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No. 618

# INCREASING THE STRENGTH OF ALUMINUM-ALLOY COLUMNS BY PRESTRESSING

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# INCREASING THE STRENGTH OF ALUMINUM-ALLOY COLUMNS BY PRESTRESSING

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## SUMMARY

A series of tests was made in which the column strength of 17S-T tubing was increased as much as 50 percent by prestressing the tubing to 40,000 pounds per square inch in compression under conditions of support that prevented column failure at this stress. This prestressing achieves its beneficial effects entirely by improving the compressive properties of the material, principally the proportional limit.

## INTRODUCTION

There is a range of large slenderness ratios in which the column strengths of a group of alloys or tempers of a metal are independent of the compressive proportional limit and yield strength. In this range of slenderness ratios the average stresses at failure are in the elastic-stress range and the curve of column strengths under axial loads can be represented by the Euler column formula. For decreasing slenderness ratios, the curve of column strengths rises and, when the limit of the elastic-stress range of an alloy is approached, its curve of column strength departs from and is lower than the Euler column curve. Thus the greater the compressive proportional limit of an alloy, the higher will the column strengths follow the Euler curve and the higher will be the resulting curve of column strengths.

Since the elastic-stress range of aluminum alloys can be changed by suitable cold working (straining), it appears that the column strength of an aluminum alloy could be increased by prestressing the material to a compressive stress exceeding the compressive proportional limit of the original material. Of course, in order to obtain this increase, the pieces from which the columns are to be taken would have to be supported laterally to prevent buckling at the column strength of the piece of original material.

The investigation described in this report was planned for the purpose of studying the effects of compressive prestressing on the column strength of aluminum alloys.

## DESCRIPTION OF TESTS

All tests in this investigation were made on pieces of 17S-T seamless tubing with an outside diameter of 2 inches and a wall thickness of 0.083 inch. This material was made according to present commercial fabrication procedure. The tensile properties were well above the specified minimum values as indicated in table I. Compressive stress-strain tests made on samples of the tubing in the as-received condition indicated an average compressive yield strength 6,000 pounds per square inch below the tensile yield strength, as is also shown in table I. This difference in yield strengths is not unusual in material of this type.

Column tests were made on part of the tubing in the as-received condition and on part after it had been prestressed to 40,000 pounds per square inch in compression. The prestressing was done in a 40,000-pound capacity testing machine in practically the same manner that a column test is made except that the tubes were laterally supported at intervals of about 10 inches (L/r about 15) so that no column failure would occur during the prestressing operation. The lateral supports consisted of wooden stocks that fitted tightly to the posts of the testing machine and snugly around the tubes. The holes in the stocks were counterbored leaving a contact only 3/4-inch wide between the tube and the stock. The contact surfaces were lubricated with soap so that a force of only 50 pounds would slide the tube through the stocks. Figure 1 is a photograph showing the prestressing arrangement.

After prestressing, samples were cut from the tubes for the determination of tensile and compressive properties and the results are shown in table I.

The column tests on the tubing, both as-received and prestressed, were made with two conditions of ends, round and flat. The round-end tests were made using ball-bearing spherical seats at each end of the test specimens; and flat-end tests were made with the ends of the specimens bearing directly against the fixed heads of the testing machine. The ends of all specimens were carefully machined flat, mutually parallel, and square with the longitudinal axis to insure proper seating of the specimen against the testing-machine heads. Great care was exercised in lining up all specimens to minimize eccentricities of loading.

## RESULTS OF TESTS

Figures 2 and 3 show the results of the column tests made with round ends and with flat ends. Curves have been drawn to fit the data in each case, the extreme right-hand portions on each figure being the well-known Euler curve based on a modulus of elasticity of 10,300,000 pounds per square inch. The Euler curve for the flat-end tests is that for completely fixed ends (c = 4).

At the top of figures 2 and 3, curves are given showing the percentage increase in column strength resulting from prestressing. In the case of the round-end tests (fig. 2), it will be found that prestressing has raised the column strength over a range of slenderness ratios from 20 to 80, the maximum increase indicated by the curves being 50 percent at a slenderness ratio of about 50. In the case of the flat-end tests (fig. 3) an increase is found over a range of slenderness ratios from 40 to 140, the maximum increase being 34 percent at a slenderness ratio of about 100.

Figure 4 shows a typical compressive stress-strain curve for the as-received tubes in comparison with one for the prestressed tubes. Comparing the two it will be found that the principal difference is an increase in the proportional limit and that the increase in yield strength is not nearly so large. The proportional limit has been raised practically to the stress used in the prestressing operation. This fact, of course, is responsible for the principal increase in column strength. By increasing the extent of elastic action of the material in compression, prestressing has raised the stress at which the column curves begin to drop below the Euler curve.

## PRACTICAL APPLICATION OF PRESTRESSING

Prestressing in compression is entirely practical as a method of improving the compressive properties, and hence the column strength, of both tubing and shapes of any of the aluminum alloys. The equipment required is a press of suitable length and capacity equipped with a rigid frame and a set of guides for preventing lateral failure of the material being prestressed. A press similar to a testing machine, on which the load can be measured and controlled, is desirable but not essential. In the absence of a load-weighing device, it is only necessary to use a strain-measuring device on the pieces being prestressed.

The selection of the proper stress (or strain) to use in the prestressing operation is a matter of considerable importance. Obviously, the stress must be above the original elastic range of the material or no improvement is accomplished. In the ideal case, the new compressive proportional limit of the material will be equal to a value just below the amount of prestress and, if no eccentricities of loading are present, the new column curve will follow the Euler curve practically up to this stress. This method gives a means of predicting the results of prestressing and helps in the selection of the amount of prestress, but there is one important restriction to be observed. Members subject to local failure cannot be prestressed above their critical buckling stress unless local stiffening is applied in addition to the stiffening against general sidewise bending. Therefore, the degree of benefit to be derived from prestressing is a function of the degree to which a member is subject to local failure.

It will be noticed from table I and figure 4 that the compressive yield strength of the 17S-T tubes used in this investigation was raised 13 percent by prestressing to 40,000 pounds per square inch. In a preliminary test in this same investigation another piece of the tubing was prestressed to 45,000 pounds per square inch with a resulting increase of 24 percent in compressive yield strength. On tubes with thicker walls even greater increases could be obtained with higher amounts of prestress. Generally speaking, however, the difficulties encountered in prestressing increase considerably after the amount of prestress exceeds the original compressive yield strength of the material; so, for practical purposes, it would seem that a stress equal to or slightly greater than the original compressive yield strength might well be selected as the limiting value of prestress.

Another reason for not carrying the prestressing operation too far is the lowering of the tensile yield strength. It will be noted in table I that the tensile yield strength was lowered 5 percent by prestressing to 40,000 pounds per square inch in compression. In the preliminary test where the piece was prestressed to 45,000 pounds per square inch in compression, the tensile yield strength was reduced to 39,000 pounds per square inch (11 percent), which placed it below the specified minimum for the material. It should be noted that the change in tensile yield strength is less than half the change in the compressive yield strength.

There is no reason to expect any marked changes in the other properties as a result of prestressing in compression. The process is essentially one of mild cold working or "work hardening" and as such is not new to the metal industry. An interesting parallel of compressive cold working is found in reference 1.

Prestressing in compression has a tendency to exaggerate any initial crookedness of members, which in turn has a tendency to detract from the beneficial effect on column strength. This effect can be minimized, however, by close spacing and proper alinement of the lateral supports used in the prestressing operation. With careful attention to such details, there is practically no limit to the length of member that can be successfully prestressed.

It should be obvious from the foregoing discussion that the beneficial effects of prestressing are applicable only to members which are to be used as compression members in service. Members which are to be subjected exclusively to tensile stresses in service would, of course, derive no benefit. In a large number of service applications members are subjected to both tension and compression, and on such members prestressing may or may not be beneficial, depending upon the relative magnitudes of the service loadings in tension and compression. When a member is designed principally for compression loadings and the tensile loadings are distinctly smaller than the compression loadings, the prestressing operation will always be found to be beneficial provided that the member is in the critical range of slenderness ratios as previously outlined. When, however, the tensile loadings are equal to or greater than the compressive loadings, some or all of the benefits of prestressing may be removed.

In order to illustrate this point, figure 5 has been prepared showing three compressive stress-strain curves on samples of prestressed 17S-T tubing. The curve marked 2 is the same as curve 2 in figure 4; that is, it shows the compressive stress-strain curve for the 17S-T tubing prestressed to 40,000 pounds per square inch in compression. No tension was applied prior to determining this curve. Curve 3 in figure 5 represents the compressive stress-strain curve of a piece of the same tubing which was loaded to 30,000 pounds per square inch in tension after having been prestressed in compression. Compressive stress-strain curve 4 represents another piece of the same tubing loaded to 40,000 pounds per square inch in tension after having been prestressed in compression. It is clear from an examination of these three curves that the tensile loadings have had only a small effect on the compressive yield strength of the material, but a much greater effect on the compressive proportional limit of the material. The 30,000 pounds per square inch tensile loading produced very little change in the general shape of the stress-strain curve, whereas the 40,000 pounds per square inch tensile loading lowered the curve considerably. In fact, a comparison of curve 4 in figure 5 with curve 1 in figure 4 indicates that the application of 40,000 pounds per square inch in tension brought the compressive stress-strain curve of the material about halfway back to its original position before prestressing in compression. This result would, of course, have a very marked effect on the column strength of the material and indicates that tensile loadings having a magnitude about equal to the amount of compressive prestress will remove a considerable portion of the beneficial effects of prestressing. The small change produced by the 30,000 pounds per square inch tensile loading on the compressive stress-strain curve, however, indicates that tensile loadings less than three-quarters of the amount of compressive prestress would produce relatively little reduction in the beneficial effects of prestressing.

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New Kensington, Pa., Sept. 23, 1937.

## REFERENCE

1. Woldman, N. E.: Cold Working of Hollow Cylinders by Auto-Frettage. Trans. Am. Soc. for Metals, March 1937.

## TABLE I

## MECHANICAL PROPERTIES OF MATERIAL BEFORE AND AFTER PRESTRESSING

| | As received | After prestressing in compression to 40,000 lb./sq.in. | Percentage change |
|---|---|---|---|
| | Tensile properties | | |
| Ultimate strength, lb./sq.in. | 64,000* | 65,000 | +2 |
| Yield strength, lb./sq.in. | 44,000* | 42,000 | -5 |
| Elongation in 2 inches, percent | 28* | 28 | 0 |
| | Compressive properties | | |
| Yield strength, lb./sq.in. | 38,000 | 43,000 | +13 |
| Proportional limit, lb./sq.in. | 23,000 | 39,000 | +70 |

*Navy Department Specification 44T21a, October 2, 1933, gives the following minimum properties for 17S-T tubing of this size: Tensile strength, 55,000 lb./sq. in.; yield strength, 40,000 lb./sq. in.; and elongation in 2 inches, 12 percent.

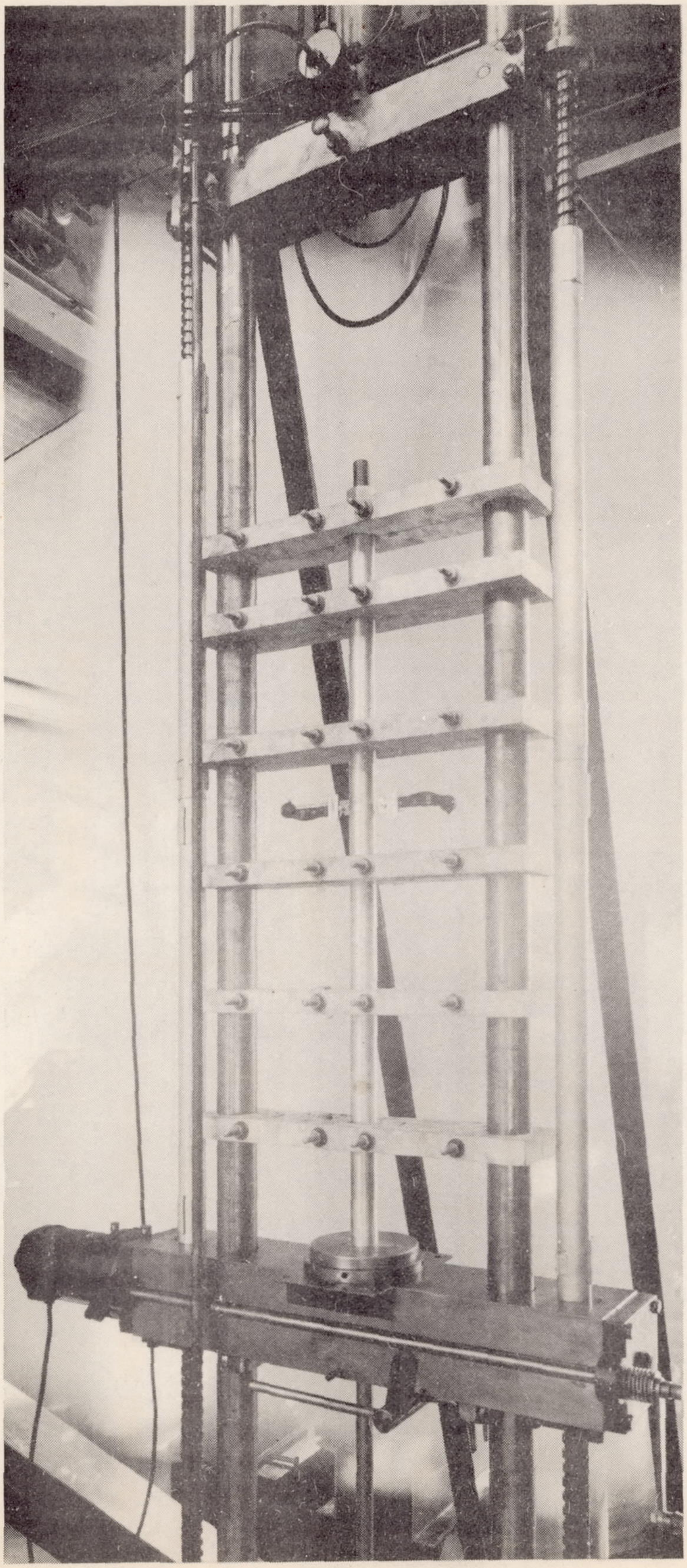


Figure.1 Photograph showing aluminum-alloy tube ready for prestressing.

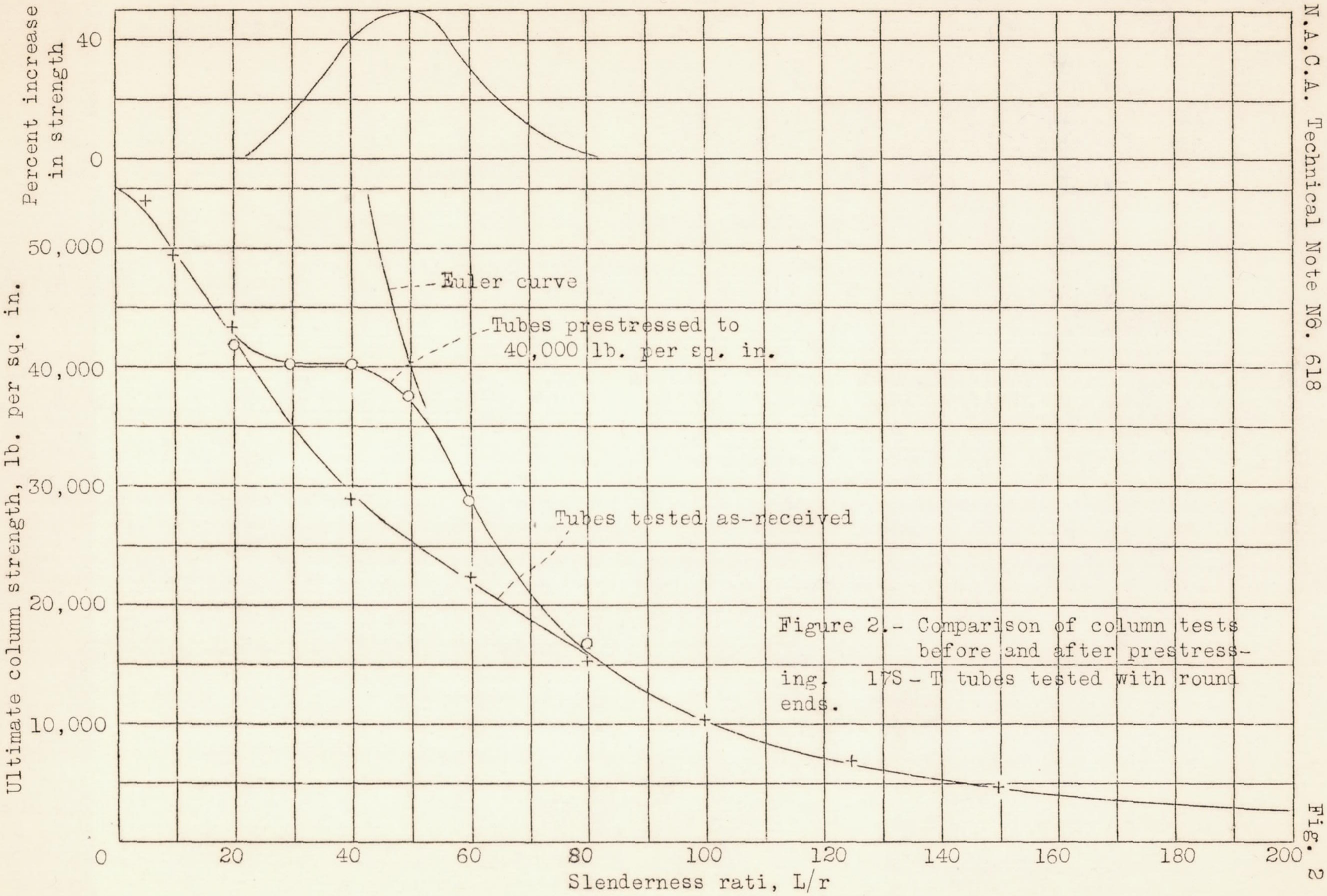


Figure 2.- Comparison of column tests before and after prestressing. 17S - T tubes tested with round ends.

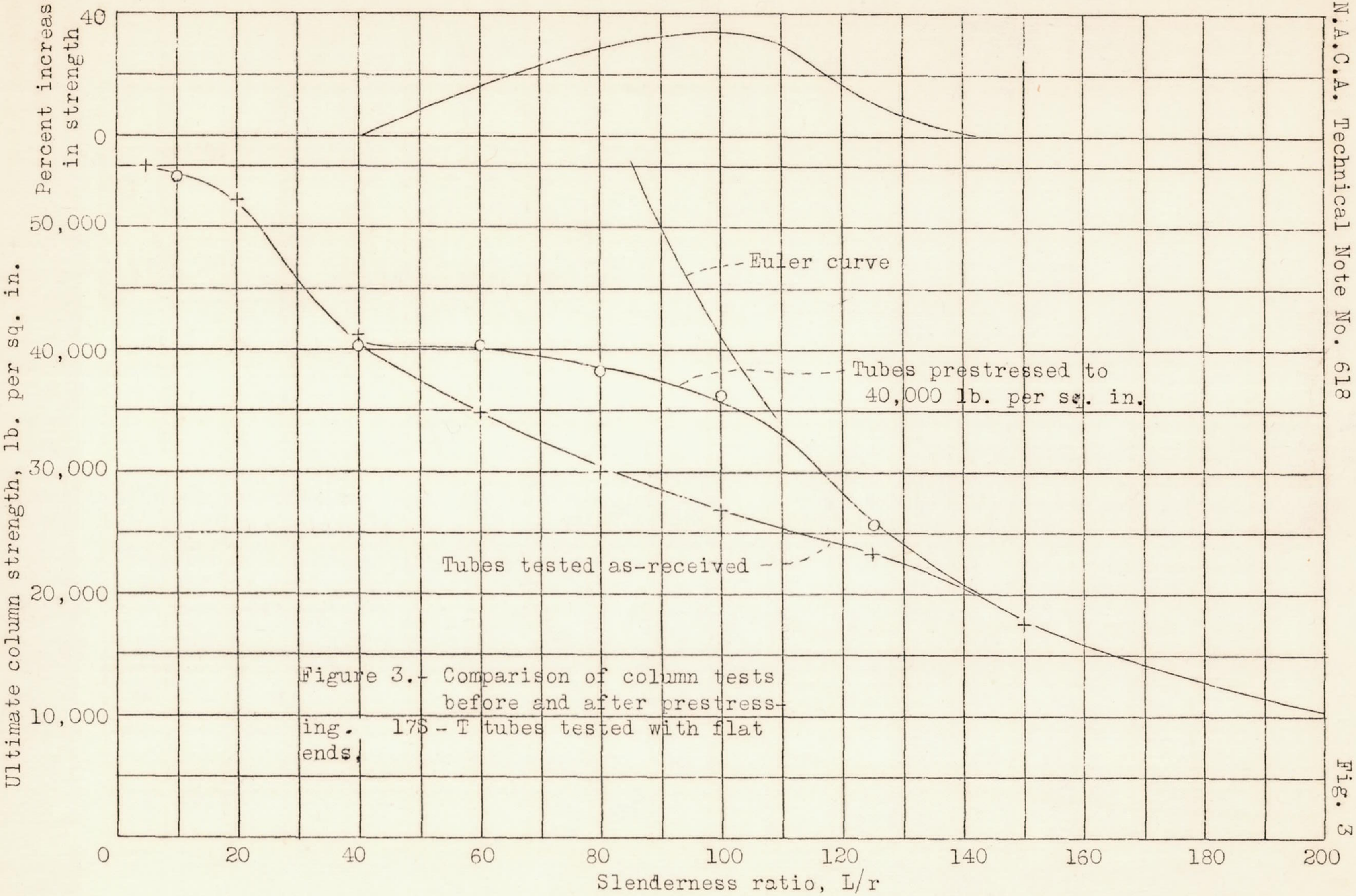


Figure 3.- Comparison of column tests before and after prestressing. 17S - T tubes tested with flat ends.

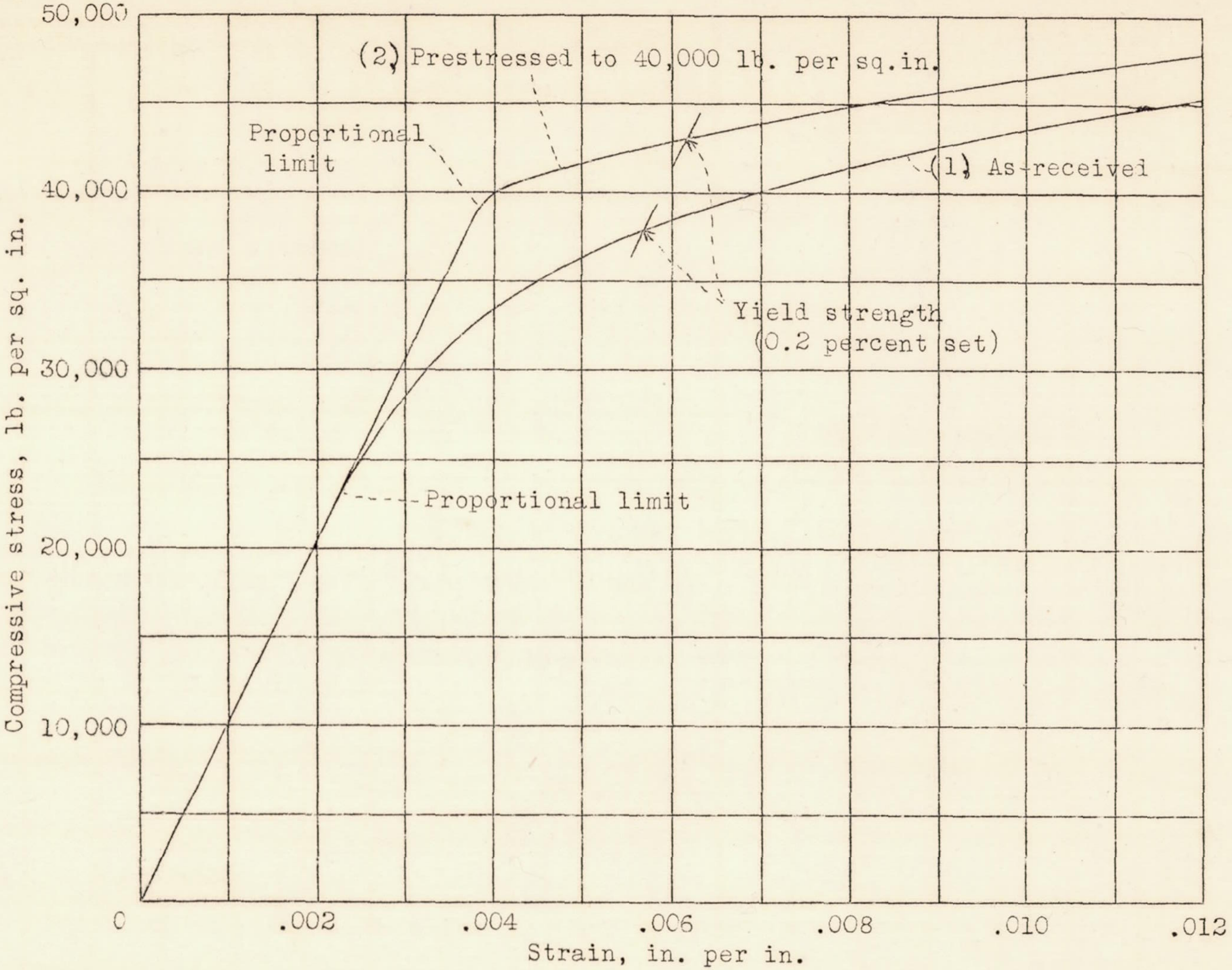
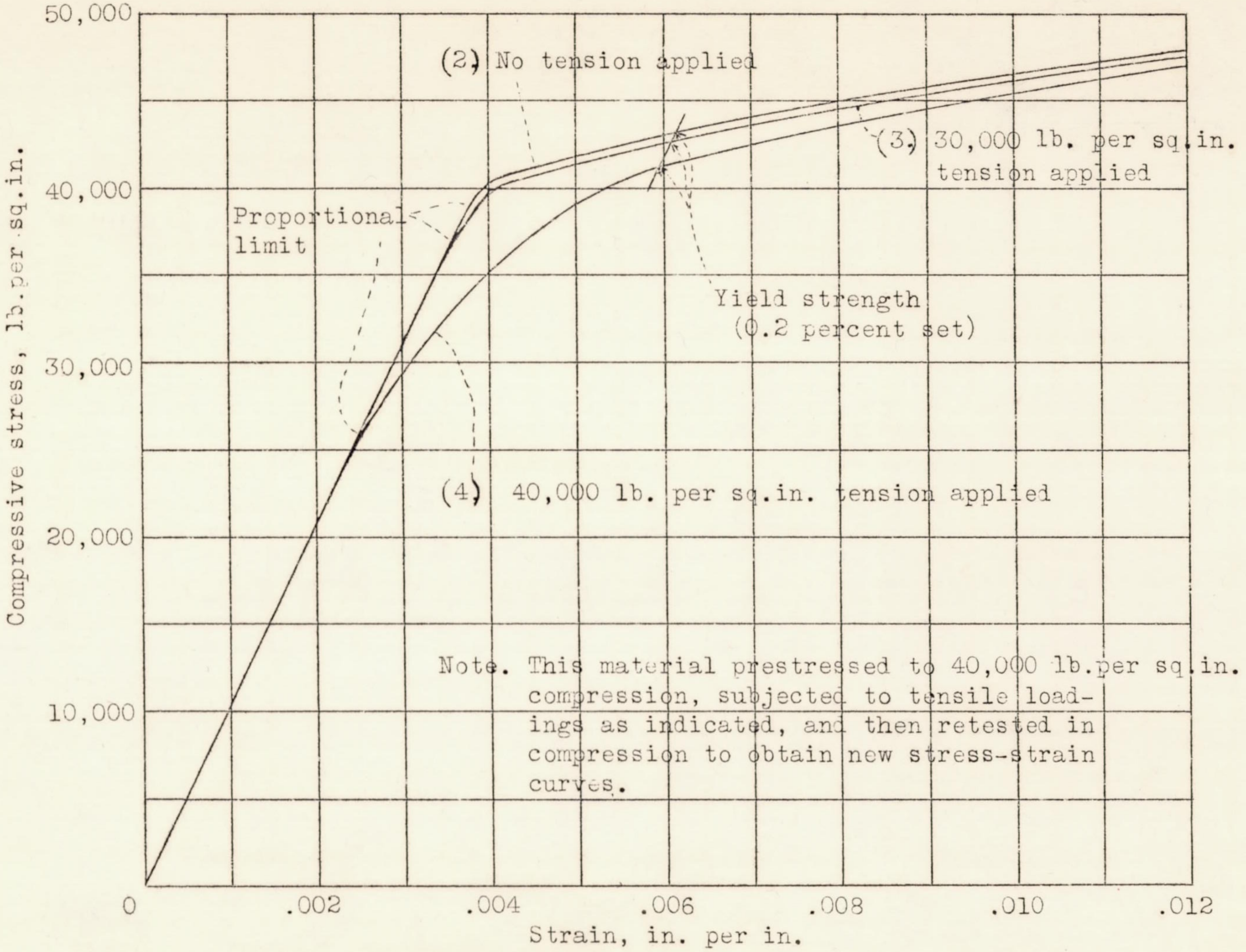


Figure 4.- Typical compression stress-strain curves before and after prestressing. 17S - T tubing.



Note. This material prestressed to 40,000 lb. per sq.in. compression, subjected to tensile loadings as indicated, and then retested in compression to obtain new stress-strain curves.

Figure 5.- Effect of tensile loadings on compression stress-strain curves of prestressed 17S - T tubing.