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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 585

MECHANICAL PROPERTIES OF ALUMINUM-ALLOY RIVETS

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National Bureau of Standards

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MECHANICAL PROPERTIES OF ALUMINUM-ALLOY RIVETS

By Wm. C. Brueggeman

I. INTRODUCTION

The development of metal construction for aircraft has created a need for accurate and detailed information regarding the strength of riveted joints in aluminum-alloy structures. To obtain this information the National Bureau of Standards in cooperation with the National Advisory Committee for Aeronautics is investigating the strength of riveted joints in aluminum alloys.

The strength of riveted joints may be influenced by the form of the head, the ratio of the rivet diameter to the sheet thickness, the driving stress, and other factors. This note gives the results of tests to develop the riveting technique for test specimens and to determine the effects of these factors.

II. MATERIAL

Both rivets and sheet were of alloy 17ST. The mechanical properties of the rivets conformed to Navy Department Specification 43R5b for Rivets and Rivet Wire and Rod, Aluminum and Aluminum Alloy (Aircraft Use) Grade C. The mechanical properties of the sheet conformed to Navy Department Specification 47A3b, Aluminum Alloy (Aluminum-copper-magnesium-manganese), sheet and plate, physical condition type 2, heat-treated.

All rivets were $1/4$ inch in diameter and were manufactured from the same coil of rivet wire. Typical mechanical properties of the wire in the heat-treated condition are given in table I.

The sheets were 16 inches wide, 14 feet long, and of the following thicknesses: 0.051 inch, 0.081 inch, 0.102 inch, and 0.125 inch. Typical mechanical properties of the sheets are given in table II.

TABLE I. Typical Mechanical Properties of 1/4-Inch
Rivet Wire in the Heat-Treated Condition

Specimen number	Yield strength, lb./in. ²	Yield strength, lb./in. ²	Elongation in 4 diameters, percent
1	34,750	58,710	28.0
2	34,700	58,430	31.0
3	34,800	58,350	28.6
4	33,400	58,380	28.8
5	35,000	58,510	28.0
6	34,500	58,350	28.0

TABLE II. Typical Mechanical Properties of 17ST Sheets

Sheet thickness, in.	Yield strength, lb./in. ²	Tensile strength, lb./in. ²	Elongation in 2 inches percent
0.051 L*	40,800	60,630	--
	40,200	59,050	21
.051 T*	35,800	59,270	22
	35,600	58,920	21
.081 L	39,700	60,260	24
	41,700	61,080	23
.081 T	35,400	59,890	23
	36,400	60,010	22
.102 L	42,900	61,470	22
	44,000	62,540	22
.102 T	37,400	61,680	22
	37,000	61,010	22
.125 L	40,300	60,800	22
	43,000	59,940	20
.125 T	35,400	58,320	--
	36,500	58,430	20

*L = longitudinal; T = transverse.

III. TYPES OF HEAD

The following combinations of types of head were used in making specimens:

<u>Driven head</u>		<u>Manufactured head</u>
round	with	round
mushroom	"	mushroom
button	"	round
brazier	"	brazier
cone point	"	round
flat	"	round

The head proportions are shown in figure 1. The dimensions given conform to Navy specification 43R5b for all types except the cone point and the mushroom.* The cone point is a type of head recommended by the Aluminum Company of America for driven heads. Among the advantages claimed for it are completeness of the head at low driving stress, adequate tensile strength, ease of maintaining concentricity with the shank, the fact that one set may be used to drive several sizes of rivet, and satisfactory appearance. At the present time cone-point heads are not supplied by the manufacturer.

The rivet sets were machined to fit the heads, using the dimensions of figure 1, except for flat and cone-point heads. The set for flat heads consisted simply of a flat hardened-steel bearing surface. For cone-point heads the set had a cone-shaped bearing surface.

IV. PREPARATION OF SPECIMENS

1. Rivets

Figure 2 shows a jig for cutting the rivets to the exact length required for driving. It is adjustable to any desired grip (total sheet thickness) and head allow-

*Using dimensions given in Specification 43R5b for mushroom heads, the arcs forming the head contour do not meet in a common tangent. For this reason, in making rivet sets, the dimension $R = 1.563d$ was substituted for the specified dimension $R = 1.634d$.

ance (length of shank projecting from the sheets to form the driven head).

The rivets were heat-treated by submerging them for 15 minutes in a bath of sodium nitrate held at 940° F. and then quenching in cold water. They were driven within one hour after quenching. Specimens were held at room temperature and tested two weeks after driving the rivets.

2. Sheets

The sheets were cut to size by either sawing or shearing. To insure uniformity the holes were subdrilled, then reamed. A hole size was chosen that would insure that the largest rivet meeting the diameter tolerance would enter the hole freely. For this purpose the plus tolerance (0.004 in.) of the rivet diameter was added to the nominal diameter (0.250 in.), and a special reamer equal in diameter to the next larger commercial drill size (F, 0.257 in.) was used.

3. Riveting

All riveting was done by the "squeeze" method. The load was applied in a hydraulic testing machine, as shown in figure 3. The upper rivet set is attached to the upper head of the machine and the lower set rests on the movable platen. The sheets were clamped together during riveting and were kept in a position normal to the rivet axis by means of a flange and frame centered about the lower rivet set.

When referring to the pressure applied to the rivet when forming the head, the term "driving stress" is used for convenience. It is a nominal stress obtained by dividing the maximum driving load by the nominal cross-sectional area of the shank and is, of course, in all cases larger than the actual stress on the head.

V. DIMENSIONS OF DRIVEN RIVETS

1. Head Dimensions

Information was desired on the dimensions of incomplete heads of the several types and the driving stress at which the dimensions of the driven head approached those

of the manufactured head. Measurements of the depth and the diameter of the driven head were made on all of the types shown in figure 1. These are plotted against driving stress in figures 4 to 9 inclusive, in terms of the nominal depth and diameter of the manufactured head (scale at bottom of graphs) and nominal shank diameter d , (scale at top).

A head allowance H (fig. 4) sufficient to form an approximately complete head was used. Rivets were driven at successively increasing driving stresses until the driven head was practically complete or until severe radial buckling and separation of the sheets had occurred. The cone-point head was found to be the only type which could be driven to its full nominal diameter without excessive buckling of the sheets.

It is difficult to express quantitatively the amount of such buckling and it is realized that the permissible amount probably varies for different applications. However, it may be said that a marked buckling and appreciable separation of the sheets began to occur for $d/t = 2.0$ at about 325,000 lb./in.² for all joints, and at lower driving stresses when d/t was 2.5 and above.

It was found that the diameter of the driven head was affected very little by the head allowance H , as shown in figure 4 for round-head rivets. The diameters of flat heads, figure 9, showed a similar agreement when H was $1.5d$ and $1.75d$. Only the curve for $H = 1.5d$ is plotted.

The several types of driven heads had nearly the same diameter at the same driving stress. The greatest difference was between the button head (fig. 6) and the flat head (fig. 9), which had diameters of approximately $1.60d$ and $1.82d$, respectively, at 250,000 lb./in.² driving stress.

Eccentricity of the flat heads occurred frequently when care was not exercised in aligning the shank normal to the sheets before driving. This effect was not pronounced for other types of head.

The brazier head was less complete when buckling of the sheets commenced than any of the other types. The high driving stress which it requires is doubtless due to its large diameter, shallow contour, and sharp edge.

The driving stress required to form a complete cone-point head (about 175,000 lb./in.²) was less than the driving stress required for any of the other types, principally because of its small diameter. It is evident from figure 8 that a head allowance of 1.5d is slightly excessive for the cone-point head.

2. Upsetting of Shank

Upsetting of the rivet shank affects the strength of a joint because (1) the cold-working changes the properties of the material, (2) the cross-sectional area of the shank is increased. Measurements were made to determine the relation of the upsetting to driving stress, type of head, and d/t ratio.

After driving rivets, the sheets were removed by making diametrically opposite saw cuts, then wedging them apart. The shank of a driven rivet is somewhat tapered and for high driving stresses has a slight shoulder between the sheets. The diameter was measured by means of a measuring microscope, at d_2 , figure 10, the section at which shearing failure would occur under single-shear loading.

The results are shown in figures 10, 11, and 12. There is no appreciable effect of type of head on the relation between upsetting and driving stress. The amount of upsetting of the shank at a given driving stress was nearly constant for the three ratios of d/t .

The measurements of upsetting do not take into account any elastic increase in diameter which might have occurred when the sheets were removed. A rough calculation indicates that this elastic recovery is probably negligible, but further measurements are contemplated to determine its magnitude.

VI. STRENGTH OF DRIVEN RIVETS

1. Effect of Upsetting

To determine how the mechanical properties of a rivet shank are affected by the amount of upsetting, the tensile strength, elongation and shearing strength were measured directly on specimens of rivet wire which had been upset different amounts immediately after quenching, then aged.

Specimens 0.184 inch in diameter and $5\frac{1}{2}$ inches long, were upset in the fixture shown in figure 13. The specimen B was lubricated with soap and graphite. A compressive load was applied in a testing machine through the plunger D. To insure uniform upsetting the block was then inverted and the load again applied. A sudden increase in the load indicated that the specimen had completely filled the hole. The amount of upsetting was varied by using holes of the following sizes: 0.188 inch, 0.197 inch, 0.203 inch, and 0.219 inch.

The tensile strength and elongation in a gage length of four diameters were determined for the tensile specimens. The specimens for the shearing test were tested in double shear using the fixture shown in figure 14.

Both the tensile and shearing strengths of the rivet wire (fig. 15) showed a marked decrease for a small amount of upsetting, followed by a gradual increase. The elongation decreased continuously as the upsetting increased.

The tensile and shearing strengths of upset rivet wire (fig. 15) show almost no variation in the range of upsetting corresponding to driving stresses used in practice. (See figs. 10, 11, and 12.) The elongation shows a considerable decrease in this range (fig. 15).

No tests were made to determine the effect on the strength of the slight upsetting of the shank during the formation of the manufactured head. Because this occurs while the material is in the annealed temper, the effect is believed to be small.

2. Shearing Strength of Joints

To determine whether the shearing strength of rivets depends on the type of head, single-shear tests were made on rivets of two types of head. The specimen is shown in figure 16 and the results in figure 17.

A single-shear test specimen was used because it was believed that any differences in strength due to the type of head would be greater than in a double-shear test because of the eccentricity of the loading. The sheets were eight diameters wide. The rivet was on the center line four diameters from the overlapping ends.

There was little difference between the shearing

strength of the round and cone-point rivets. The difference between the results for the several d/t ratios was less than the variation for individual specimens of the same d/t ratio.

To determine how the results of shearing tests for upset wire agreed with results of shearing tests of actual rivets, the shearing strength of the wire after upsetting was obtained from figure 15 and multiplied by the ratio of the actual cross-sectional area to the nominal area. The strengths computed in this manner for $\frac{d}{t} = 2.5$ are shown by the dotted line in figure 17. In determining the computed shearing strength, it was assumed that the effect of upsetting upon the shearing strength of the 1/4-inch rivets was the same as shown in figure 15 for the 3/16-inch rivet wire. The tensile strength of the 1/4-inch wire heat-treated but not upset, was only 1.7 percent lower than the strength of the 3/16-inch wire.

If it can be shown that the shearing strength of a riveted joint can be determined by such a computation, it is believed that joints could be designed on a more rational basis than if nominal values were used. There are obvious differences between the conditions obtained in the double-shear test of wire and those in an actual joint. Although a good agreement between the computed and observed results is evident in figure 17, it is believed that a further check of this agreement should be made on rivets under double-shear loading and of different diameters.

3. Tensile Strength of Joints

Although rivets are seldom intended to carry tensile loads, there are some applications where the tensile strength of the rivet is a consideration and where information regarding the strength of the head under tensile load would be useful.

Tensile tests were made of all the types of head shown in figure 1. As it was desired to test actual riveted joints, the form of specimen shown in figures 18 and 19 was used. It consists of two square sheets riveted together at the center. Each is fastened to one of the flanges (fig. 19) by four cap screws. Holes to provide clearance for the screw heads are drilled in the opposite sheet and flange. A tensile load was applied by connecting the flanges to the testing machine through spherical bearings.

Although the tensile strength of riveted joints depends on the design of the fixture and specimen, it is believed that the results obtained afford a valid basis for comparing different types of head under tensile load. The results are plotted in figures 20 to 25, inclusive. The nominal cross-sectional area of the rivet was used in computing stresses.

In general, for the lower ratios of d/t , the driven heads pulled through the sheet when the driving stress was below a critical value. When higher driving stresses were used, either the shank failed in tension or the head sheared from the shank around the shank circumference. Except in the cases of the flat and brazier heads, all joints having a d/t ratio of 3.1 and greater, failed by pulling the driven head through the sheet.

All of the brazier-head rivets except those of the highest d/t ratio failed by shearing of the manufactured head. The strength showed little variation with driving stress, but increased with a decrease in the d/t ratio. The latter effect is probably caused by the "dishing" of the sheets under load. The effect of such dishing in a shallow rivet head of large diameter is to bend the shoulder of the head away from the shank. The resulting concentration of bending stress at the shank contributes to shearing failure of the head. As the d/t ratio is increased the "dishing" becomes more marked and higher bending stresses result.

Figure 25 shows that the tensile strength of the flat-head rivets is reduced if the depth becomes too small due to excessive driving stress.

VII. DEFORMATION OF SHEETS

The upsetting of the rivet shank during driving produces a considerable radial compressive stress in the sheets. If the driving stress is excessive this causes the buckling and separation of the sheets already noted.

To determine whether there was a relation between the radial deformation of the sheets and the driving stress at which buckling occurred, measurements of the radial deformation were made with the results shown in figures 26, 27, and 28. The specimen is shown in figure 26.

Joints were made with rivets of three types of head and three ratios of d/t . Gage circles $2\frac{1}{2}d$ in diameter were scribed concentric with the rivet hole on both external surfaces of the sheets. The increase in the diameter of the gage circle caused by driving the rivet was measured for two mutually perpendicular diameters on each sheet by means of a measuring microscope.

It is apparent that the deformation commences at low driving stresses and increases continuously. No correlation with the driving stress at which buckling occurred was noted. Some differences in the amount of deformation produced for round, mushroom and cone-point heads are evident, but these differences appear to be too small to form a basis of preference.

VIII. CONCLUSIONS

1. Complete heads of the round, button, mushroom, and brazier types could not be driven by the "squeeze" method because excessive buckling and separation of the sheets occurred when the driving stress was sufficient to complete the head. Complete cone-point heads were driven without buckling of the sheets.

2. Although the cross-sectional area of a rivet is increased by driving, the shearing strength, tensile strength, and elongation of the material are decreased. The shearing strength of a driven rivet, computed from measurements of shank upsetting and the strength of upset material agrees closely with test results.

3. Failure of riveted joints under tensile loading occurred by rupture of the sheets when the driven heads had less than the following diameters (a), approximately,

d/t	a
2.0	1.5d
2.5	1.7d

For larger diameters failure occurred either in the shank or the manufactured head. For d/t ratios above 3.1, it was impracticable to obtain a head diameter such that failure of the rivet occurred. The head allowances used

in riveting the tensile specimens were sufficient to provide adequate shearing strength of the driven head for all types except the flat head.

4. It was found impracticable to use measurements of radial deformation in the sheets as a criterion of excessive buckling.

IX. ACKNOWLEDGMENT

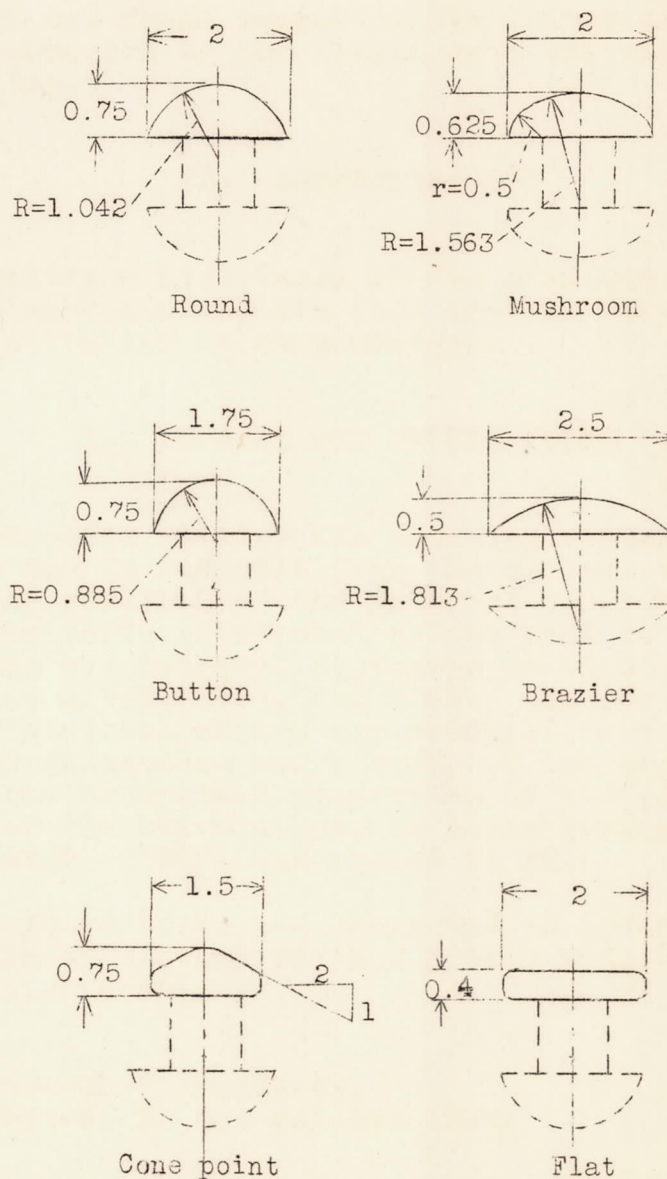
The valuable assistance of the Aluminum Company of America in making available test results obtained in their research laboratory is acknowledged.

X. PROGRAM FOR FUTURE TESTS

To determine whether the shearing strength of a riveted joint can be computed from the cross-sectional area and shearing strength of the material after upsetting, double-shear tests of riveted joints will be made. Additional tests are believed desirable on rivets of other alloys such as Al7ST, 24ST, and 53SW. The contemplated tests of these additional alloys are confined to a determination of the head dimensions and a study of the effect of upsetting upon the mechanical properties of the shank. A stock of rivets of the above alloys is being procured, also sheets in alloys 24ST, 24SRT, and alclad 24 ST.

After these tests are completed an investigation of the strength of typical riveted joints will be made to provide design data.

National Bureau of Standards,
Washington, D. C., October 1936.



Note- All dimensions are in terms of the shank diameter.

———— Driven heads

----- Manufactured heads

Figure 1.- Types of driven heads tested.

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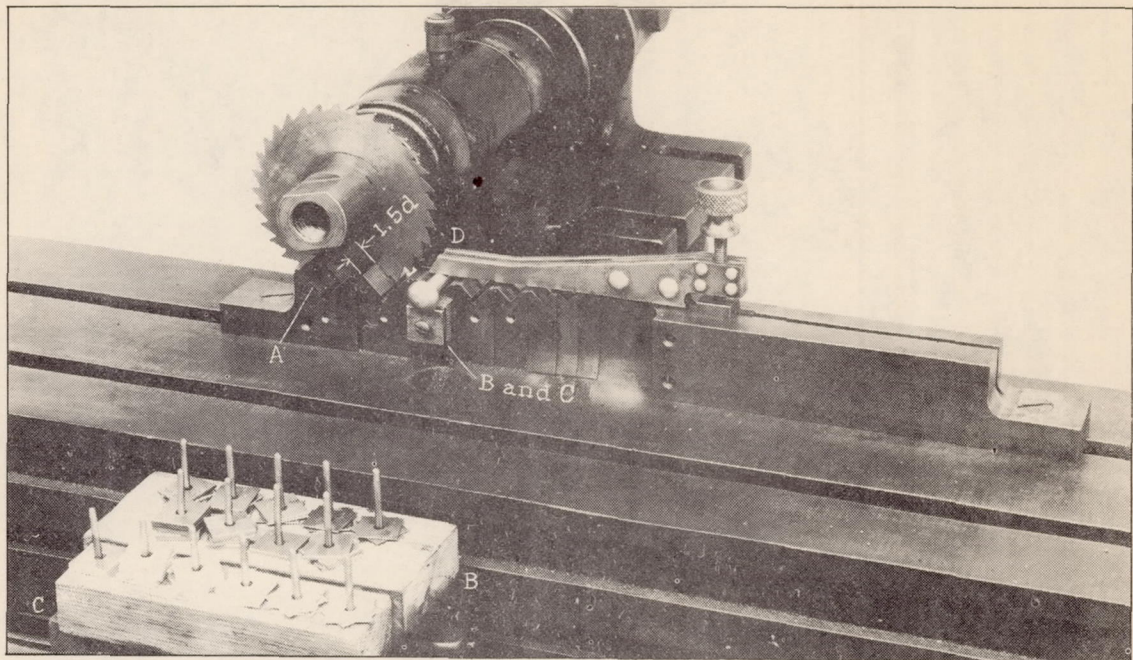


Figure 2.- Jig for cutting rivet shanks to obtain any desired grip and head allowance.

Each notch A corresponds to one diameter of rivet (from $1/16$ to $3/8$ in.). The length of the notches is $1\frac{1}{2}$ times the rivet diameter. Spacers B, each equal to $d/4$, are inserted under the rivet head to provide head allowances larger than $1\frac{1}{2}d$ when desired. Additional spacers C, equal to the thickness of the sheets, are similarly inserted to obtain the grip allowance. Tightening the thumb screw clamps the rivet by pivoting the arm D on a movable pin for which a series of holes, corresponding to the notches, is drilled in the back of the block.

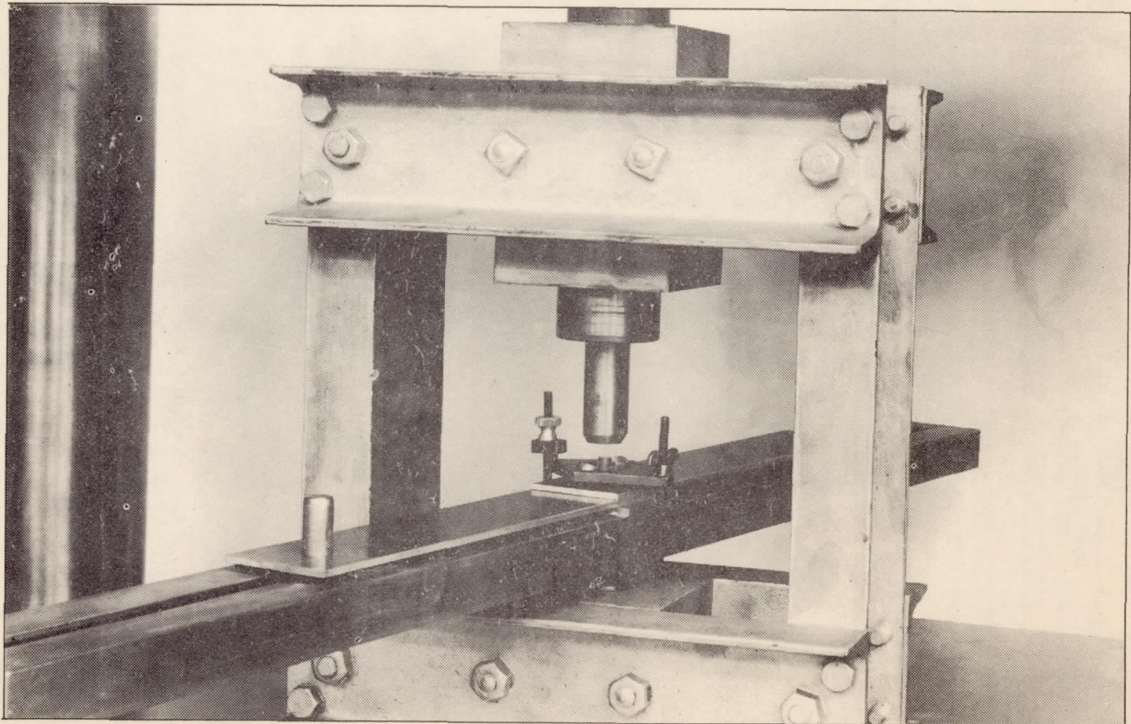
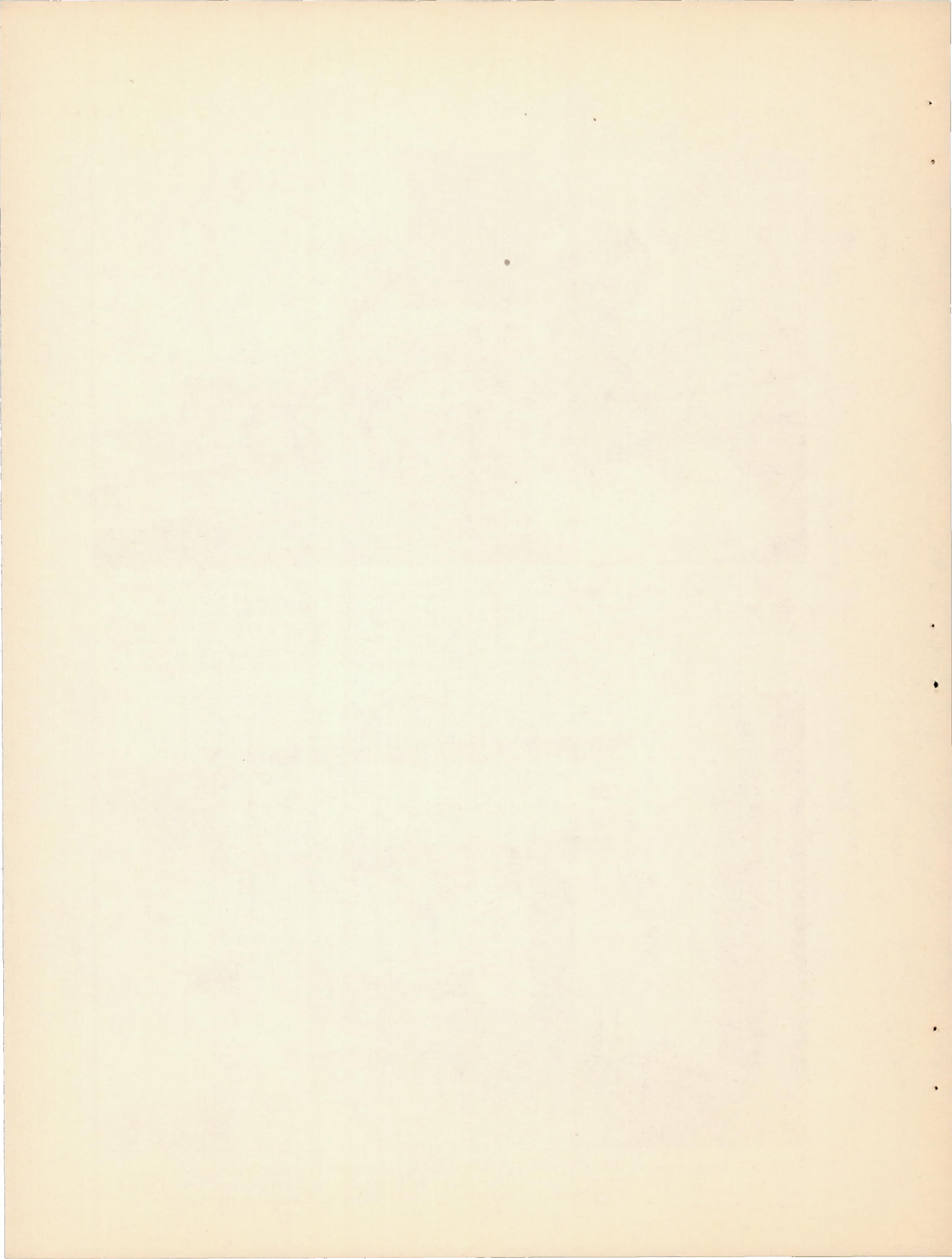


Figure 3.- Jig used to drive rivets by the "squeeze" method. The load is applied in a hydraulic testing machine. The holes in the ends of the specimen are aligned with the rivet hole and are used to connect the specimen to the testing machine when testing the joint.



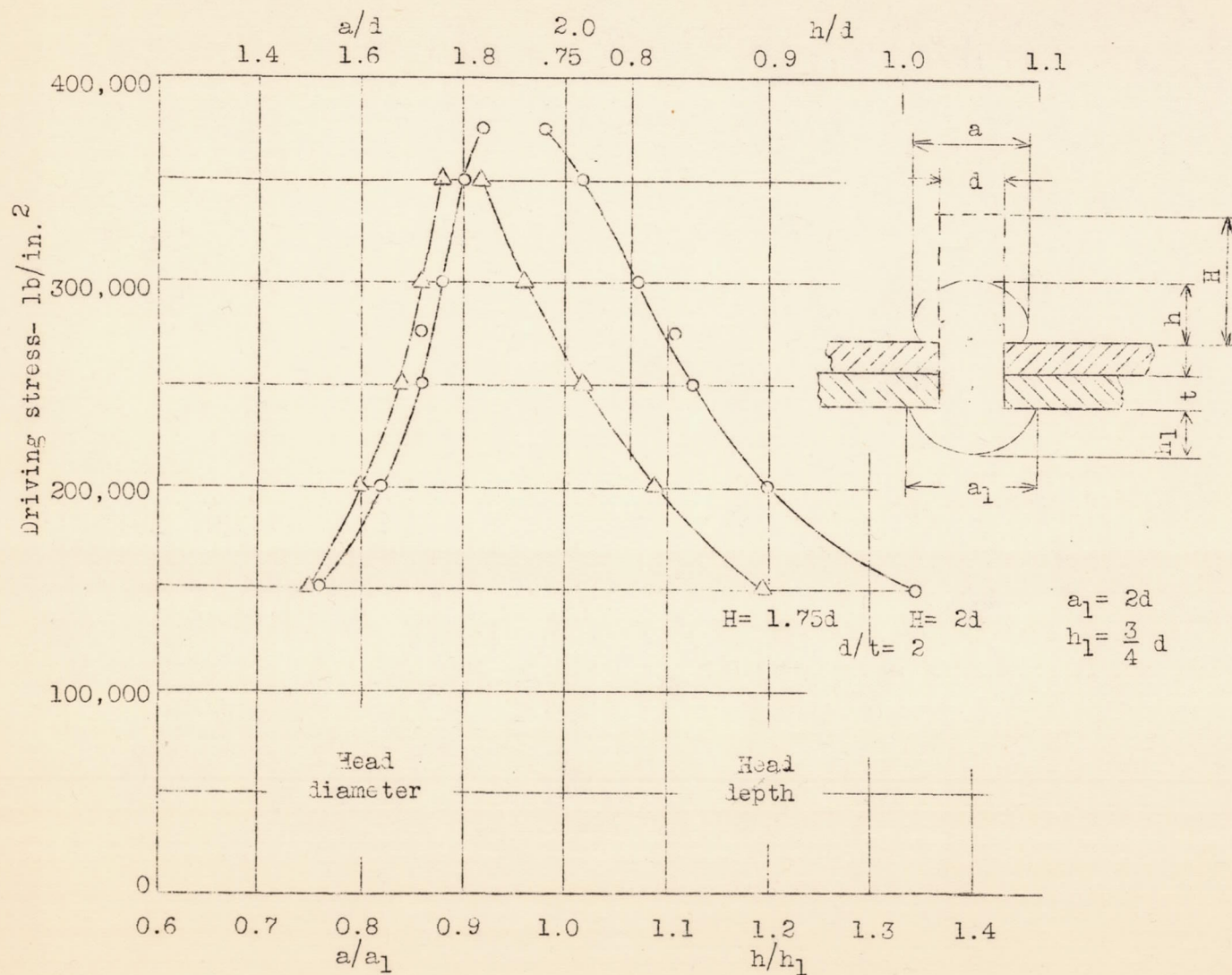


Figure 4.- Dimensions of driven round heads.



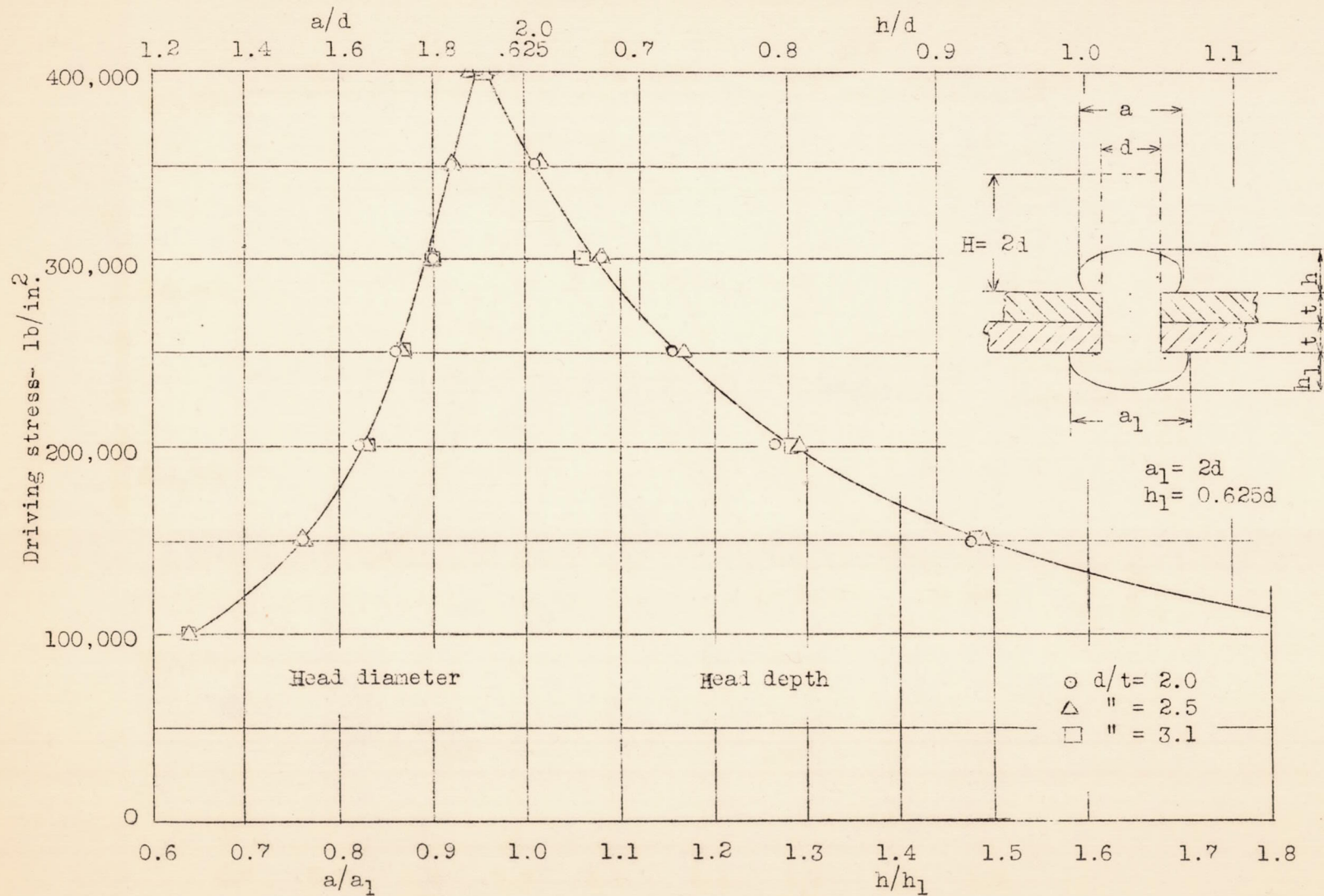


Figure 5.- Dimensions of driven mushroom heads.



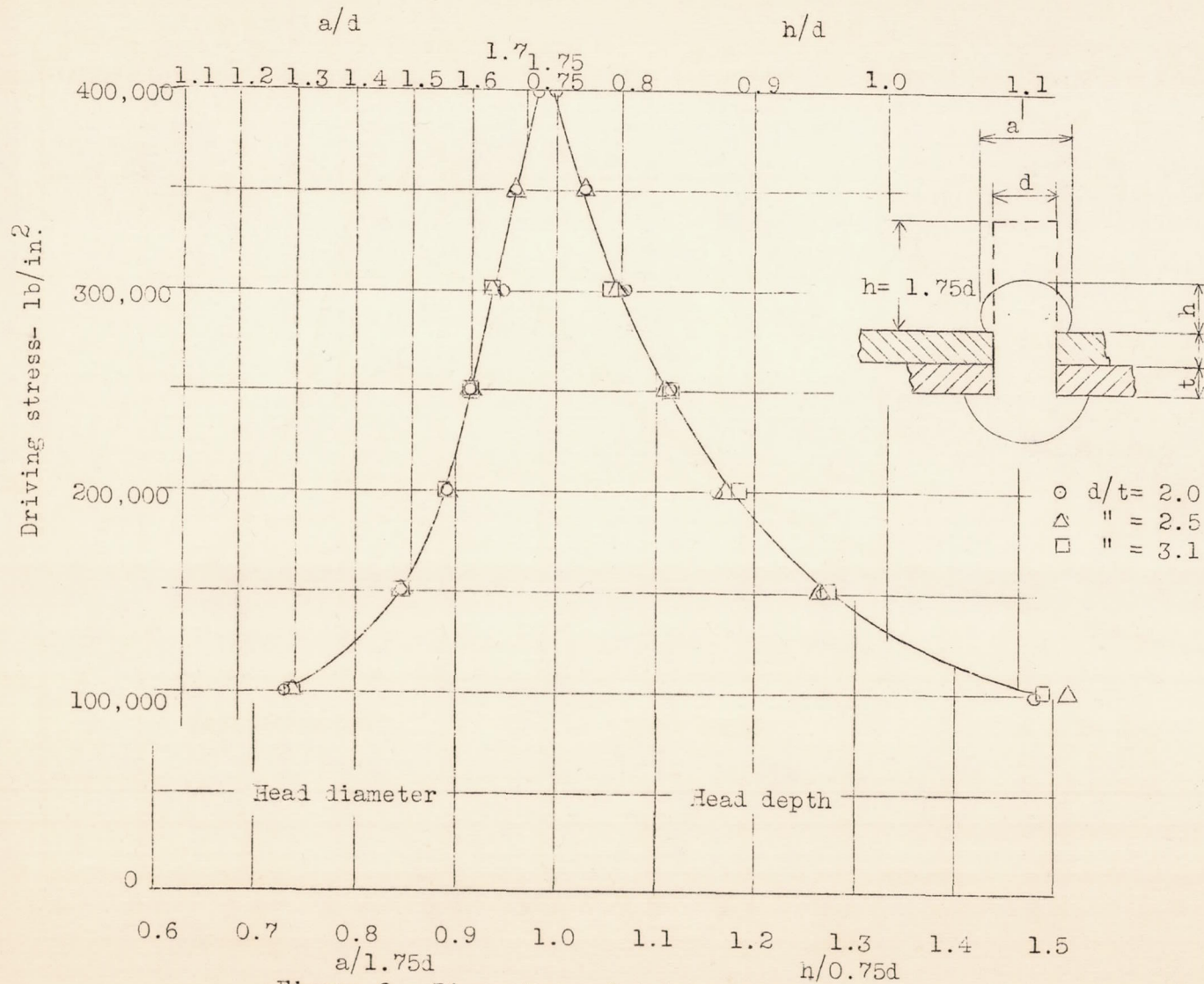


Figure 6.- Dimensions of driven button heads.

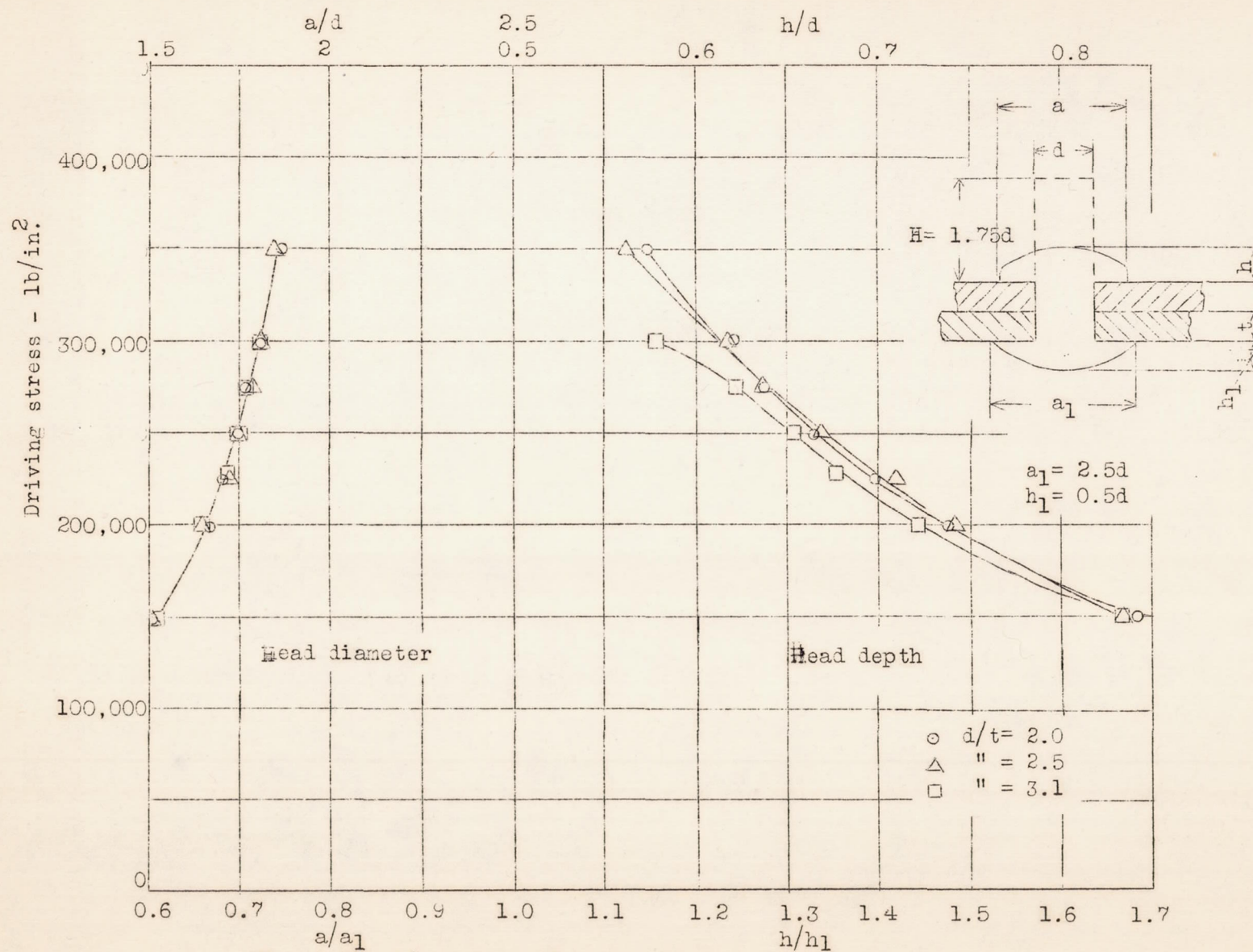


Figure 7.- Dimensions of driven brazier heads.



FIGURE 1. PERCENTAGE OF THE POPULATION WITH ACCESS TO ELECTRICITY AND TELEPHONE.

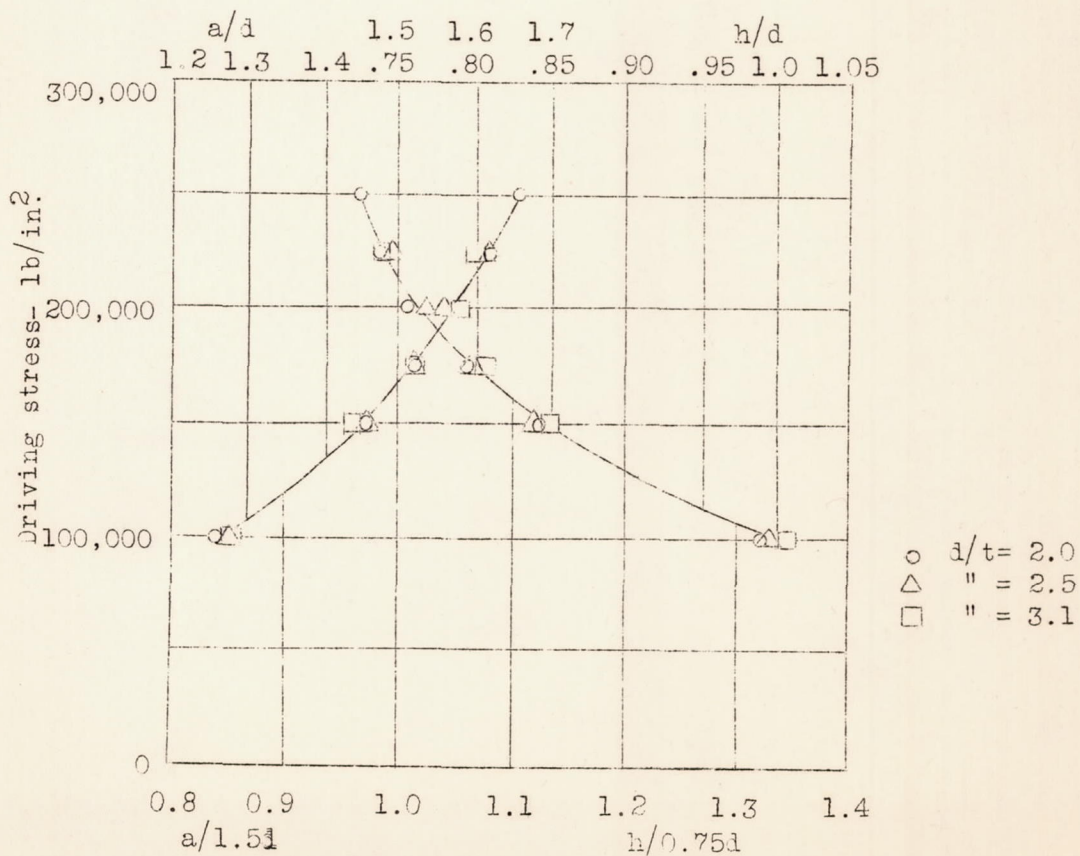
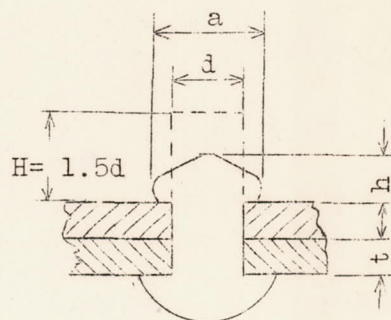


Figure 8.- Dimensions of driven cone-point heads.

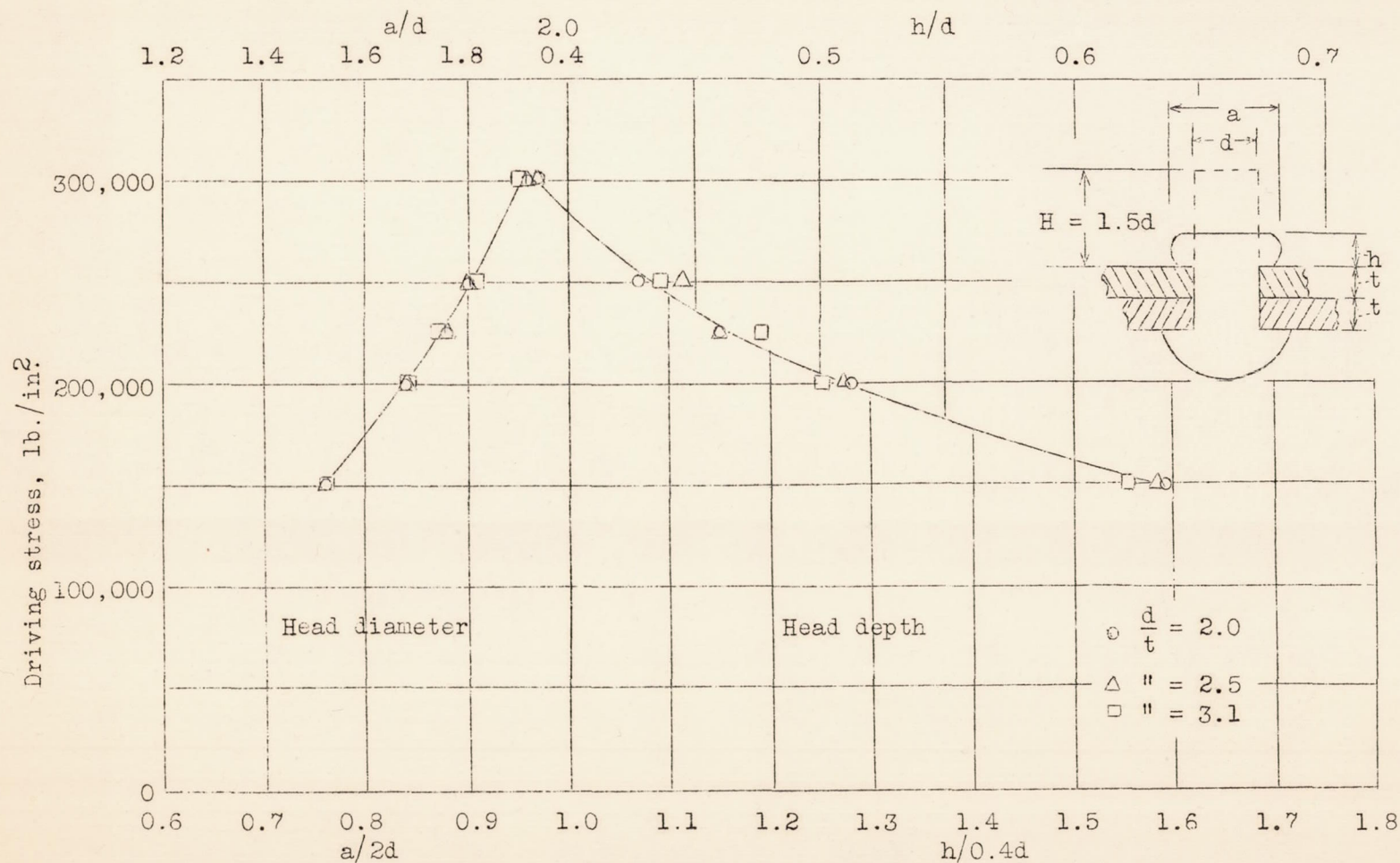


Figure 9.- Dimensions of driven flat heads.

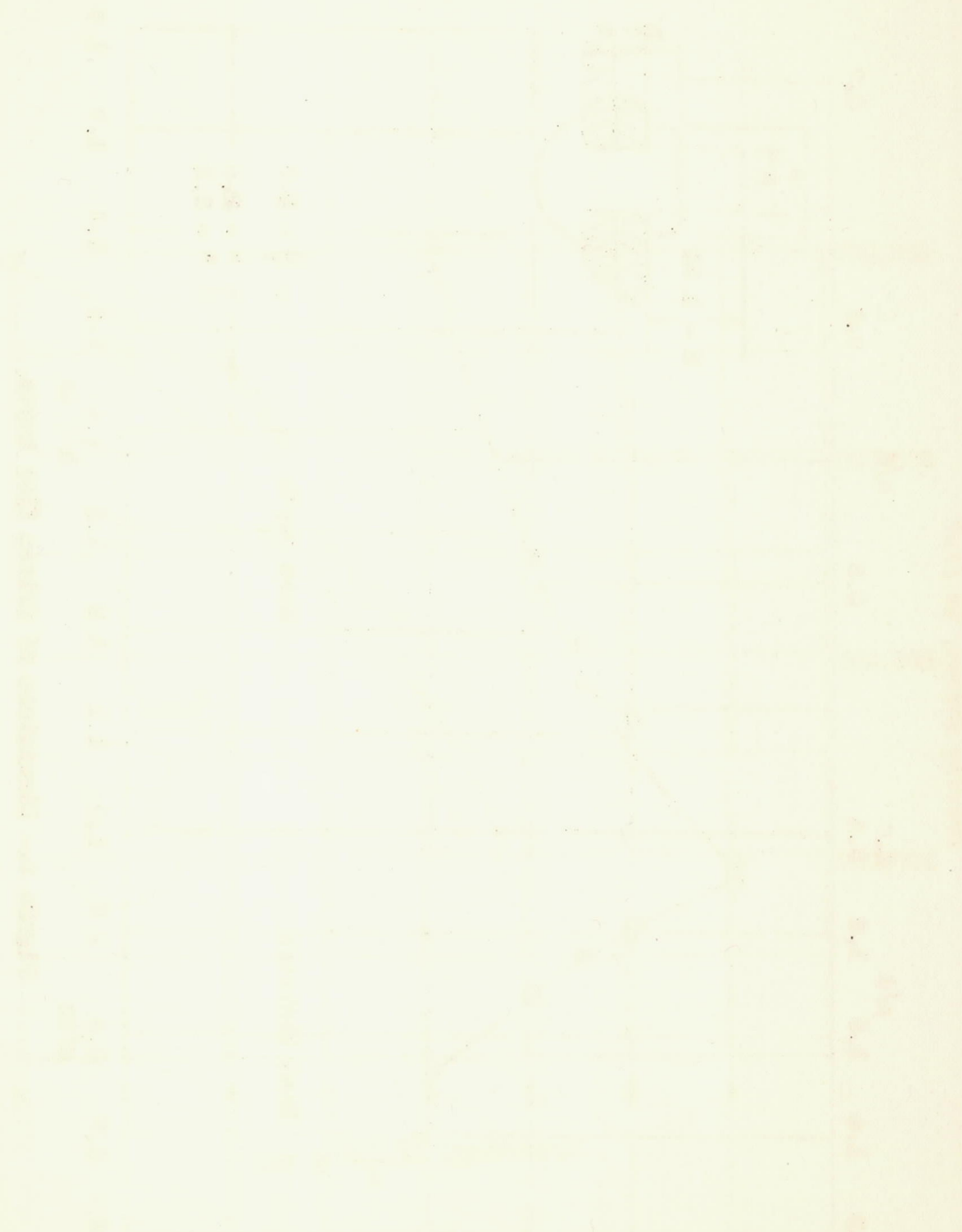
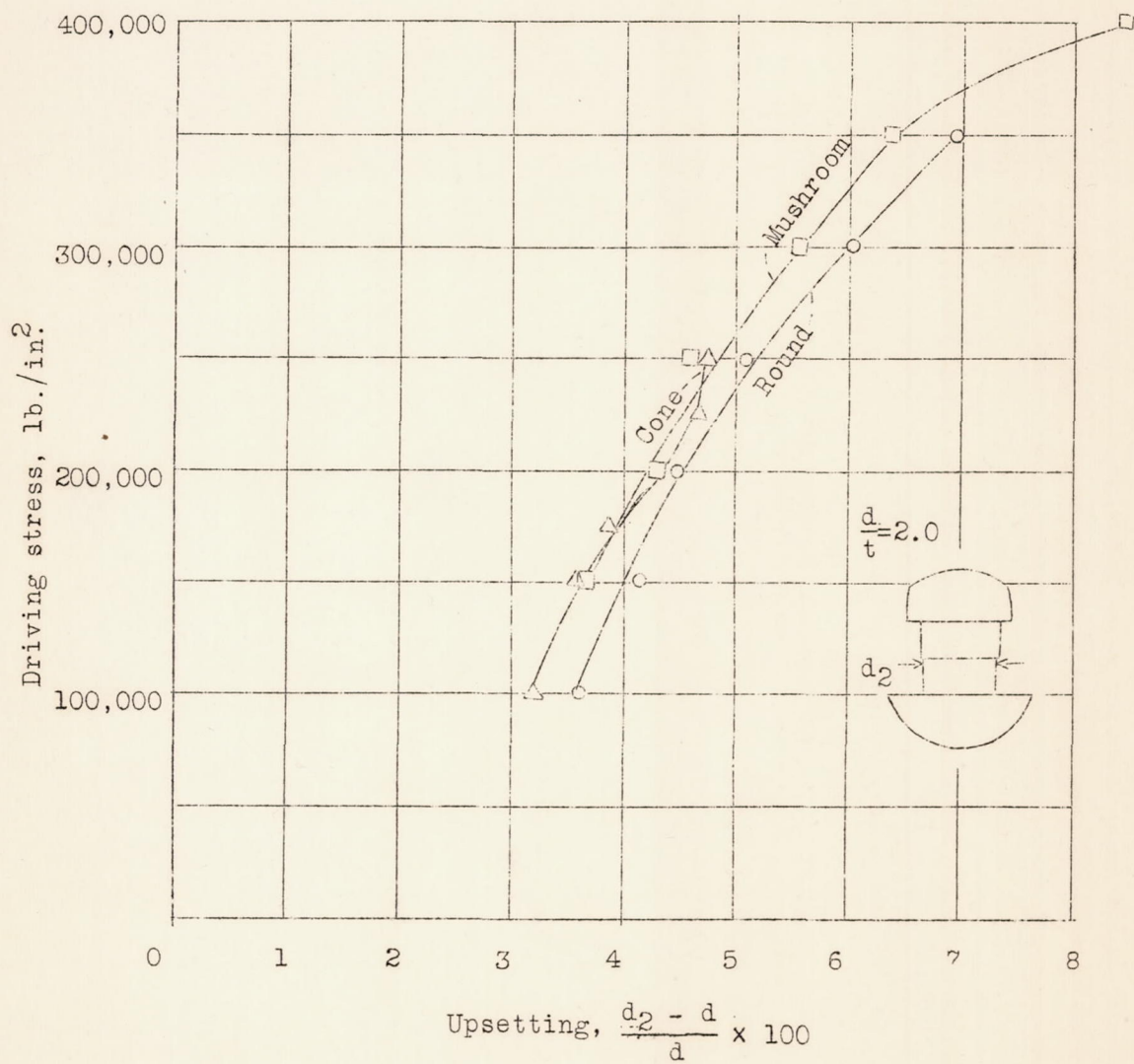
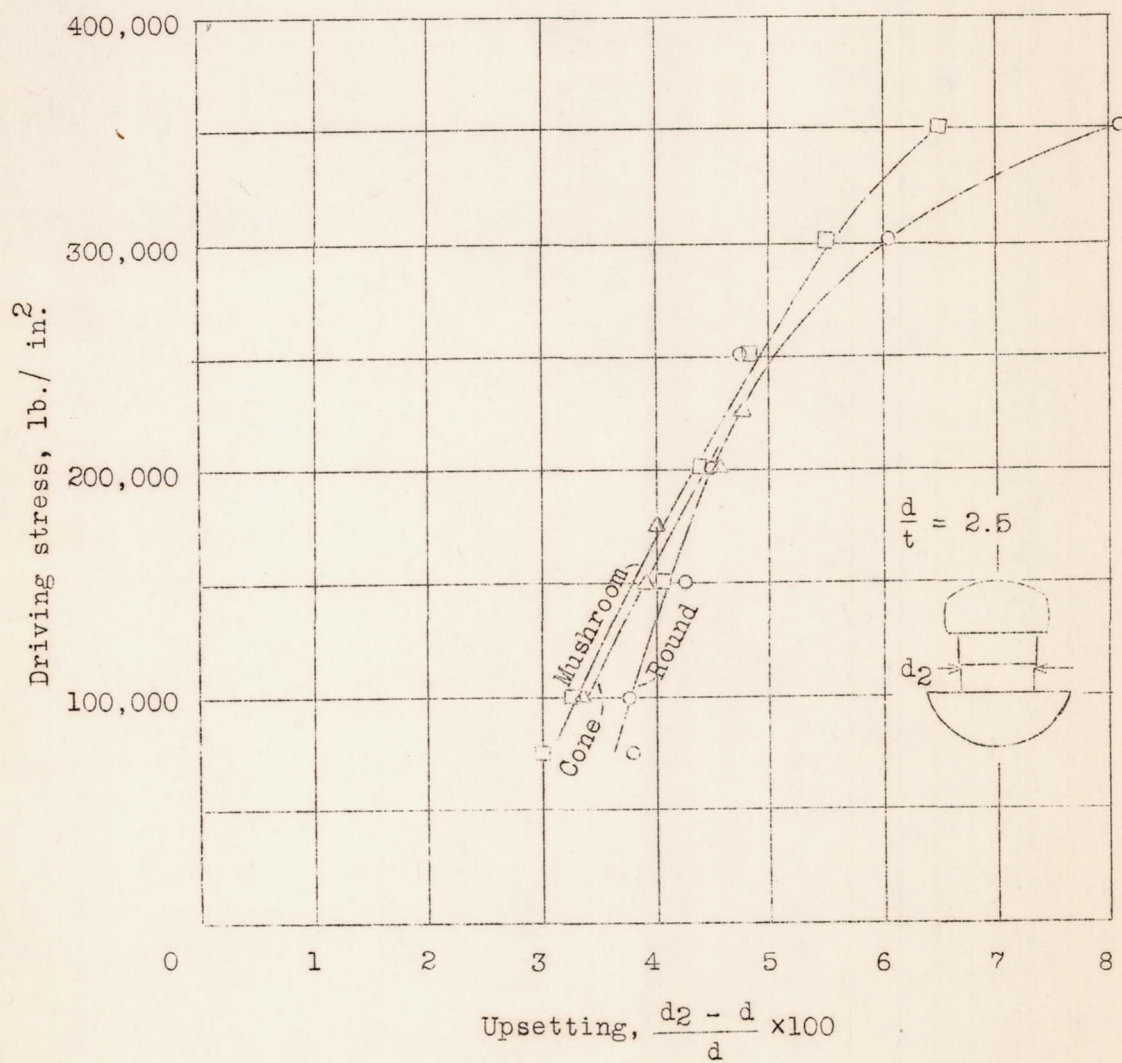
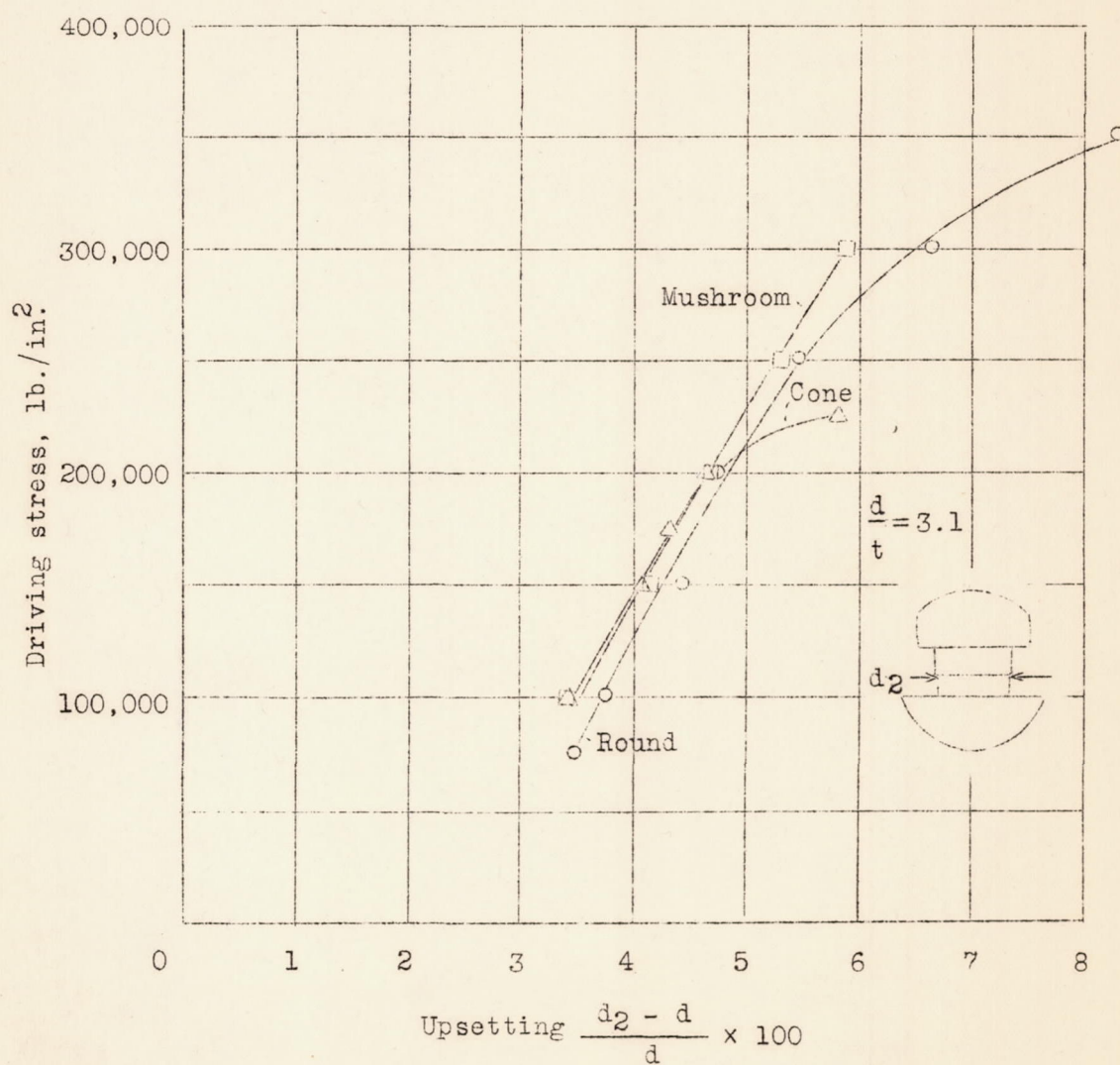


FIGURE 1. A line graph showing the relationship between the x and y variables.

Figure 10.- Upsetting of shank produced by driving, $d/t = 2.0$

Figure 11.- Upsetting of shank produced by driving, $d/t = 2.5$.

Figure 12.- Upsetting of shank produced by driving, $d/t = 3.1$.

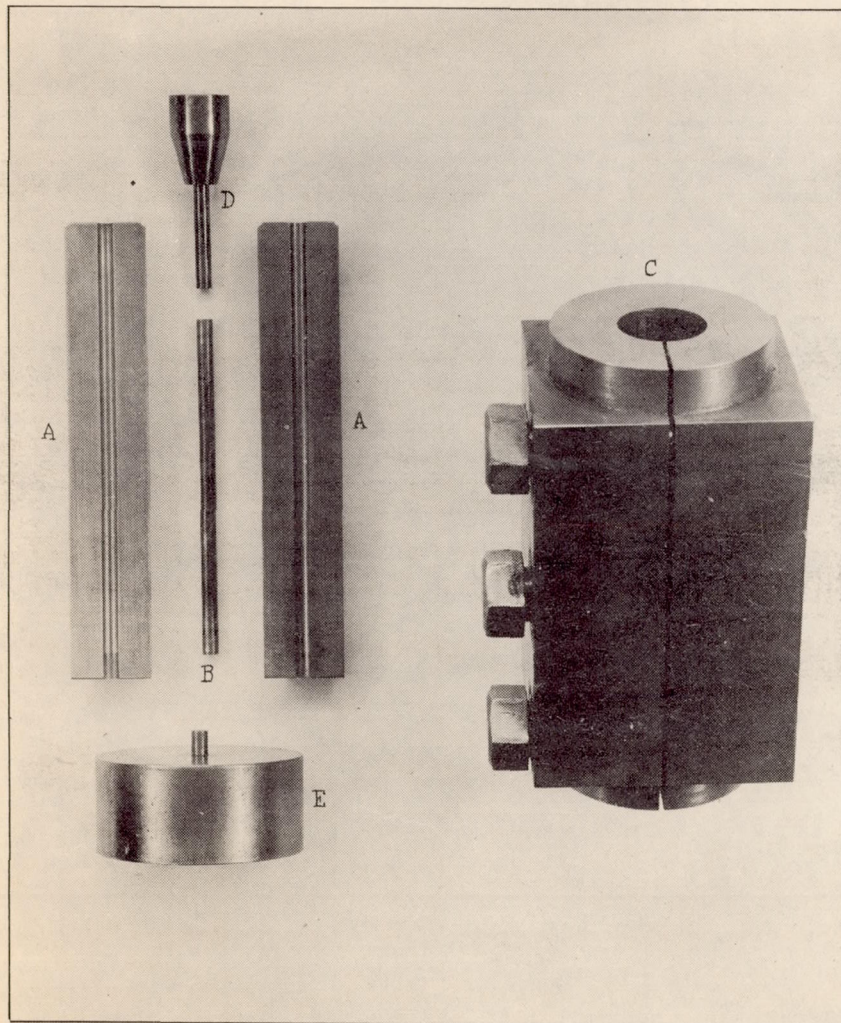


Figure 13.- Fixture for upsetting rivet wire. The inside diameter of the split bushing A is slightly larger than the specimen B; the block C contains a hole in which the bushing is clamped and rests on base E; the load is applied between the plunger D and the base E.

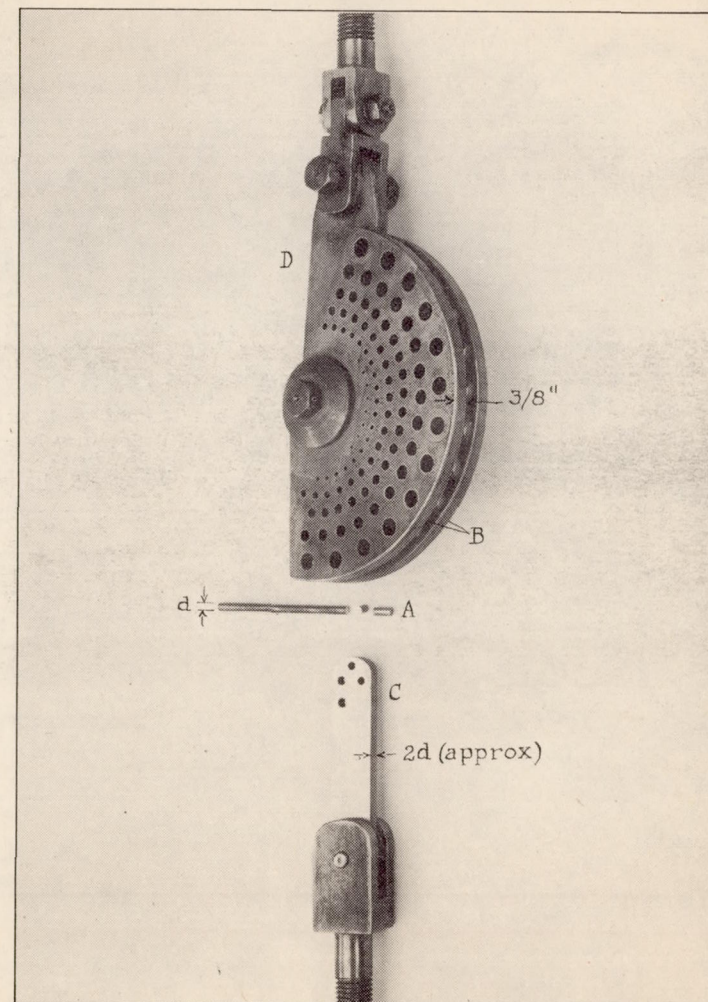


Figure 14.- Double shear fixture for testing rivet wire. The specimen A is inserted in holes in the hardened steel plates B (outer) and C (inner) which are connected to the testing machine. The clearance between the plates is adjusted to approximately $0.05d$ by means of the spacers D. When the cutting edges at the holes become dull they are sharpened by refacing the plates.

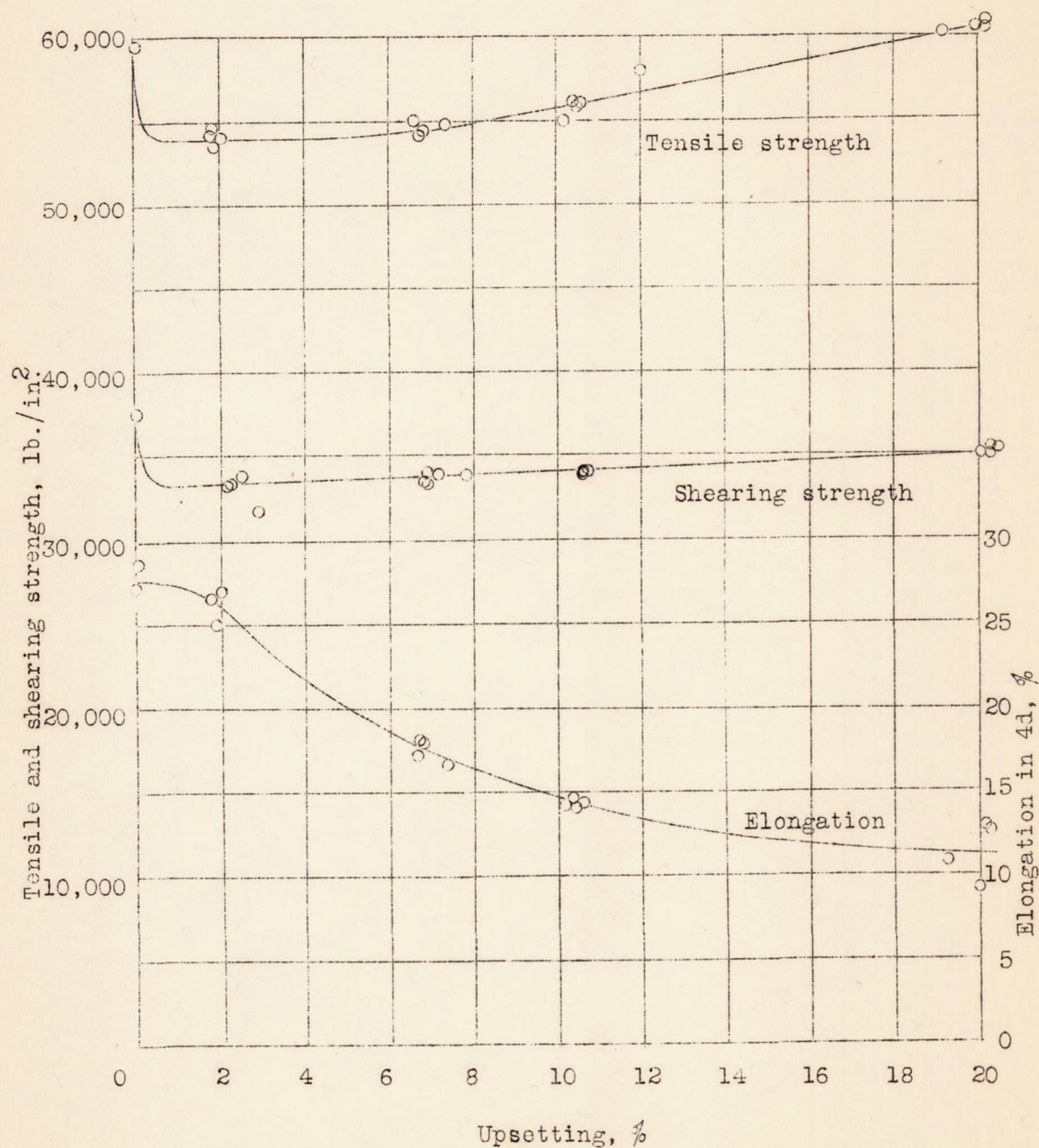


Figure 15.- Effect of upsetting on mechanical properties of heat-treated rivet wire. Specimens were upset immediately after quenching and aged before testing.

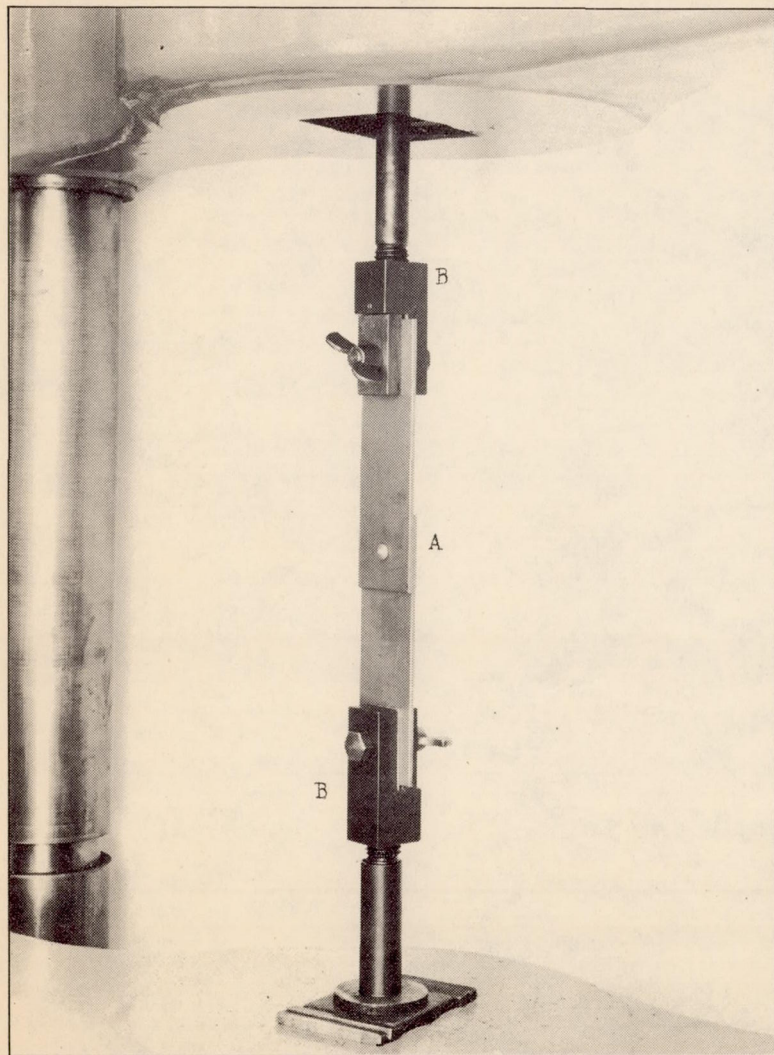


Figure 16.- Single shear specimen of riveted joint.
The loading axis is contained in the
contact surfaces of the specimen A and the blocks B.
These blocks are connected to the testing machine
through spherical bearings.

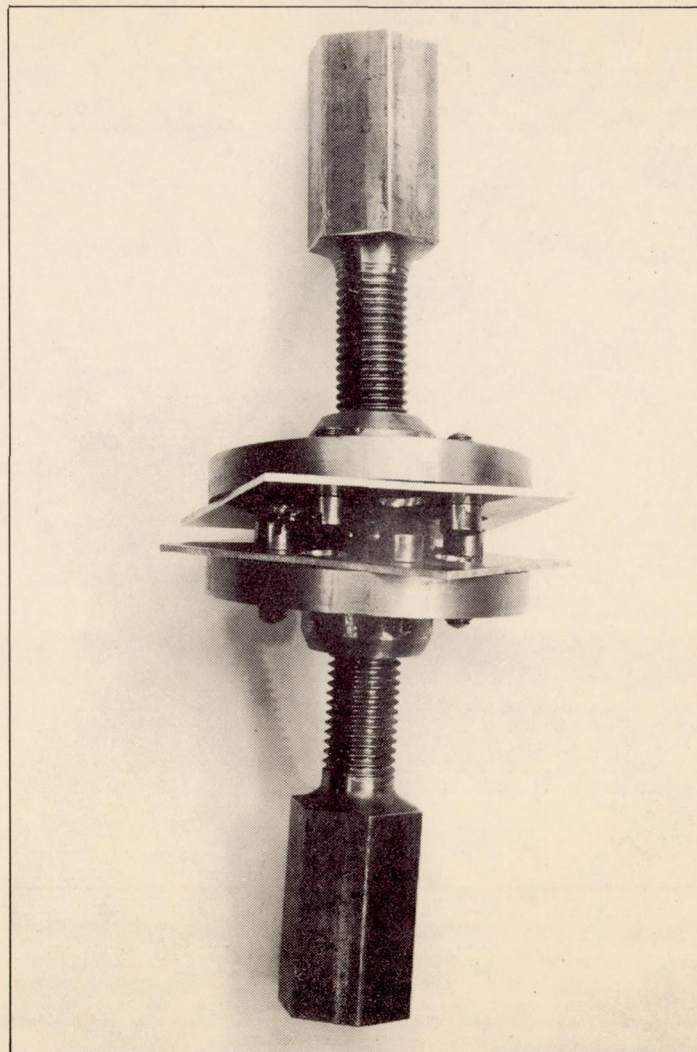


Figure 19.- Fixture for tensile test
of riveted joint.

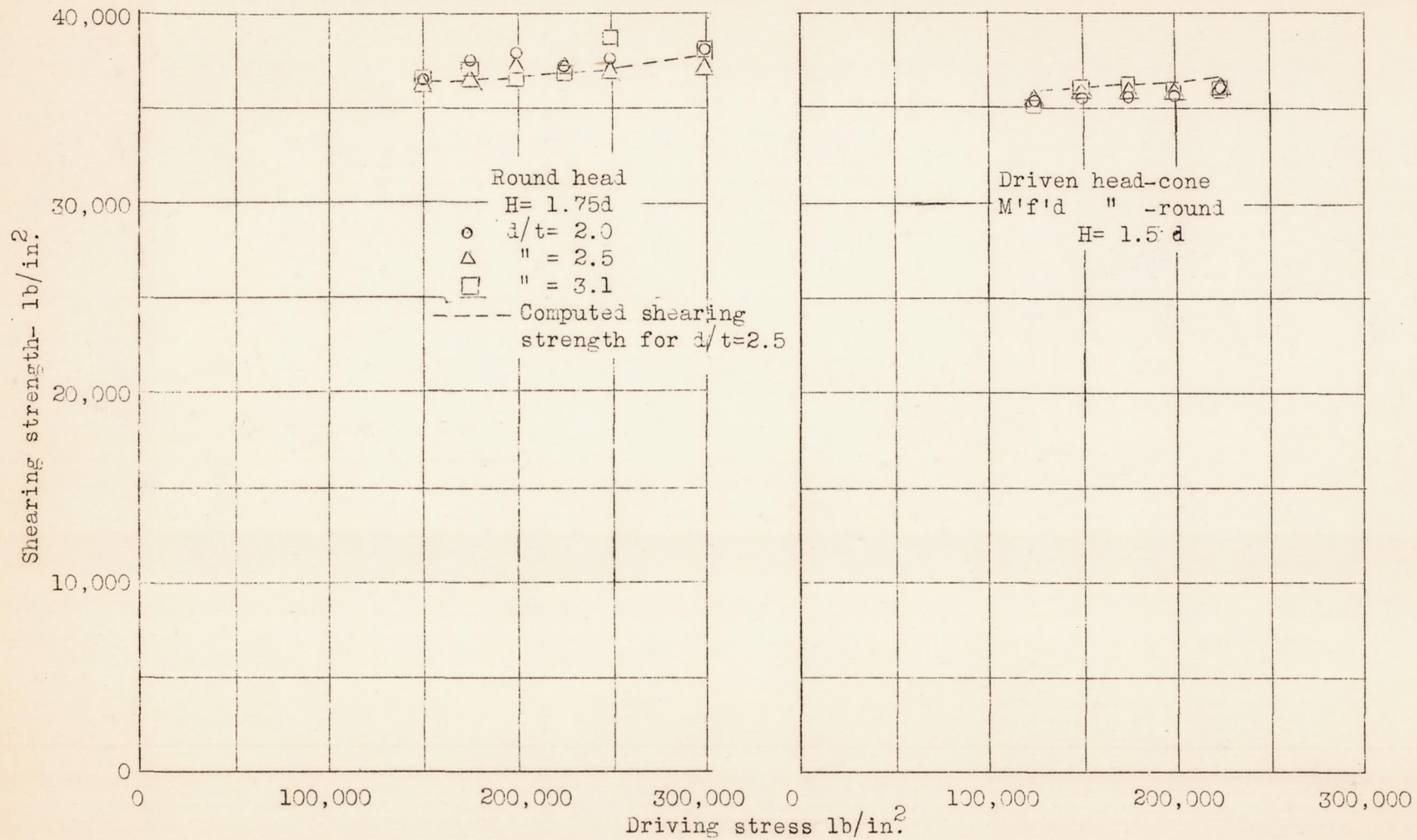


Figure 17.- Strength of round and cone-point head rivets under single-shear loading.

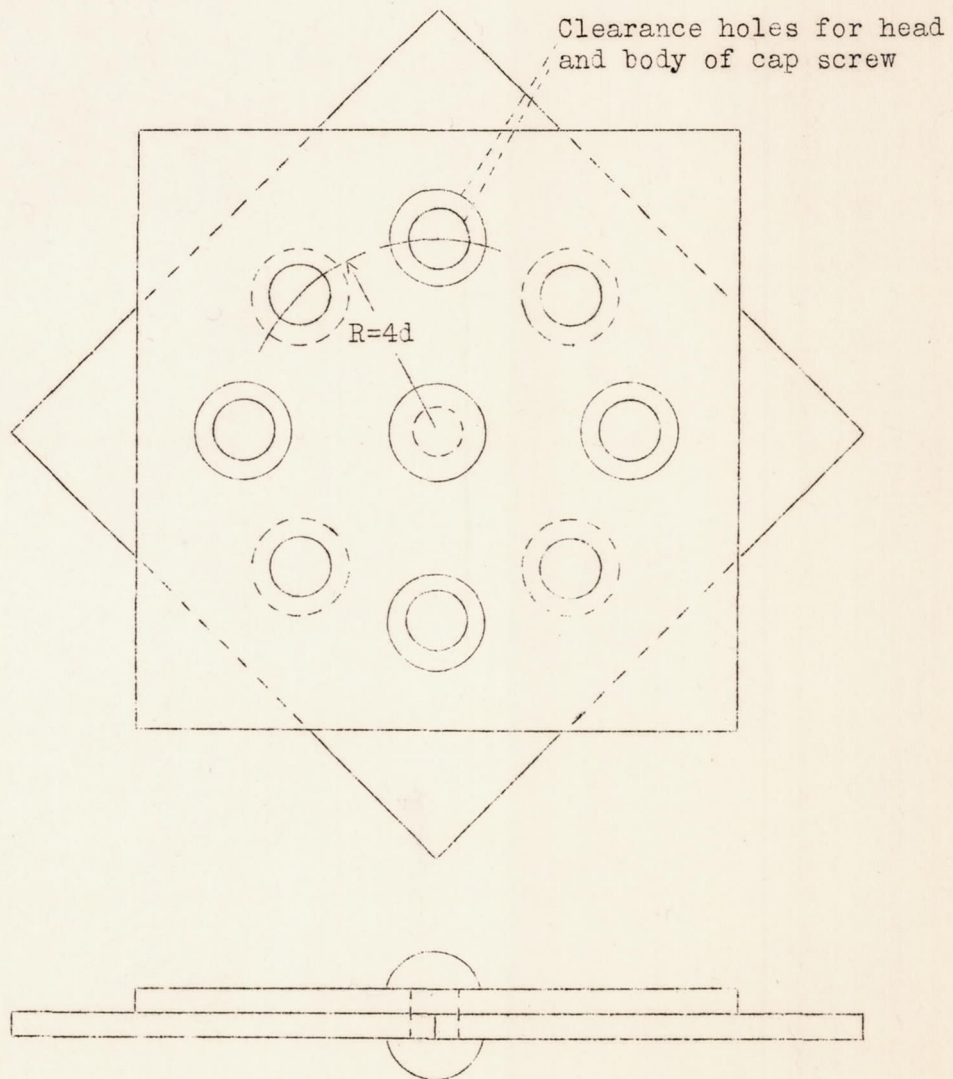


Figure 18.- Tensile specimen of riveted joint.

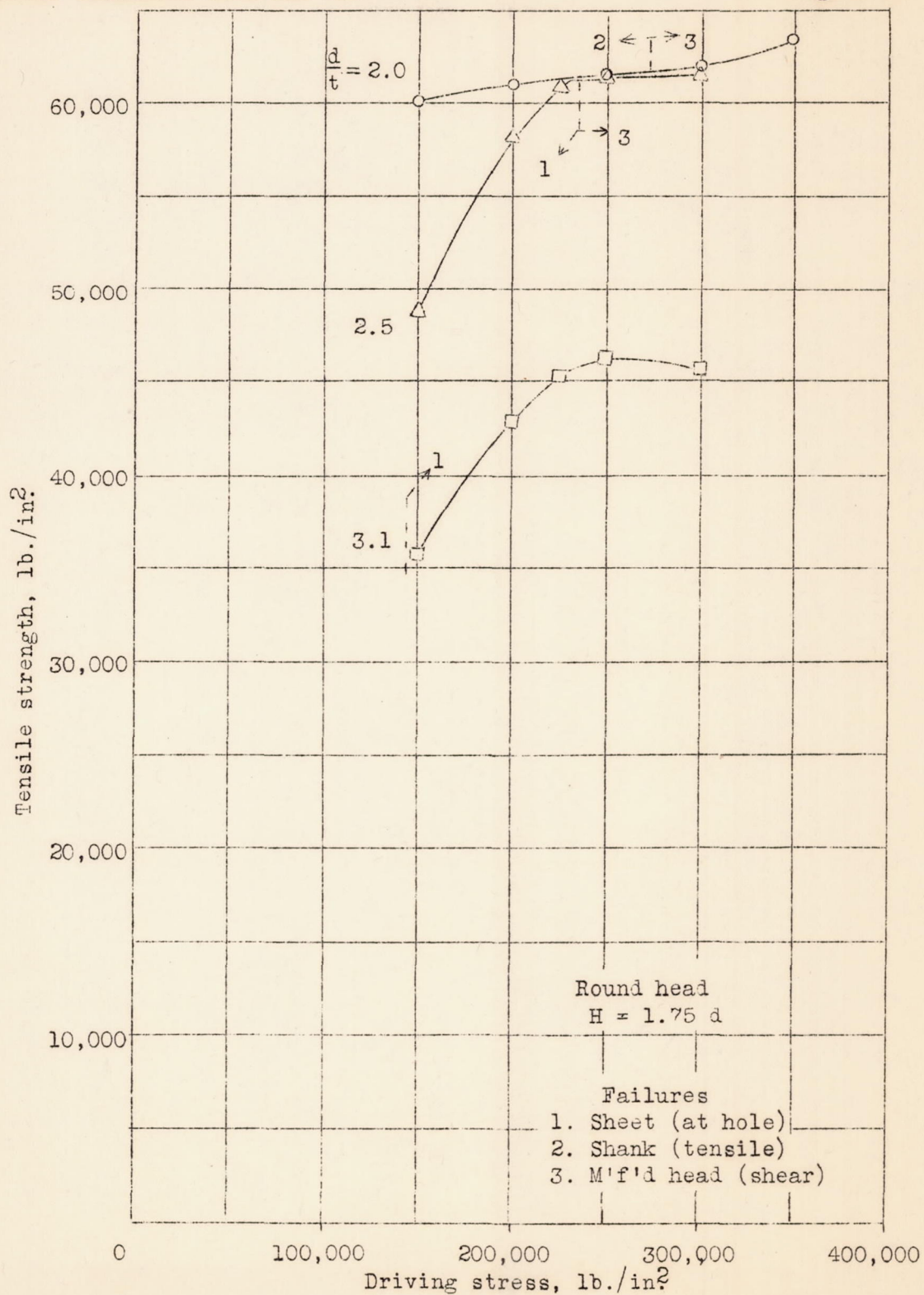


Figure 20.- Tensile strength of round-head rivets.

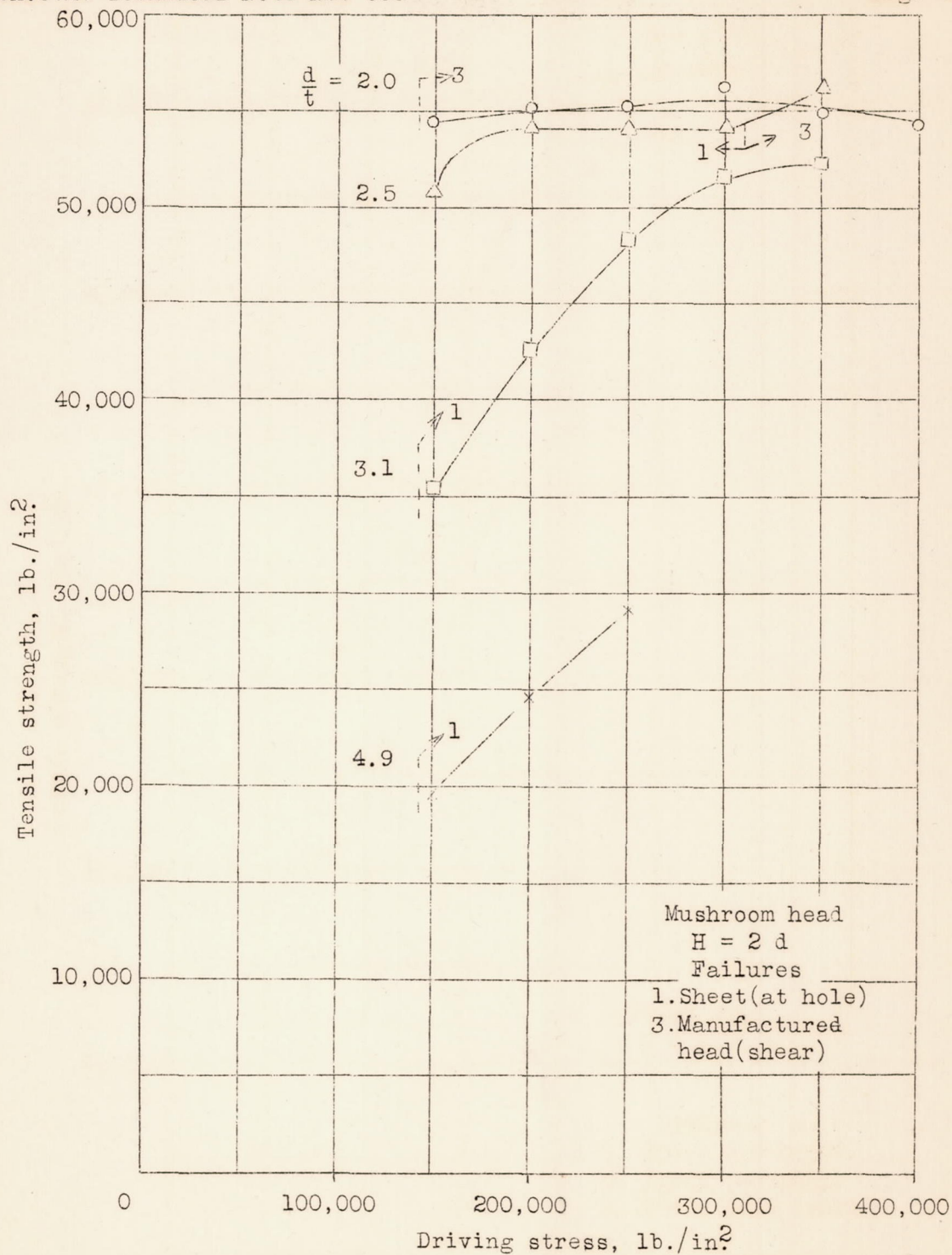


Figure 21.- Tensile strength of mushroom-head rivets.

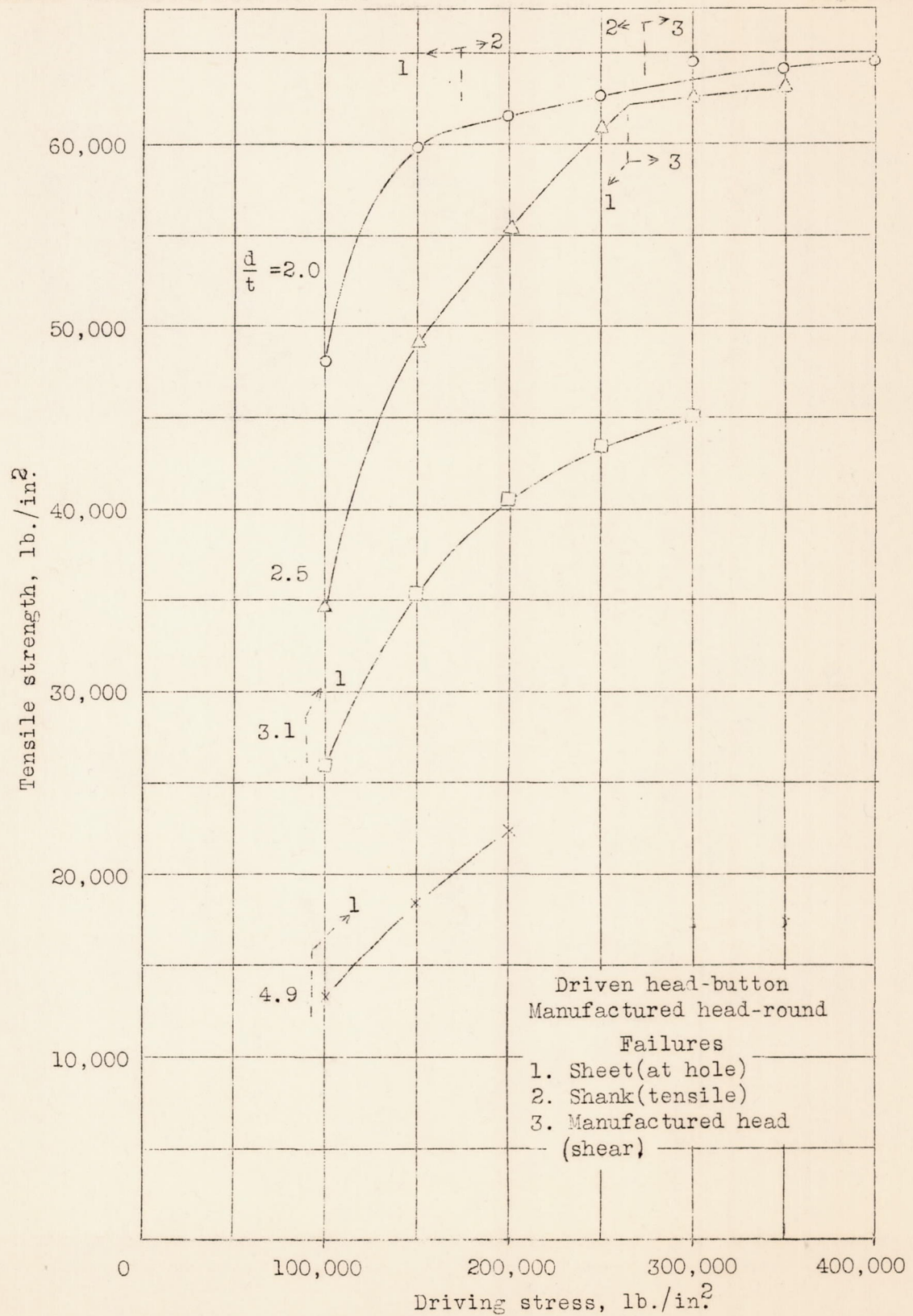


Figure 22.- Tensile strength of button-head rivets.

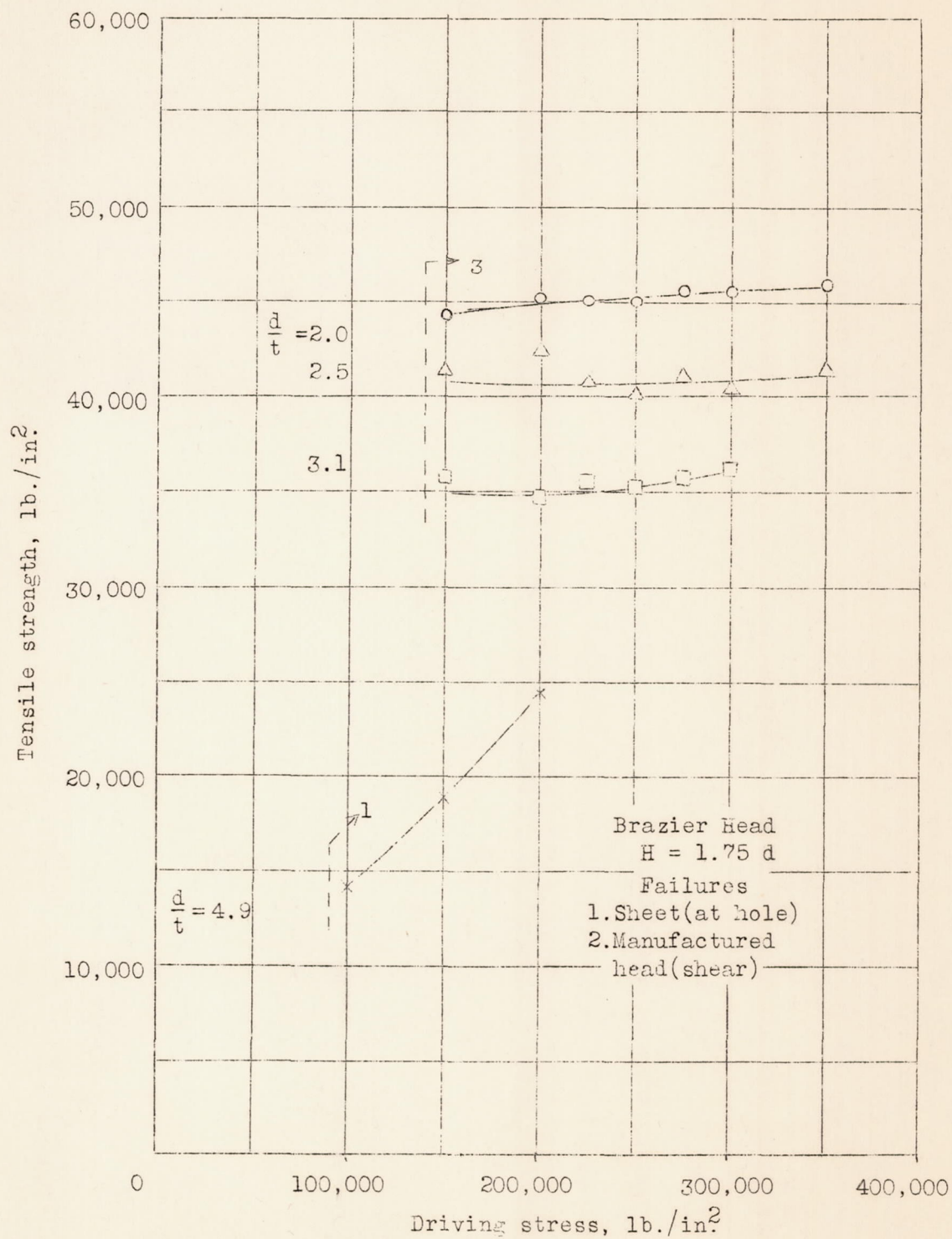


Figure 23.- Tensile strength of brazier-head rivets.

TABLE I		TABLE II	
RESULTS OF TREATMENT		RESULTS OF TREATMENT	
Case No.	Result	Case No.	Result
1	Recovered	11	Recovered
2	Recovered	12	Recovered
3	Recovered	13	Recovered
4	Recovered	14	Recovered
5	Recovered	15	Recovered
6	Recovered	16	Recovered
7	Recovered	17	Recovered
8	Recovered	18	Recovered
9	Recovered	19	Recovered
10	Recovered	20	Recovered
21	Recovered	22	Recovered
23	Recovered	24	Recovered
25	Recovered	26	Recovered
27	Recovered	28	Recovered
29	Recovered	30	Recovered
31	Recovered	32	Recovered
33	Recovered	34	Recovered
35	Recovered	36	Recovered
37	Recovered	38	Recovered
39	Recovered	40	Recovered
41	Recovered	42	Recovered
43	Recovered	44	Recovered
45	Recovered	46	Recovered
47	Recovered	48	Recovered
49	Recovered	50	Recovered
51	Recovered	52	Recovered
53	Recovered	54	Recovered
55	Recovered	56	Recovered
57	Recovered	58	Recovered
59	Recovered	60	Recovered
61	Recovered	62	Recovered
63	Recovered	64	Recovered
65	Recovered	66	Recovered
67	Recovered	68	Recovered
69	Recovered	70	Recovered
71	Recovered	72	Recovered
73	Recovered	74	Recovered
75	Recovered	76	Recovered
77	Recovered	78	Recovered
79	Recovered	80	Recovered
81	Recovered	82	Recovered
83	Recovered	84	Recovered
85	Recovered	86	Recovered
87	Recovered	88	Recovered
89	Recovered	90	Recovered
91	Recovered	92	Recovered
93	Recovered	94	Recovered
95	Recovered	96	Recovered
97	Recovered	98	Recovered
99	Recovered	100	Recovered

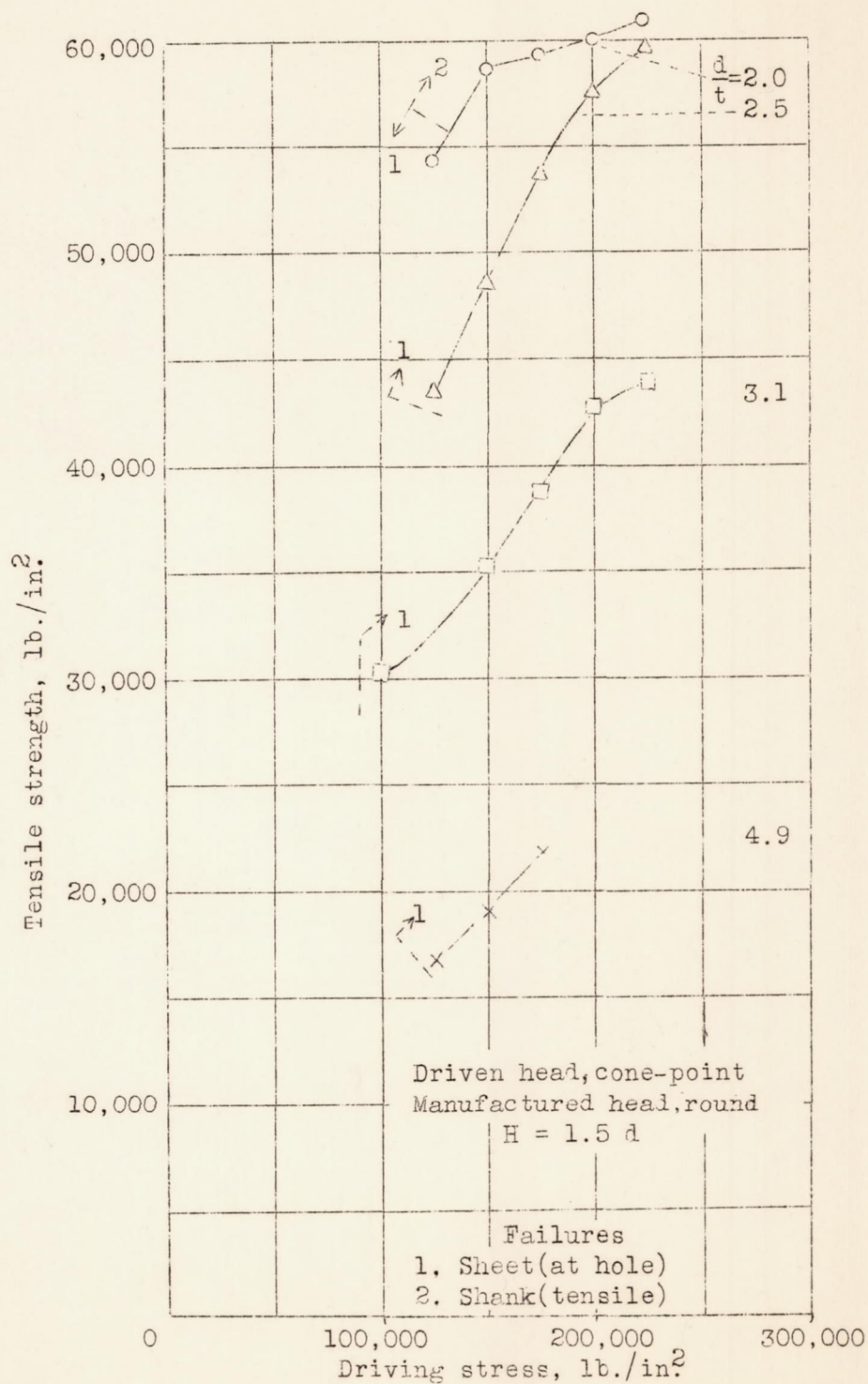


Figure 24.- Tensile strength of cone-point head rivets.

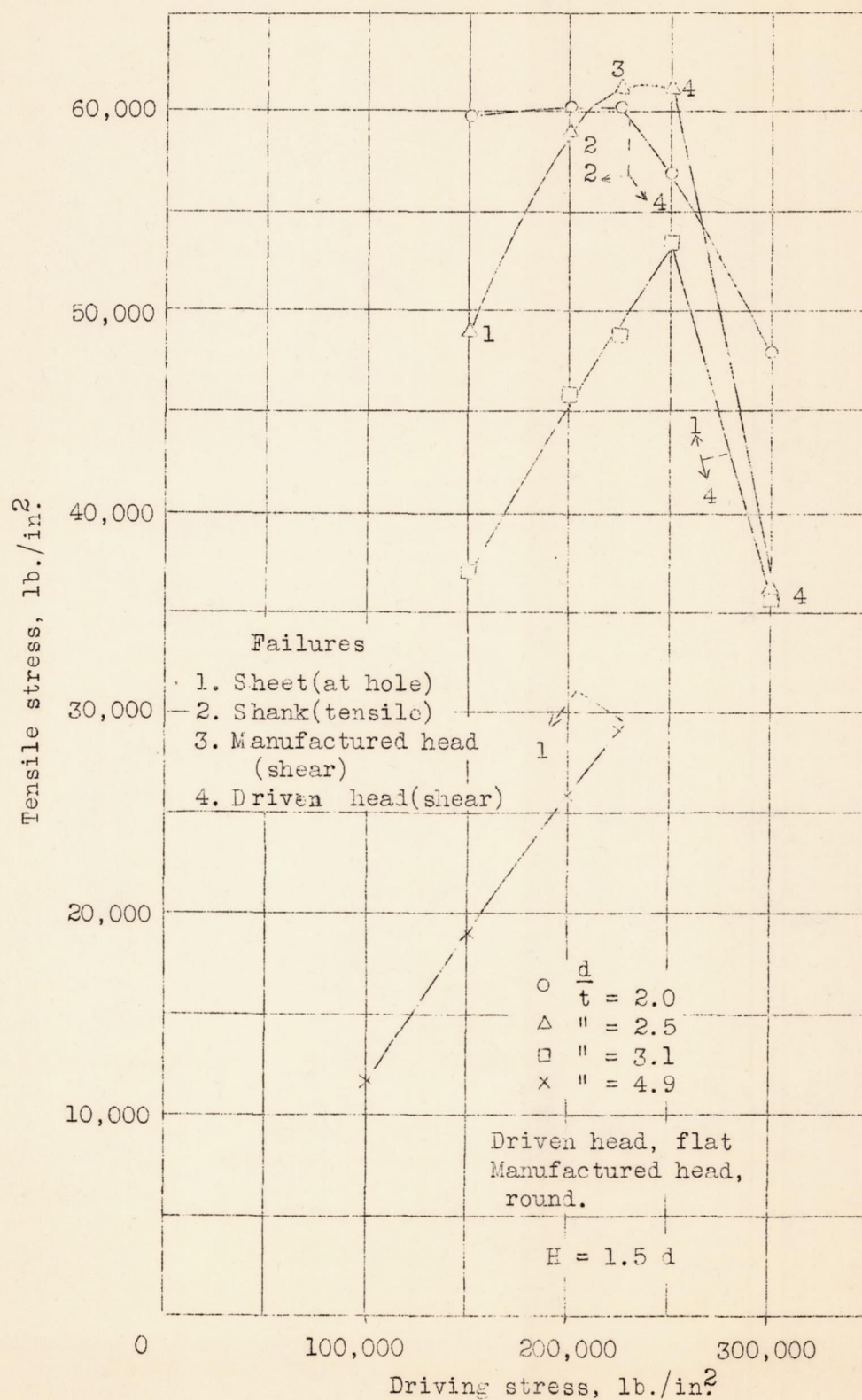


Figure 25.- Tensile strength of flat-head rivets.

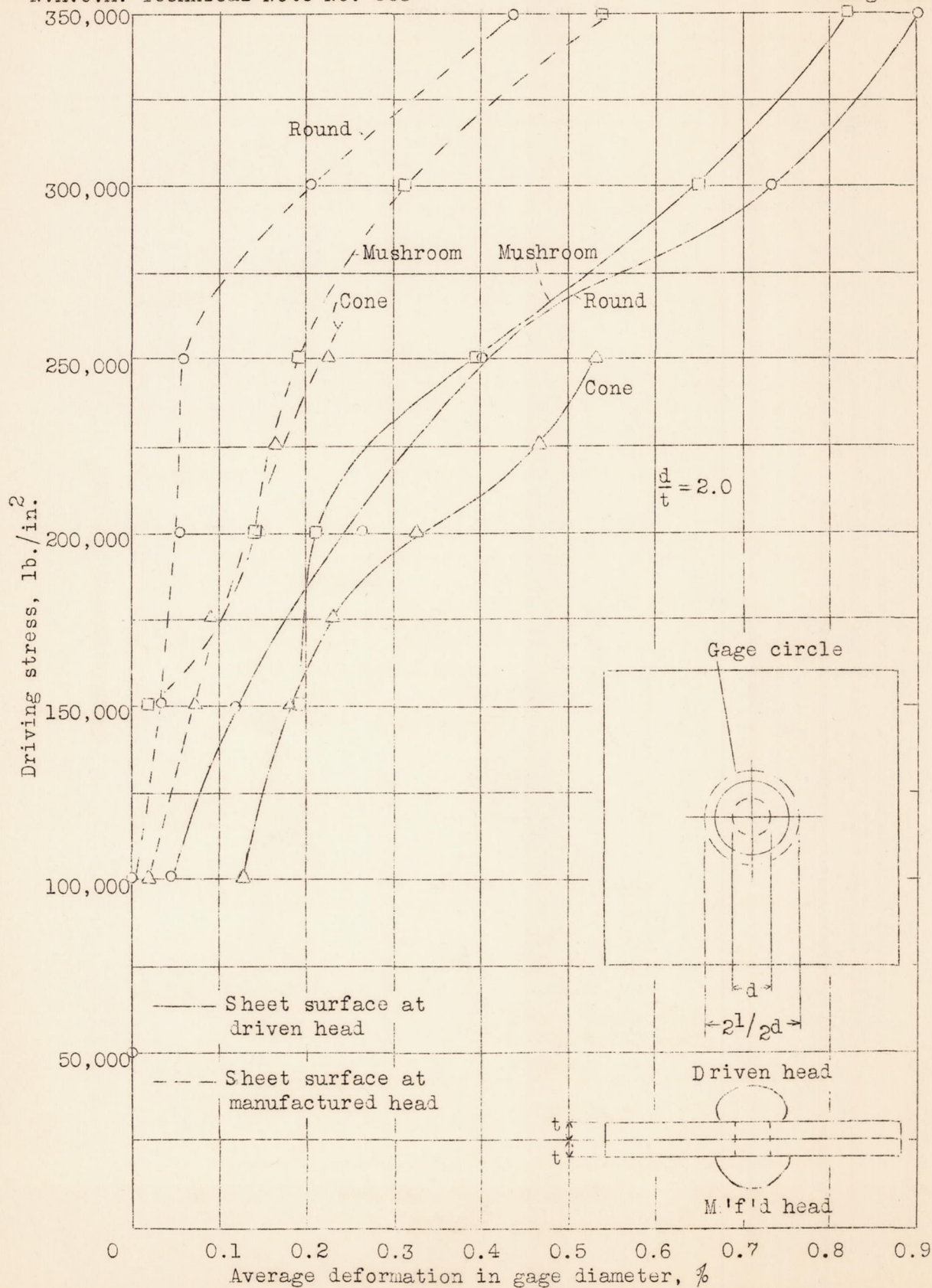


Figure 26.- Radial deformation produced in sheets by driving rivets, $d/t = 2.0$.

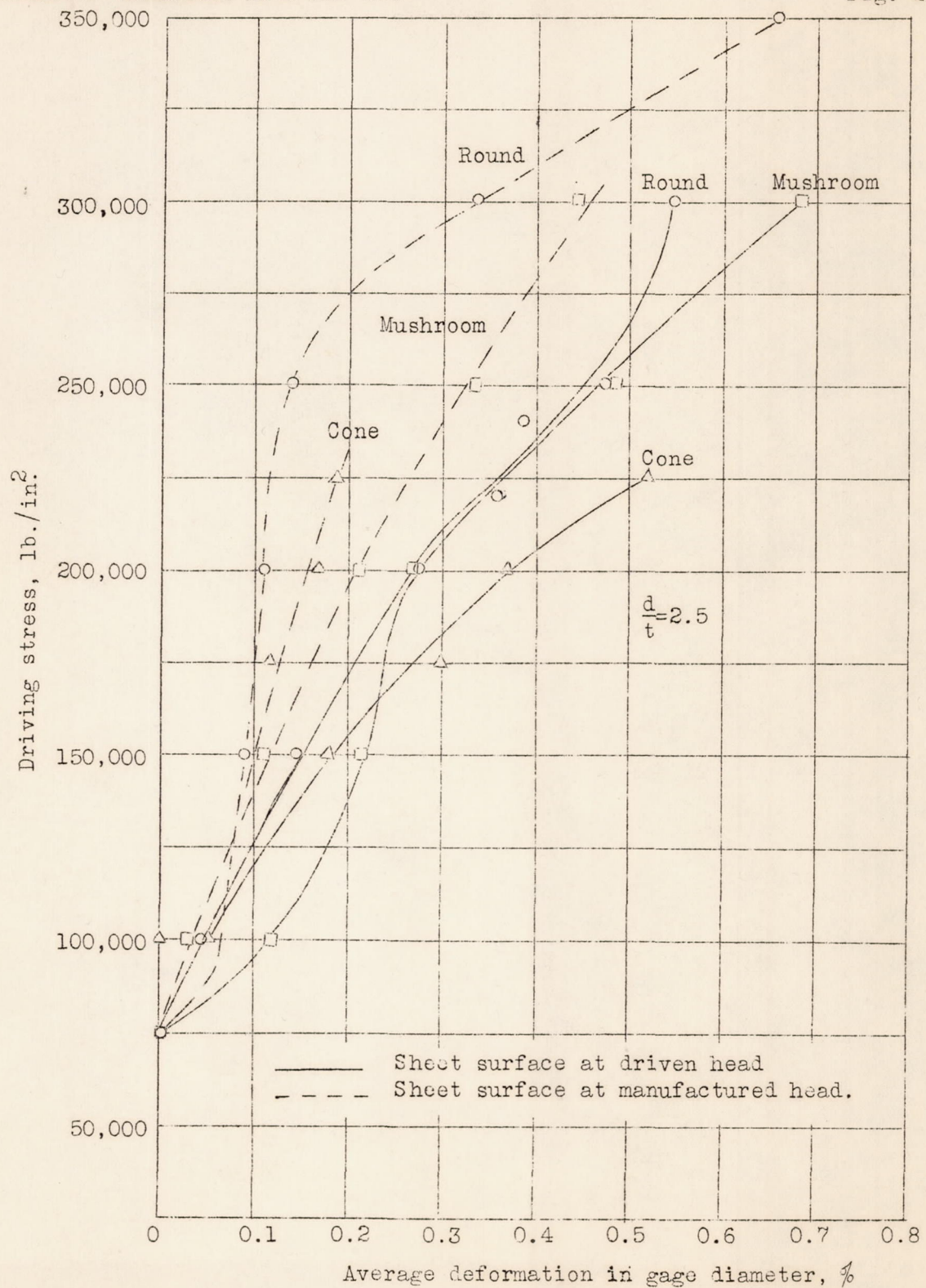


Figure 27.- Radial deformation produced in sheets by driving rivets, $d/t = 2.5$.



Figure 10 - Graph showing the relationship between the variables X and Y. The graph is plotted on a grid with X-axis ranging from 0.0 to 10.0 and Y-axis ranging from 0.00 to 10.00. The lines represent different data series labeled A through Z. The lines generally trend upwards from left to right, with some showing a more pronounced curve or change in slope.

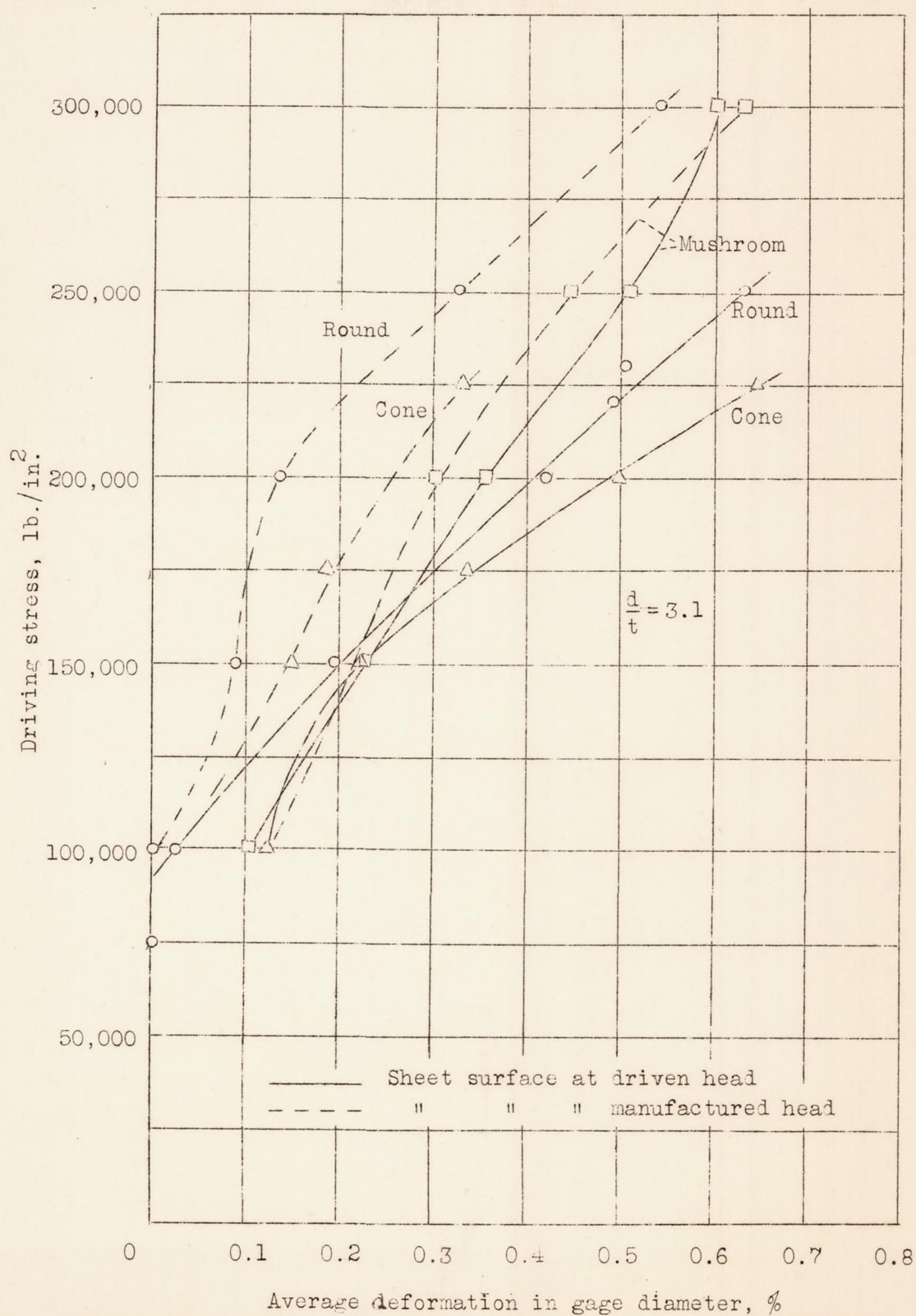


Figure 28.- Radial deformation produced in sheets by driving rivets,
 $\frac{d}{t} = 3.1$