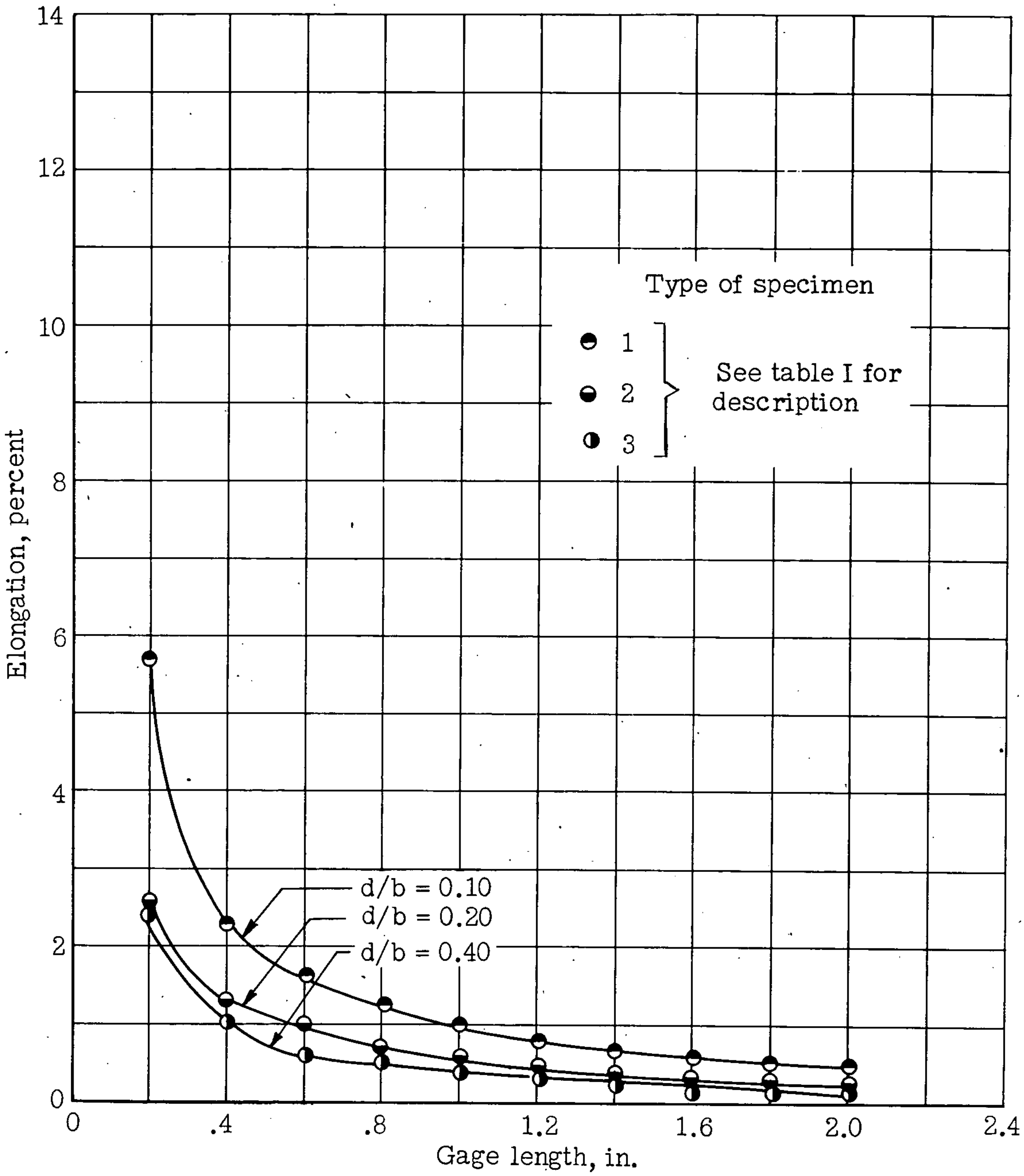


Figure 4.- Ratio of elongation of perforated to solid specimens against gage length. Various aluminum alloys.



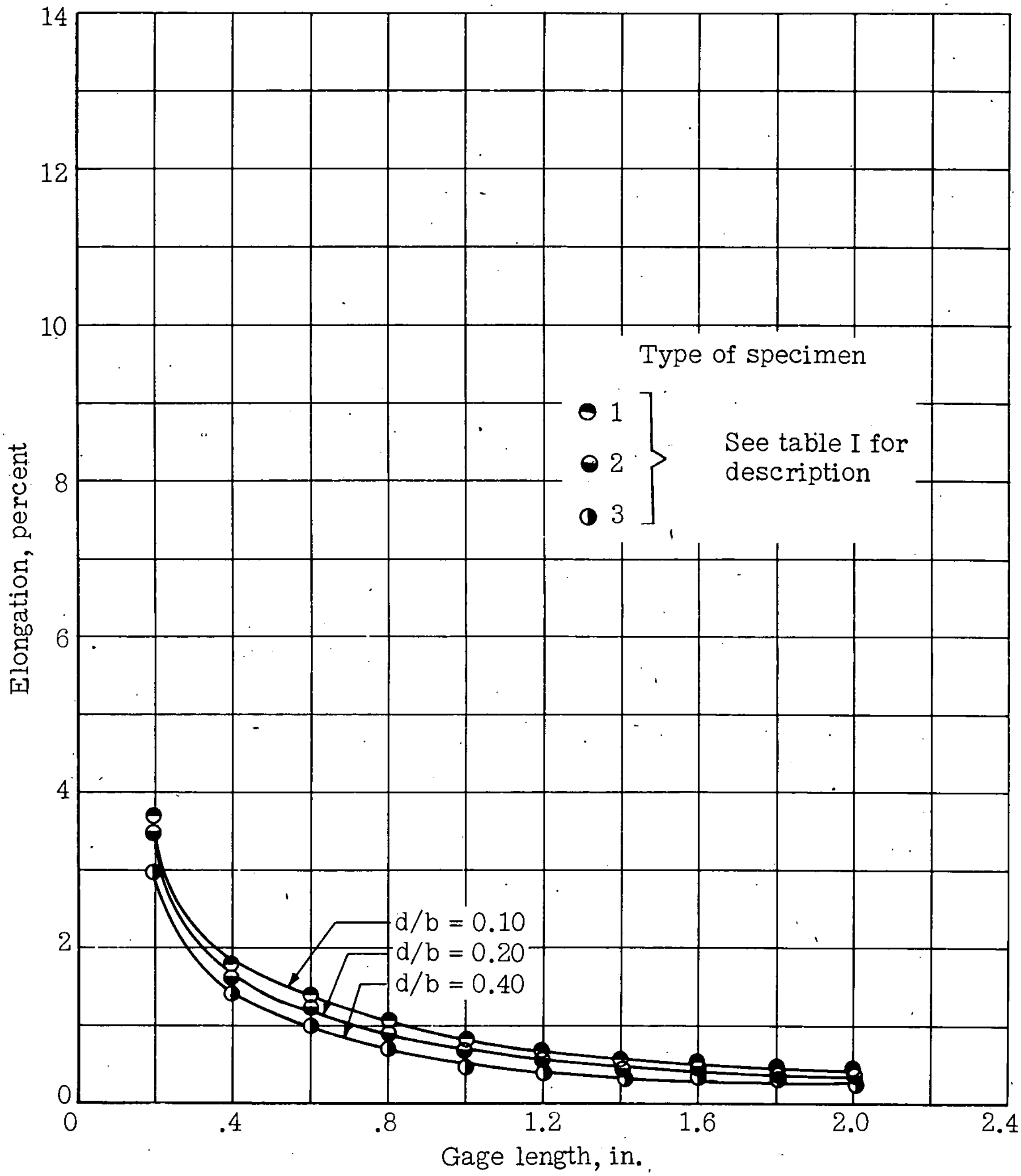
(a) 24S-T3 aluminum alloy.

Figure 5.- Variation of elongation with gage length for various d/b ratios.



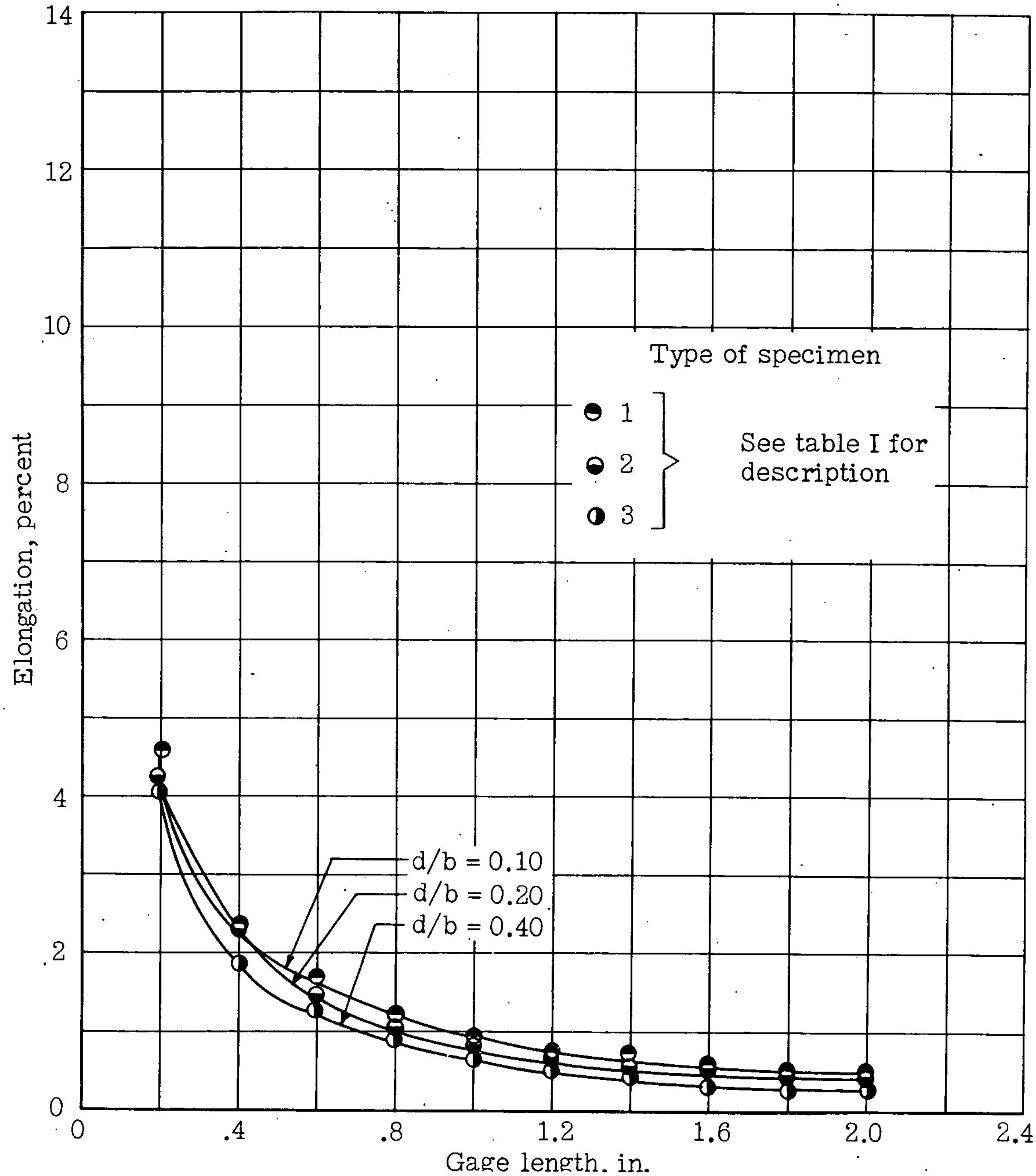
(b) 24S-T81 aluminum alloy.

Figure 5.- Continued.



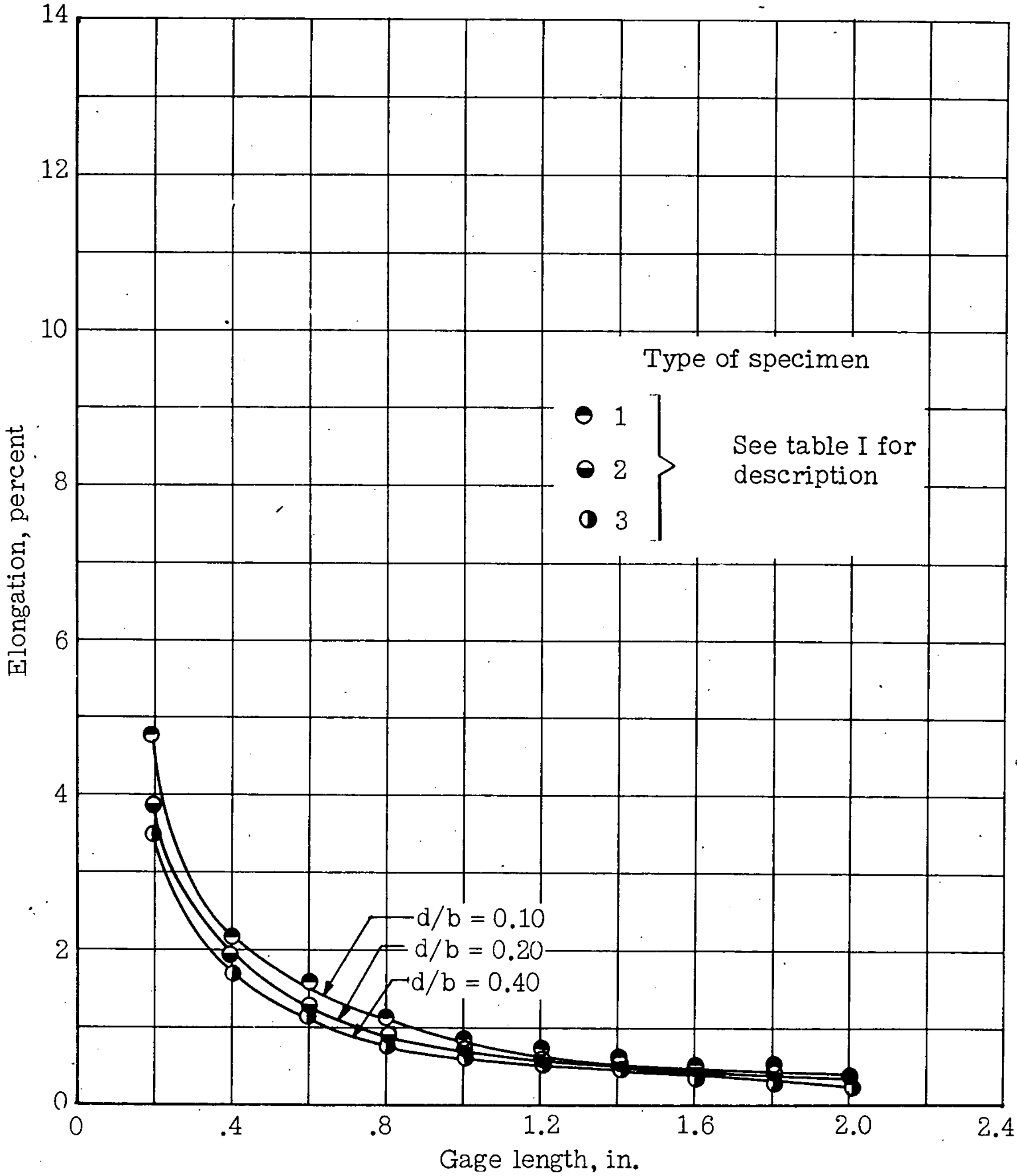
(c) 24S-T86 aluminum alloy.

Figure 5.- Continued.



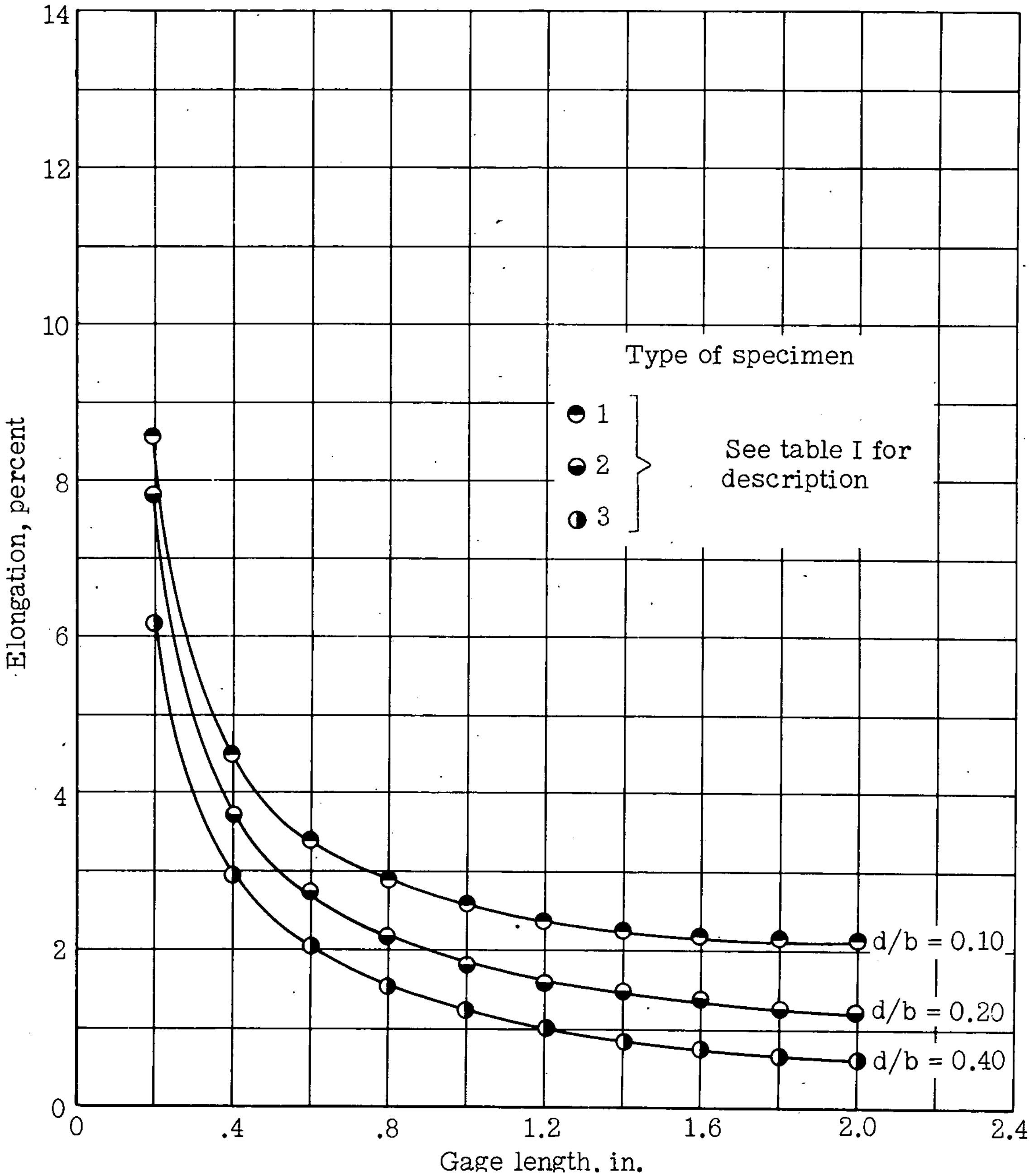
(d) 75S-T6 Alclad aluminum alloy.

Figure 5.- Continued.



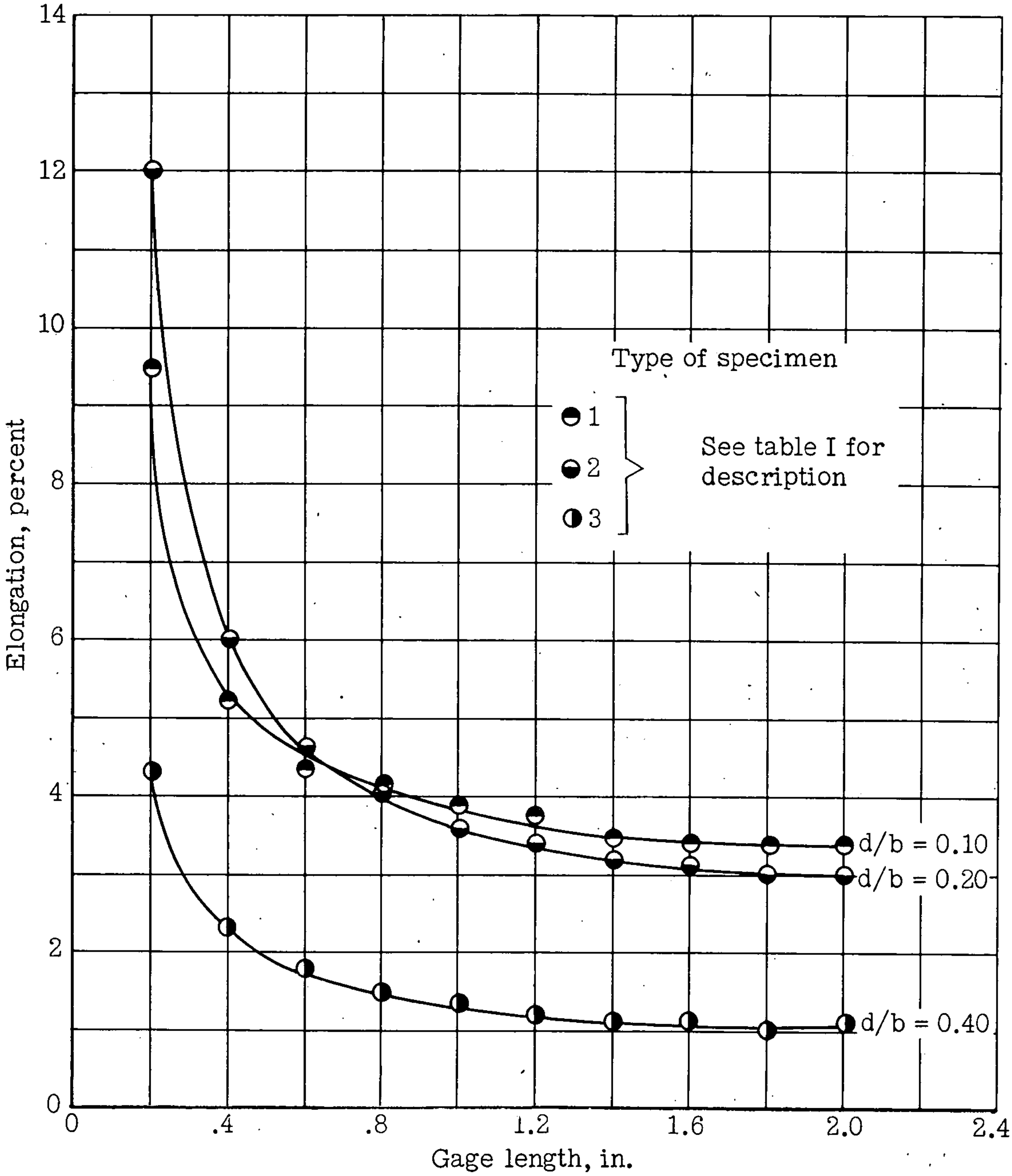
(e) 14S-T6 Alclad aluminum alloy.

Figure 5.- Continued.



(f) 14S-T3 Alclad aluminum alloy.

Figure 5.- Continued.



(g) 24S-0 aluminum alloy.

Figure 5.- Concluded.

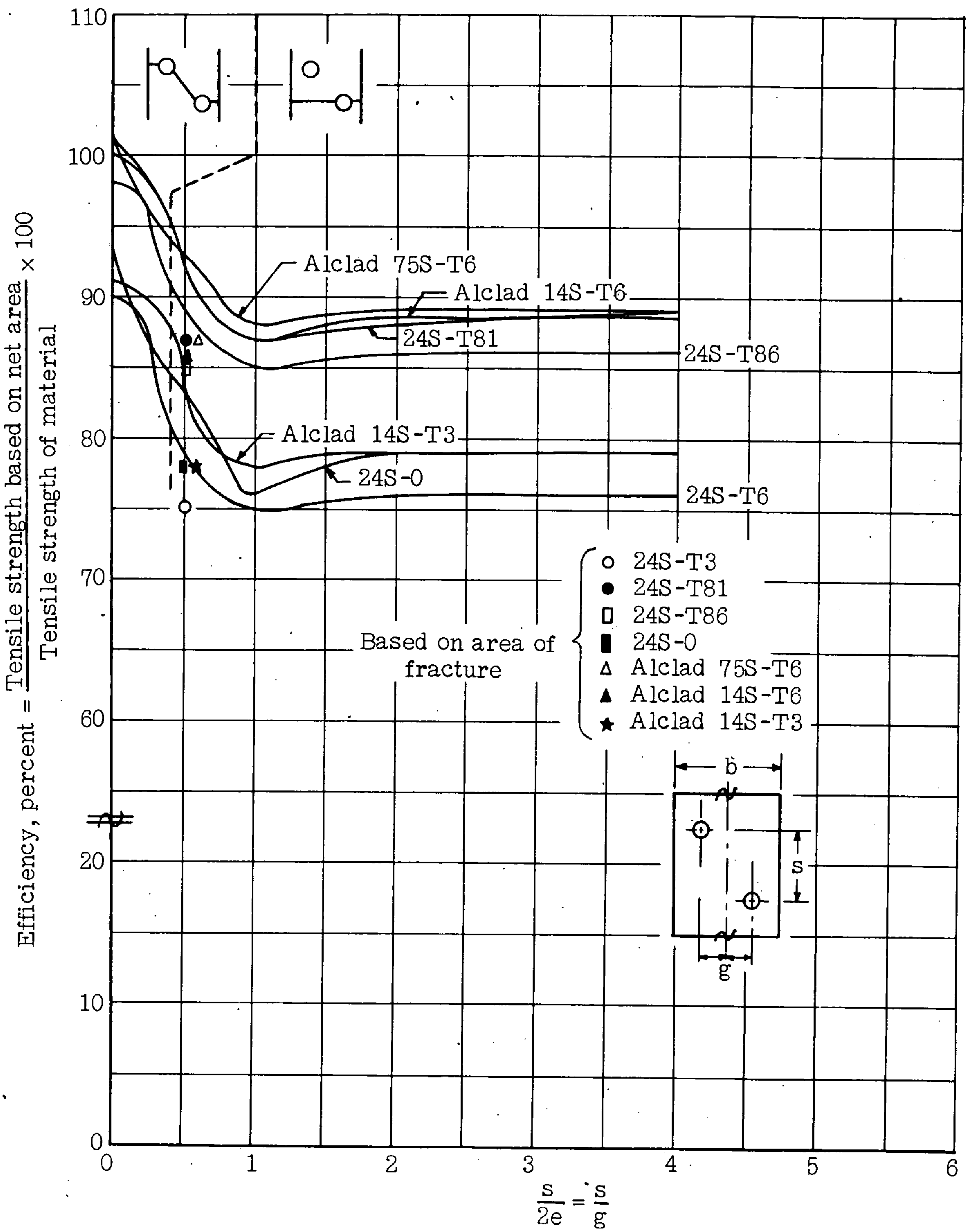


Figure 6.- Effect of two staggered holes on tensile strength. Various aluminum alloys.

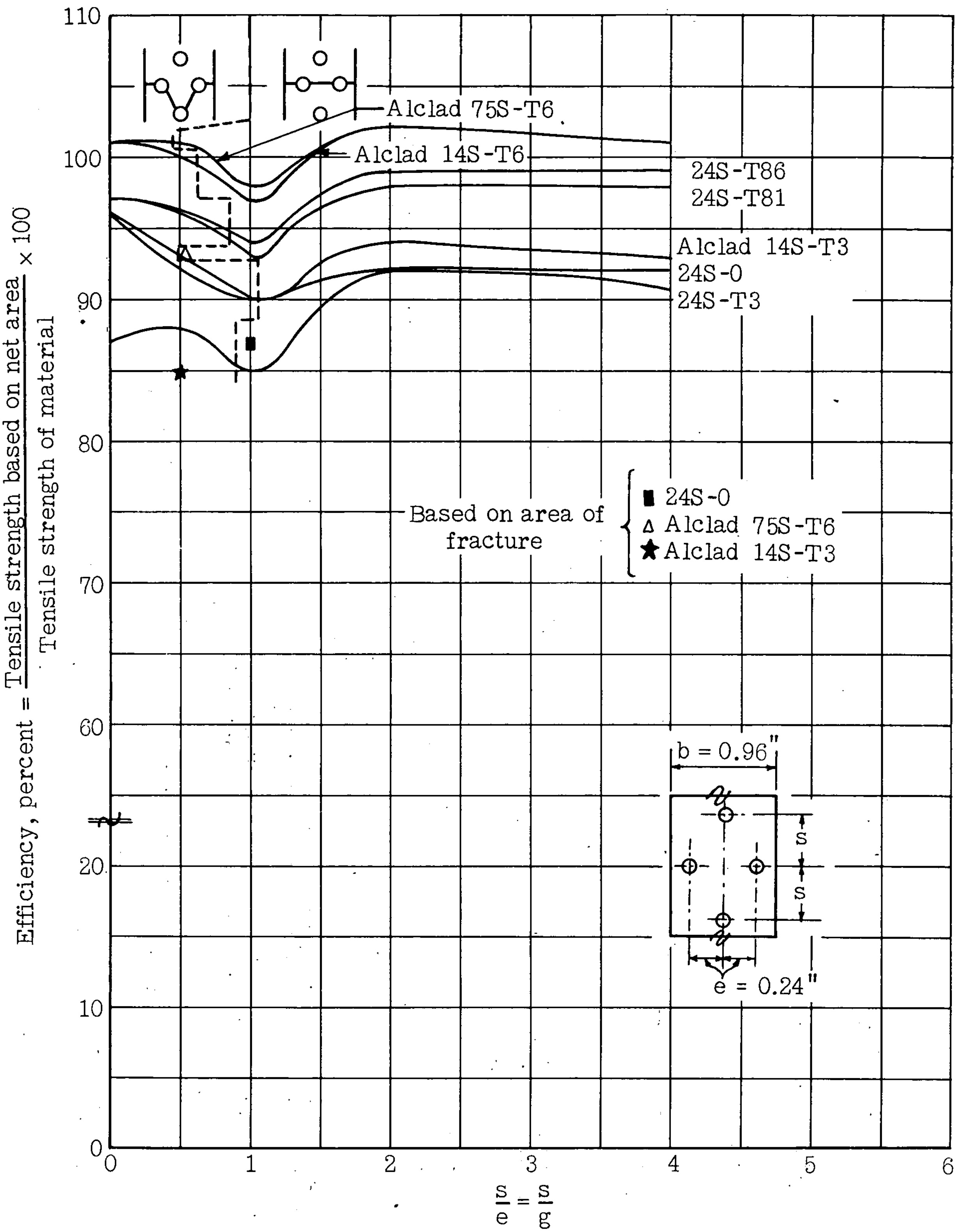


Figure 7.- Effect of four-hole pattern on tensile strength. Various aluminum alloys.