TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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THE COMPRESSIVE YIELD STRENGTH OF EXTRUDED SHAPES OF 24ST ALUMINUM ALLOY

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SUMMARY

Tests were made by the Aluminum Company of America on 267 extruded shapes of 24ST aluminum alloy selected at random from plant production to determine the relations between the compressive yield strength and the tensile properties of the material. The samples were divided into three classes according to thickness: less than 0.250 inch, from 0.250 to 1.499 inches; and 1.500 inches and over. Ratios were computed for the three classes by which the compressive yield strength could be estimated from either the tensile strength or the tensile yield strength. The assumption that the compressive yield strength is equal to the tensile yield strength was found to be fairly accurate for the thicknesses 1.500 inches and over, not seriously in error for thicknesses from 0.250 to 1.499 inches, but unsatisfactory for the sections less than 0.250 inch.

INTRODUCTION

Navy Department specification 46A9c and Federal specification QQ-A-354 require extruded shapes of 24ST aluminum alloy to have tensile yield strengths not less than certain minimum values that are dependent upon the thickness of the shape. Minimum compressive yield strengths, although perhaps more important to the engineer than minimum tensile yield strengths, are not specified because they are too difficult to determine to be included in routine inspection tests and are not needed for the control of quality. In the absence of specific information concerning compressive yield strengths, it has been common practice in the past to assume that the compressive yield strength was equal to the tensile yield strength, even though it was generally understood that materials which are straightened by stretching usually have compressive yield strengths lower than their tensile yield strengths. Preliminary tests disclosed that the difference between compressive and tensile yield strengths might be large enough to require attention in design, and it was decided to undertake a complete investigation involving a large number of samples selected at random from the general run of commercial production. The timely development of the "pack" method for determining compressive yield strengths of thin sections was an important factor in making this investigation possible. (See reference 1.)

The data upon which this report is based were discussed at a conference with representatives of several government agencies in Washington, D. C., last August. Since that time further study of the data has been made and certain considerations are presented herein that were not included in that discussion.

The object of this investigation was to determine the tensile and the compressive properties of a large number of 24ST extruded shapes selected at random from commercial production in order to investigate the interrelation of these properties. It was believed that through such an investigation a reliable method could be devised by which compressive yield strengths could be accurately estimated from tensile properties, thereby eliminating the need for elaborate expensive routine compression tests.

PROCEDURE

A total of 267 extruded shapes of 24ST aluminum alloy were selected over the period from December 1938 to August 1939. These samples represented a wide variety of shapes and sizes, as indicated in figures 1 to 5. One tensile and one compressive specimen were taken from each shape in the longitudinal direction. The tensile specimens were of the type used for testing sheet (reference 2, fig. 7) when the section thickness was less than 1/2 inch and were of the round type (reference 2, fig. 9) when the section thicknesses were 1/2 inch and greater. The compressive specimens were of the pack type (reference 1) when the section thicknesses were less than 0.243 inch and were 5/8 inch wide solid rectangular blocks when the thicknesses were in the range from 0.243 inch to 0.719 inch. For thicker sections the compressive specimens were solid rounds. In all cases the tension and the compression specimens were cut from the same part of the section and from adjacent portions of the piece.

The tensile and the compressive tests were made in the usual manner; all pack compression tests and a few of the other tests were made at the Aluminum Research Laboratories while the rest were made at the New Kensington Works laboratory.

RESULTS AND DISCUSSION

All the test data were tabulated and arranged in order of increasing thickness of the portion of the section from which the specimens were cut. There was some duplication of sections and the same die number appeared more than once because pieces made from the same die were selected at different times during the 9 months that the tests were being made.

Table I shows a summary of the tensile and the compressive properties arranged to show minimum, average, and maximum values for each of the three specification ranges of size, as well as for the group as a whole. This table also shows a comparison of the lowest tensile test results with the specified minimum values. It is clear that all the specimens selected for these tests gave results above the specified minimum values.

Figures 6, 7, and 8 show the individual tensile strengths, tensile yield strengths, and compressive yield strengths, respectively, plotted against thickness of section. In all cases there is an upward trend of the data with increasing thickness with a marked leveling off for thicknesses in excess of about 1-1/2 inches. This trend, of course, is consistent with that of the specified minimum tensile properties. In figures 6 and 7 heavy dotted horizontal lines have been drawn to represent the present specified minimum tensile properties for the three ranges of size. The lines drawn in figure 8 will be discussed later.

It is evident from a study of table I and a comparison of figures 7 and 8 that the compressive yield strengths of 24ST extruded shapes are definitely and consistently lower than the tensile yield strenghts, especially for thicknesses less than 1-1/2 inches. In order to study this relation further, the ratios of compressive yield strength to tensile yield strength were calculated for all cases; the results are plotted on a frequency basis in figure 9. These same ratios are plotted separately for each of the specification ranges of size in figures 10 and 11. These curves show that the most probable values of the ratio of compressive to tensile yield strength are as follows:

Thicknesses less than 0.250 inch 0.88

Thicknesses 0.250 inch to 1.499 inches . . 0.91

Thicknesses 1.500 inches and over 0.96

In a previous investigation based on tests of only 11 24ST shapes ranging in thickness from 0.05 inch to 0.38 inch, the average ratio of compressive to tensile yield strength was found to be 0.85 with a scatter from 0.78 to 1.03. This result agrees fairly well with the results shown in the frequency diagram in figure 10, which covers the most nearly comparable thickness range. The previous investigation also showed that there was less variation in the ratios of compressive yield strength to tensile strength than there was in the ratios of compressive yield strength to tensile yield strength. In other words, tensile strength seemed to be a more satisfactory basis for the ratios than tensile yield strength. With this consideration in mind, table II was prepared to show a comparison of the two sets of ratios summarized from the 267 cases tested. Comparison of the percentage deviation of the minimum and the maximum ratios from the average, given in the last two columns of table II, indicates that tensile strength is slightly better than tensile yield strength as a basis for the ratios, but the advantage is not nearly so pronounced as it appeared to be in the previous investigation.

Thus far in this report the emphasis has been placed on the average values of yield strength rather than on the minimum values. The minimum values, however, may be of considerable importance. The average ratios of compressive yield strength to the tensile properties having been determined, the next step would therefore be to try these ratios out in connection with the specified minimum tensile properties to see whether the resulting computed minimum compressive yield strengths agree with the lowest test results. This comparison has been shown in table III.

It is evident from table III that the general agreement between the computed minimum compressive yield strengths and the lowest test results is good. When the computed minimum compressive yield strength is based on the minimum guaranteed tensile yield strength, only two test results (three-fourths of 1 percent of the total number) are below the computed minimum values. When the computed minimum compressive yield strength is based on the minimum guaranteed tensile strength, the results are somewhat less conservative, three test results (about 1 percent of the total number) being below the minimum.

In order to show graphically how the computed minimum compressive yield strengths in table III compare with the actual test data, the dotted horizontal lines representing the computed minimum compressive yield strengths have been drawn in figure 8. Here again it will be noted that the minimums based on tensile strength are consistently above those based on tensile yield strength. The test results that lie below the computed minimums are all in the thickness range of 0.250 inch to 1.499 inches, and it should be remembered that these two or three values are only about 1 percent of the total number of tests.

It is clear from the data presented in this report that the assumption commonly made that the compressive yield strength is equal to the tensile yield strength is not very satisfactory, as far as the general run of values is concerned. It will be well, however, to investigate this assumption with respect to minimum values. Horizontal lines have been drawn in figure 8 to represent the specified minimum tensile yield strengths. It will be noted that, in the thickness range of 1.500 inches and over, no compressive yield strengths are below the specified minimum tensile yield strength. In the intermediate thickness range only four compressive yield strengths (6 percent of those determined in this range) are below the specified minimum tensile yield strength. In the smallest thickness range, sections thinner than 0.250 inch, 83 compressive yield strengths (47 percent of those determined in this range) are below the specified minimum tensile yield strength. The significance of these relations of the compressive yield strengths and the specified minimum tensile yield strengths is that, except in the thickness range below 0.250 inch, no great error would be involved in the simple assumption that the minimum compressive yield strength is equal to the minimum tensile yield strength. In the range of thickness below 0.250 inch, however, this simple assumption does not seem to be satisfactory.

CONCLUSIONS

From the results of these tests on 267 samples of 24ST extruded shapes selected at random from plant production over a period of 9 months, the following conclusions seem warranted:

1. All the samples tested had tensile strengths and tensile yield strengths greater than the minimum values called for by Federal specification QQ-A-354 and Navy Department specification 46A9c.

2. The compressive yield strength of a 24ST extruded shape can be estimated with a fair degree of accuracy from known tensile yield strength values, as follows:

Thickness	Compressive yield strength (fraction of tensile yield strength)
Less than 0.250 inch	0.88
From 0.250 to 1.499 inches	.91
1.500 inches and over	.96

3. Although the foregoing ratios are derived as averages for a large number of samples covering a wide range of properties, when used with the specified minimum tensile yield strength they are reasonably satisfactory for determining representative minimum compressive yield strengths. The following are the minimum compressive yield strengths determined by multiplying the specified minimum tensile yield strengths by the foregoing ratios:

Thickness	Minimum compressive yield strength (lb/sq in.)
Less than 0.250 inch	37,000
From 0.250 to 1.499 inches	40,000
1.500 inches and over	49,900

4. The Aluminum Company of America does not guarantee any minimum compressive yield strengths for its products because the determination of compressive yield strengths is too difficult to permit them to be included in routine

inspection tests and because compressive yield strengths are not needed for control of quality. The computed minimum compressive yield strengths given in conclusion 3 are in good agreement with the lowest test results, except in the range of thicknesses 1.5 inches and over. For this range of thicknesses, no compressive yield strengths were found lower than the specified minimum tensile yield strength, 52,000 pounds per square inch.

5. In the foregoing conclusions it has been shown how the compressive yield strengths can be computed from known tensile yield strengths. Equally satisfactory results can be obtained by computing the compressive yield strengths from known tensile strengths. The relation is as follows:

Thickness	Compressive yield strength (fraction of tensile yield strength)
Less than 0.250 inch	0.66
From 0.250 to 1.499 inches	.69
1.500 inches and over	.72

6. The computed minimum compressive yield strengths obtained by the foregoing ratios are as follows:

Thickness	Minimum compressive yield strength (lb/sq in.)
Less than 0.250 inch	37,600
From 0.250 to 1.499 inches	41,400
1.500 inches and over	50,400

7. The assumption commonly made, that the compressive yield strengths of 24ST extruded shapes are equal to the tensile yield strengths, is fairly accurate for either average or minimum values for thicknesses of 1.500 inches and over. It is not seriously in error in the range of thicknesses from 0.250 inch to 1.499 inches. For sections thinner than 0.25 inch, however, this assumption is unsatisfactory because it not only leads to estimated average values of compressive yield strength which are 6000

pounds per square inch too high, but it also overestimates the minimum compressive yield strength of more than 40 percent of material included in this thickness range by amounts up to 4400 pounds per square inch. For thicknesses less than 1.5 inches, either of the two methods given in the foregoing conclusions for estimating compressive yield strengths from tensile properties is more accurate than the commonly made assumption discussed.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Penna., October 11, 1940.

REFERENCES

1. Aitchison, C. S., and Tuckerman, L. B.: The "Pack" Method for Compressive Tests of Thin Specimens of Materials Used in Thin-Wall Structures. Rep. No. 649, NACA, 1939.

2. Anon.: Tension Testing of Metallic Materials. A.S.T.M., E8-36, 1936.

TABLE I.- Summary of Tensile and Compressive Properties of 24ST Extruded Shapes

(Values in parentheses after the minimum tensile properties are the specified minimums according to Navy Department specification 46A9c and Federal specification QQ-A-354, except the 52,000 lb/sq in. value in the tensile yield strength column. This value is given currently as 51,500 lb/sq in., but soon will be raised to 52,000 lb/sq in. Therefore, the higher value will be used throughout this report.)

Size range		Tensile strength (lb/sq in.)	Tensile yield strength (offset-0.2%) (lb/sq in.)	Compressive yield strength (offset-0.2%) (lb/sq in.)
Less than 0.250 inch	Minimum	58,480 (57,000)	42,600 (42,000)	37,600
	Average	65,380	49,125	43,270
	Maximum	79,350	59,100	54,200
0.250 to 1.499 inches	Minimum	62,190 (60,000)	46,570 (44,000)	37,500
	Average	79,645	59,910	54,830
	Maximum	86,500	69,800	65,500
1.500 inches and over	Minimum	77,460 (70,000)	57,300 (52,000)	54,900
	Average	81,060	61,080	58,700
	Maximum	85,380	65,700	62,800
All sizes	Minimum	58,480	42,600	37,500
	Average	70,425	52,950	47,615
	Maximum	86,500	69,800	65,500

TABLE II.- Summary of Ratios of Compressive Yield Strength to Tensile Yield Strength and to Tensile Strength

Size Range		Ratios		Percentage that minimum ratio is below and maximum ratio is above the average value	
		CYS/TYS	CYS/TS	CYS/TYS	CYS/TS
Less than 0.250 inch	Minimum	0.76	0.61	14	8
	Average	.88	.66		
	Maximum	1.04	.78	18	18
0.250 to 1.499 inches	Minimum	.73	.56	20	19
	Average	.91	.69		
	Maximum	1.01	.76	11	10
1.500 inches and over	Minimum	.91	.70	5	3
	Average	.96	.72		
	Maximum	.99	.77	3	7
All thicknesses	Minimum	.73	.56	19	16
	Average	.90	.67		
	Maximum	1.04	.78	16	16

TABLE III.- Computed Minimum Compressive Yield Strengths Obtained by Multiplying the Minimum Tensile Properties by the Average Ratios of Compressive Yield Strengths to Tensile Properties

(Values in columns 3 and 5 were taken from table II. Values in column 6 were obtained by multiplying column 2 by column 3. Values in column 7 were obtained by multiplying column 4 by column 5)

1	2	3	4	5	6	7	8	9	10
Thickness range	Minimum tensile yield strength (lb/sq in.)	Average ratio of $\frac{CYS}{TYS}$	Minimum tensile strength (lb/sq in.)	Average ratio of $\frac{CYS}{TS}$	Computed minimum compressive yield strength		Lowest test result (lb/sq in.)	Number of test results below computed minimum compressive yield strength	
					Based on TYS (lb/sq in.)	Based on TS (lb/sq in.)		Based on TYS	Based on TS
Less than 0.250 inch	[a]42,000	0.88	[a]57,000	0.66	37,000	37,600	37,600	0	0
0.250 to 1.499 inches	[a]44,000	.91	[a]60,000	.69	40,000	41,400	37,500	2	3
1.500 inches and over	[a]52,000	.96	[a]70,000	.72	49,900	50,400	54,900	0	0

[a]Navy Department specification 46A9c and Federal specification QQ-A-354.

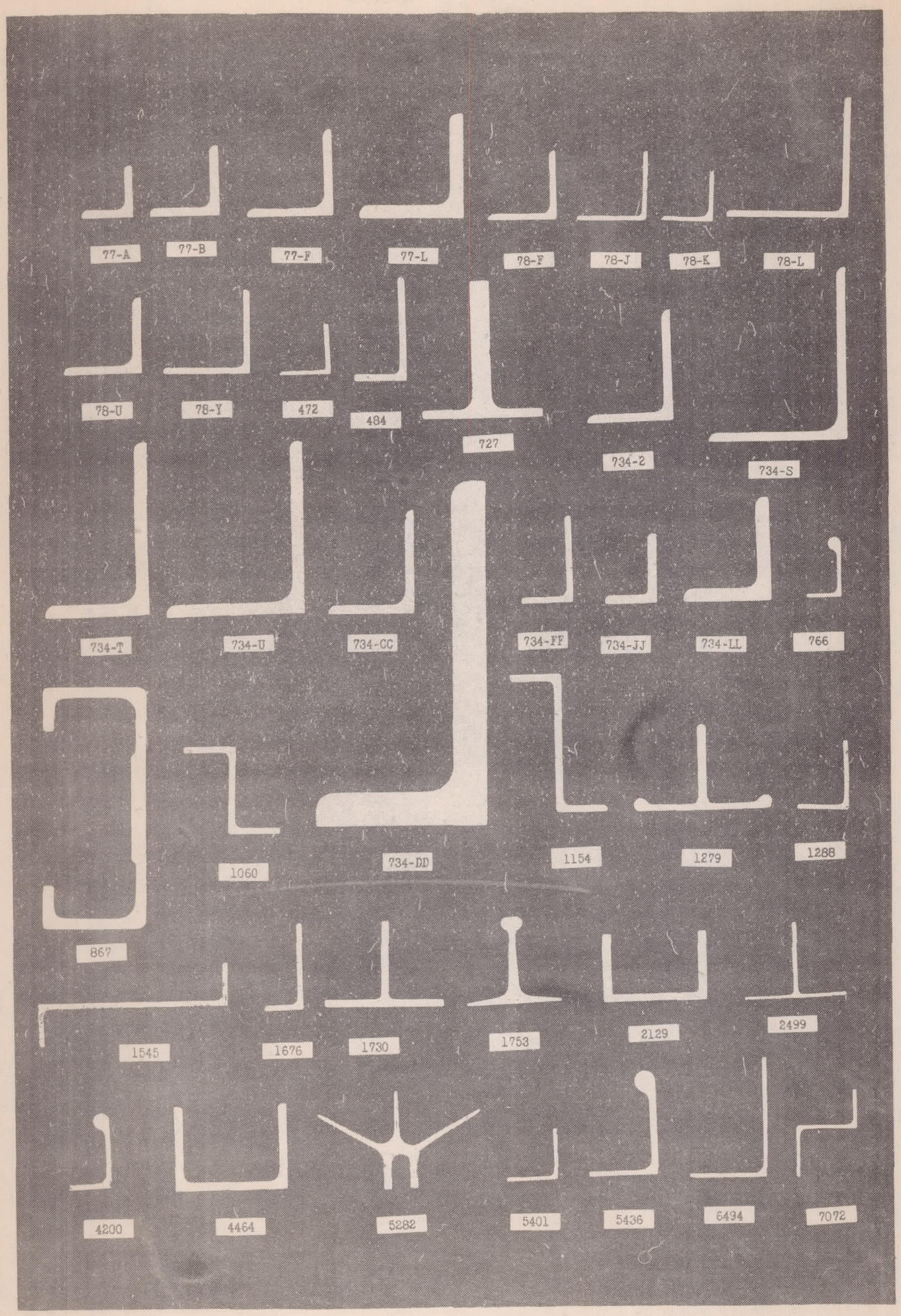

Figure 1a.-Cross sections of 24S-T Extruded Shapes Tested - Die Nos. 77-A to 7072

(About 1/2 actual size)

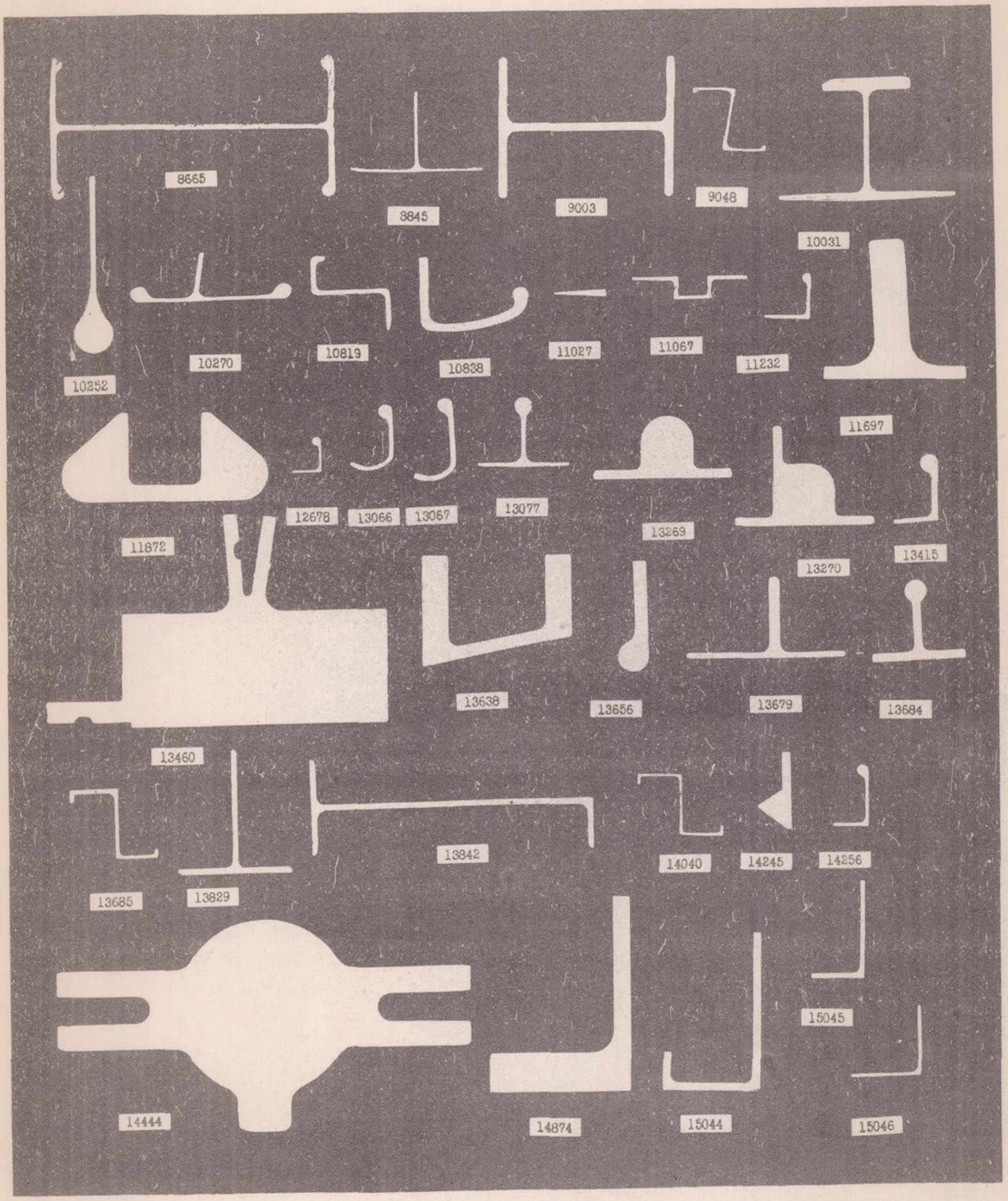

Figure 1b.-Cross sections of 24S-T Extruded Shapes Tested - Die Nos. 8665 to 15046

(About 1/2 actual size)

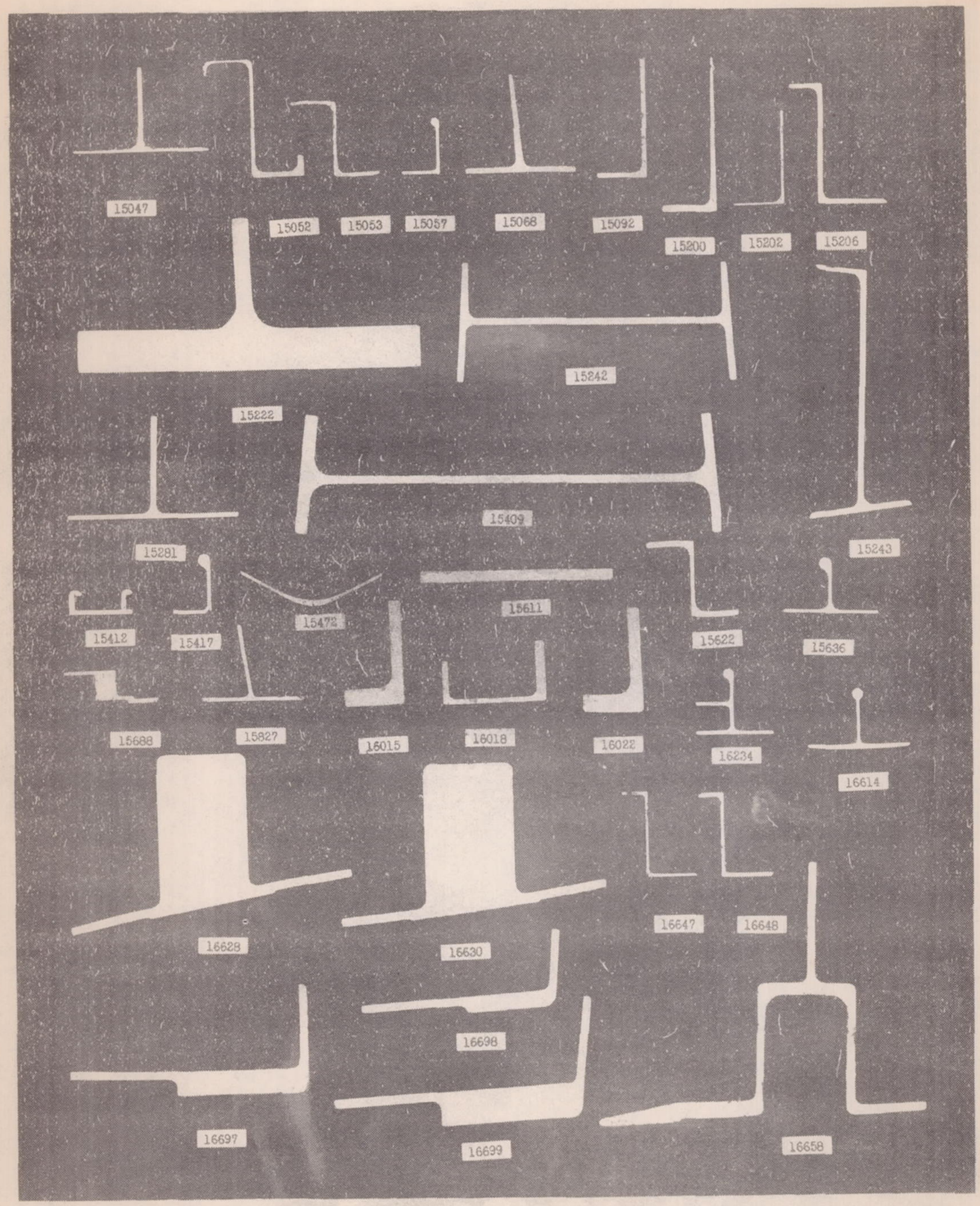

Figure 1c. Cross sections of 24S-T Extruded Shapes Tested - Die Nos. 15047 to 16658

(About 1/2 actual size)

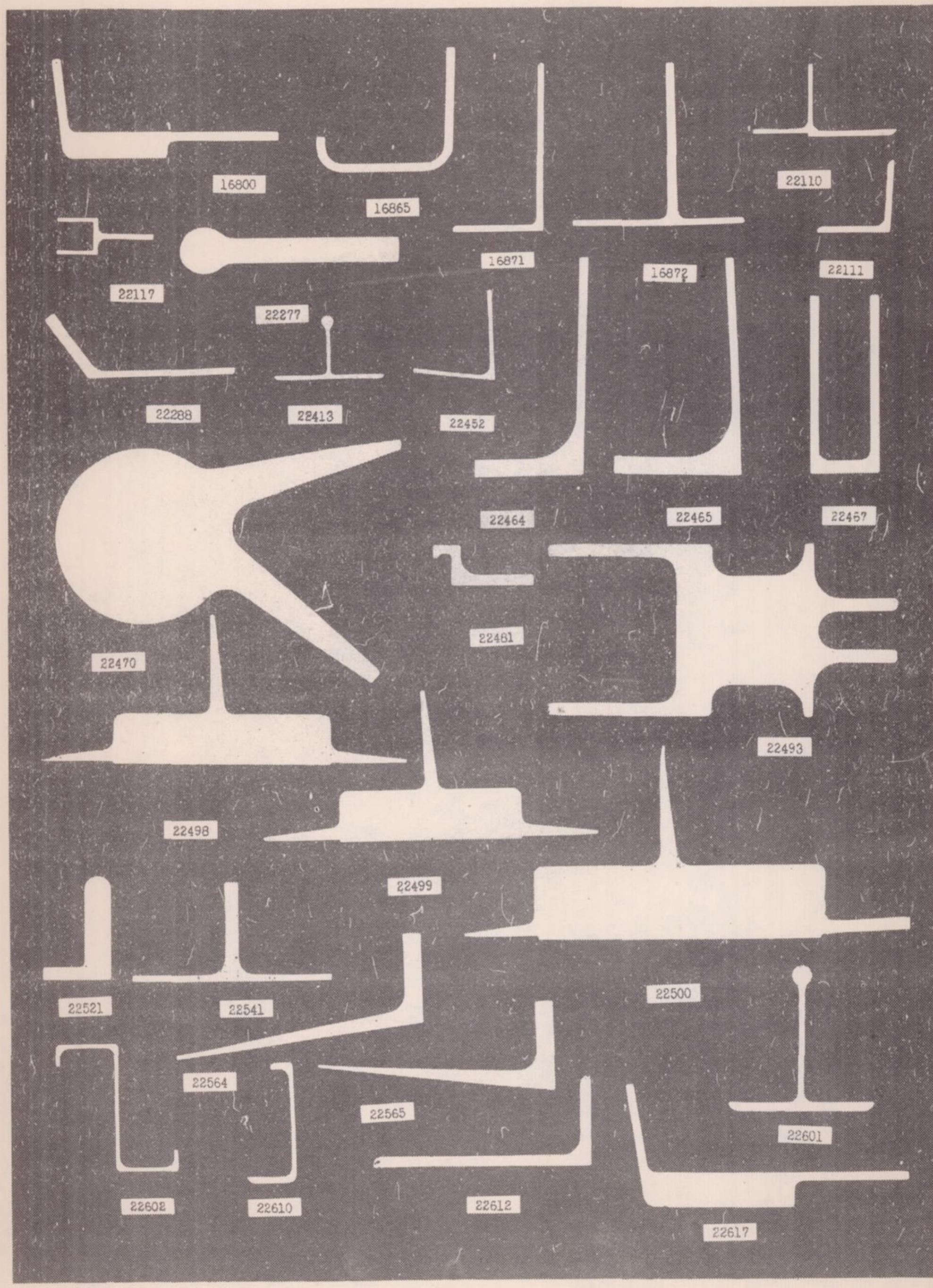

Figure 1d.- Cross sections of 24S-T Extruded Shapes Tested - Die Nos. 16800 to 22617

(About 1/2 actual size)

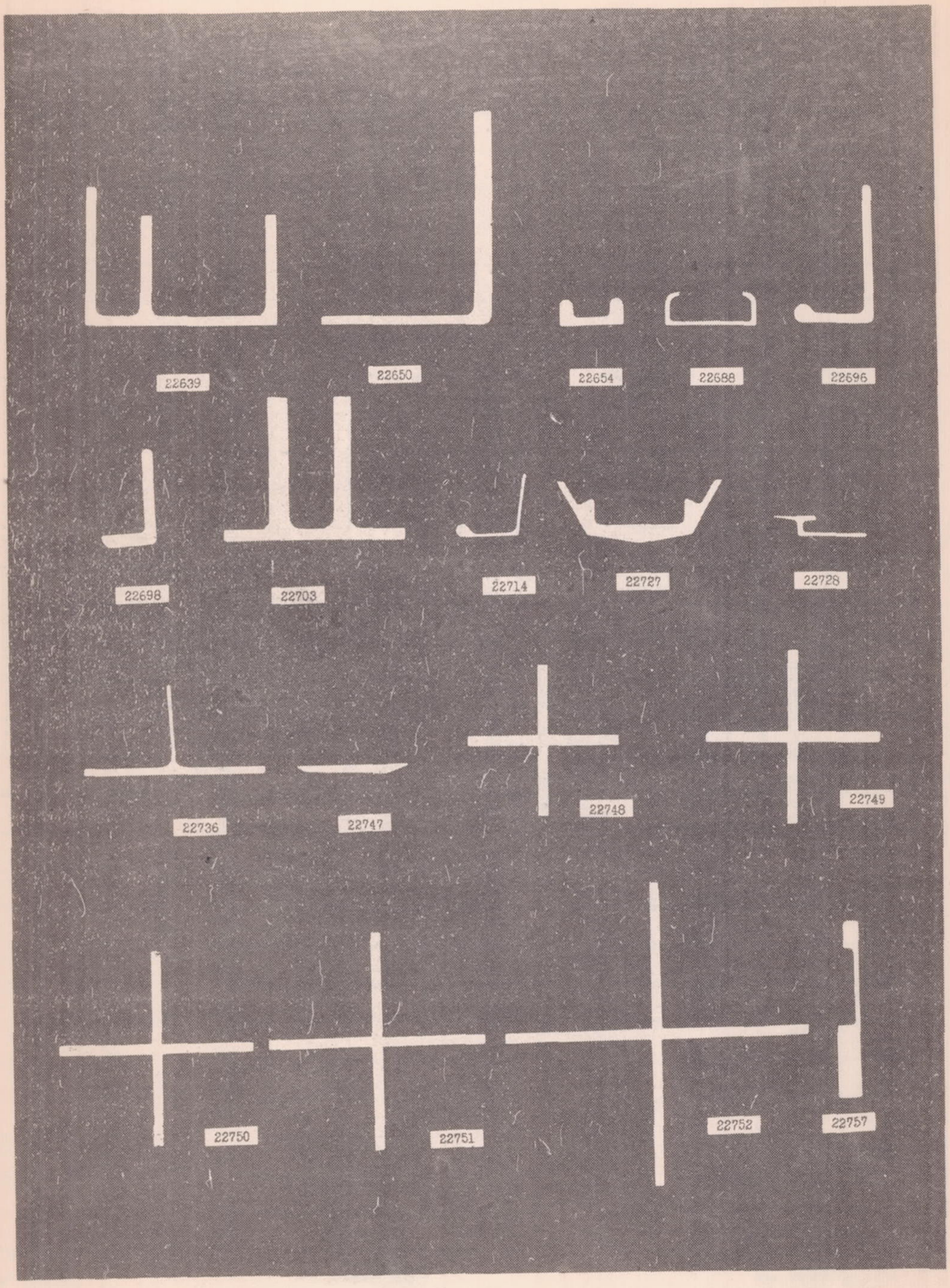

Figure 1e.- Cross sections of 24S-T Extruded Shapes Tested - Die Nos. 22639 to 22757

(About 1/2 actual size)

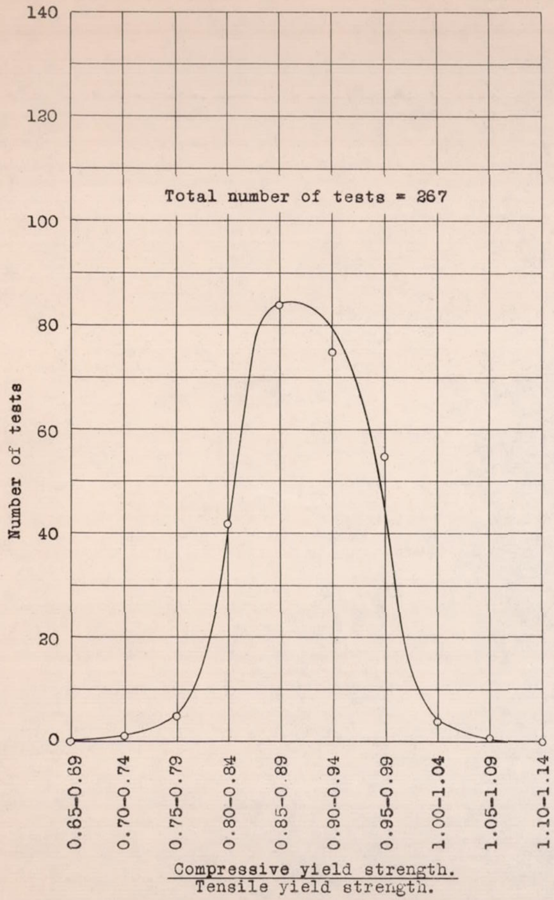

Figure 5.- Frequency curves showing the ratio of compressive yield strength to tensile yield strength for the 267 extruded shapes of 24ST aluminum alloy tested.

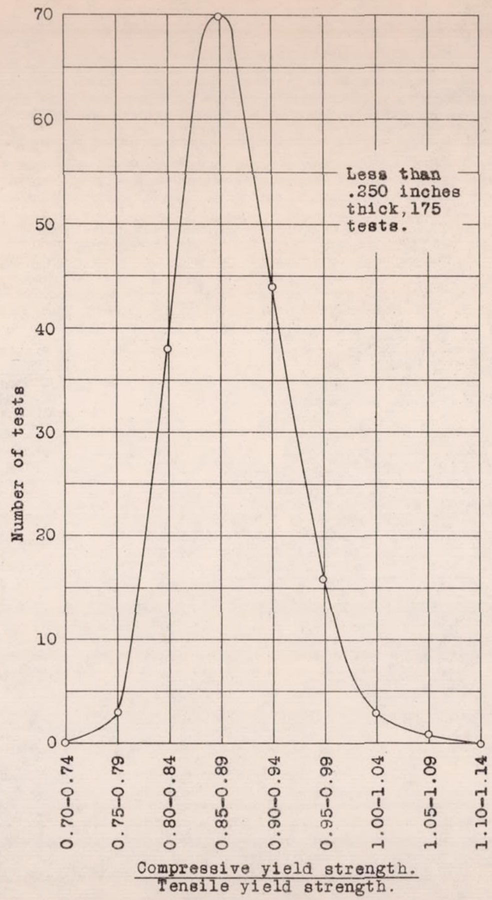

Figure 6.- Frequency curves showing the ratio of compressive yield strength to tensile yield strength for the 175 extruded shapes less than 0.250 inches thick.

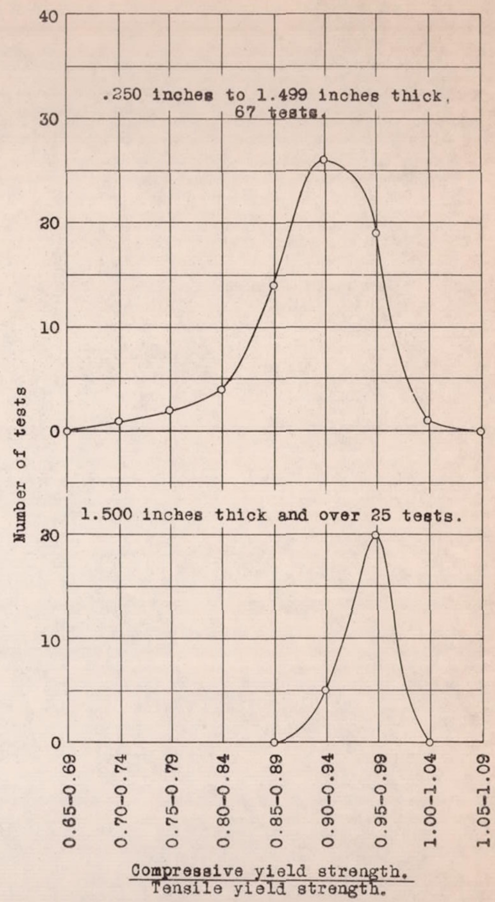

Figure 7.- Frequency curves showing the ratio of compressive yield strength to tensile yield strength for the 67 extruded shapes between 0.250 inches and 1.499 inches thick and the 25 extruded shapes 1.500 inches thick and over.