# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL NOTE 2038

# COMPRESSIVE PROPERTIES OF TITANIUM SHEET AT ELEVATED TEMPERATURES

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Washington
February 1950

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## SUMMARY

Results are presented of compressive stress-strain tests of titanium sheet at temperatures from room temperature up to 800° F, exposure times of 1/2 to 2 hours, and strain rates of 0.002 to 0.006 per minute. The results show that titanium has favorable compressive properties, comparable to those in tension, up through 800° F. Marked anisotropy in compression was also noted.

## INTRODUCTION

Aerodynamic heating and other temperature effects associated with high-speed flight may require that structures have adequate strength at elevated temperatures. The commonly used aluminum alloys suffer an appreciable reduction in strength and modulus of elasticity with increase in temperature. (See references 1 and 2.) Consequently, new lightweight heat-resistant materials need to be developed.

One new material that appears to have possibilities for aircraft structural use in the intermediate temperature range up to about 1000° F is titanium. Titanium alloys also appear to offer possibilities, but only fragmentary information is available along these lines at present, and only the unalloyed titanium is now available in sheet form.

In order to establish the strength of columns and plates made of a material it is necessary to have the compressive stress-strain curve of that material. (For buckling strength of columns, see references 3 and 4; for plate strength, references 4 to 8.) Although some data on the compressive properties of titanium at room temperature are given in reference 9, most of the available information deals with the tensile properties (see, for example, references 10 to 12). Because of the lack of data for titanium in compression, compressive stress-strain tests of commercially pure sheet were made under stabilized temperature conditions up to 800° F, at strain rates of 0.002 to 0.006 per minute, and at exposure times from 1/2 to 2 hours. The test results are presented herein.

## MATERIALS AND METHOD OF TESTING

Five sheets of commercially pure titanium, approximately 3.5 inches by 48 inches by 0.064 inch, were furnished by Remington Arms Company, Inc. The condition of the material as reported by the company is given in the following table along with Vickers hardness values determined at the Langley Aeronautical Laboratory.

| Quantity (sheets) | Condition | Vickers hardness (10-kg load) |
|---|---|---|
| 3 | Hot-rolled, pickled, annealed, and cold-worked to a reduction of 20 percent in thickness | 318 |
| 1 | One-half hard, roughly equivalent to being cold-worked to a reduction of 20 percent in thickness | 343 |
| 1 | One-fourth hard | 337 |

The single-thickness compression specimens were 2.52 inches long by 1.00 inch wide. The compression tests were made with the same equipment and procedures as described in reference 8. All test results given are for specimens cut from the lot of 3 sheets listed in the table except where noted. The test results are the average results obtained from three tests at each temperature, exposure time, and strain rate.

A few tension tests were made at room temperature for comparative purposes. Because of the narrowness of the sheet, small specimens shown in figure 1 were also necessary for the determination of the transverse properties.

## RESULTS AND CONCLUSIONS

The data, presented in table I and in figures 2 to 6, indicate in general that titanium sheet has propitious compressive properties at elevated temperatures up to 800° F, the highest temperature investigated. The following detailed results are evident:

1. The compressive yield stress and modulus of elasticity in compression hold up quite well in the range from 200° F to 800° F

(see figs. 2 to 4). In fact at 800° F, the yield stress in compression (see fig. 3) is higher than for tension, as reported by Remington Arms Company, Inc. (reference 10).

2. The yield stress and modulus of elasticity in the longitudinal direction are markedly below those for the transverse direction for each temperature (see figs. 3 and 4); therefore, a high degree of anisotropy in compression is indicated. This anisotropy decreases somewhat with rising temperature.

3. In contrast to the anisotropy evidenced in compression at room and elevated temperatures, the tensile stress-strain curves, which were determined at room temperature only, indicate the material to be very nearly isotropic under tensile loading (see fig. 5).

4. At room temperature, the compressive stress-strain curve in the transverse direction is very nearly the same as the tensile stress-strain curve in the transverse direction, whereas in the longitudinal direction there is revealed an appreciable reduction in the compressive yield stress as compared with tension (see fig. 5).

5. The tensile stress-strain curves for the longitudinal direction, obtained from tests of small tensile specimens, were only slightly higher than those for the same direction obtained with large tensile specimens (see fig. 5). Consequently, the results obtained in the transverse direction from the tests of the small tensile specimens are probably approximately representative of the tensile properties in that direction.

6. The compressive strength of titanium sheet depends upon the amount and kind of cold work employed in fabrication (see fig. 6).

7. Variation in strain rates from 0.002 to 0.006 per minute and exposure times from 1/2 to 2 hours showed no definite effect on the test results at 600° F (see table I).

The presence of anisotropy in compression at all test temperatures indicates that additional research on the strength of plate and shell structures of titanium sheet under compressive loading is required to assess the effect of this anisotropy.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va., November 30, 1949

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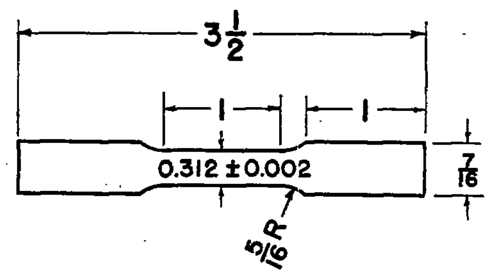
TABLE I

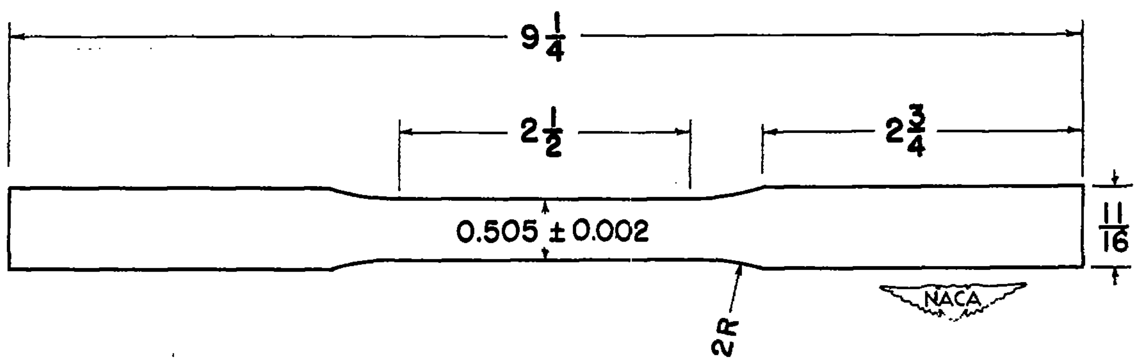
VARIATION OF COMPRESSIVE YIELD STRESS OF 20-PERCENT COLD-WORKED TITANIUM SHEET WITH EXPOSURE TIME AND STRAIN RATE

| Direction of loading | Change in compressive yield stress at 600° F (percent) | | | | | |
|---|---|---|---|---|---|---|
| | Strain rate, per minute (Exposure time, 1 hr) | | | Exposure time, hours (Strain rate, 0.002 per min) | | |
| | 0.002 (a) | 0.004 | 0.006 | $\frac{1}{2}$ | 1 (a) | 2 |
| Transverse | 0 | -2.3 | -3.9 | 0 | 0 | 1.1 |
| Longitudinal | 0 | 5.6 | 1.8 | 3.7 | 0 | 4.4 |

[a]Base for comparison.




Small specimen




Large specimen

Figure 1.- Dimensions of tensile specimens.

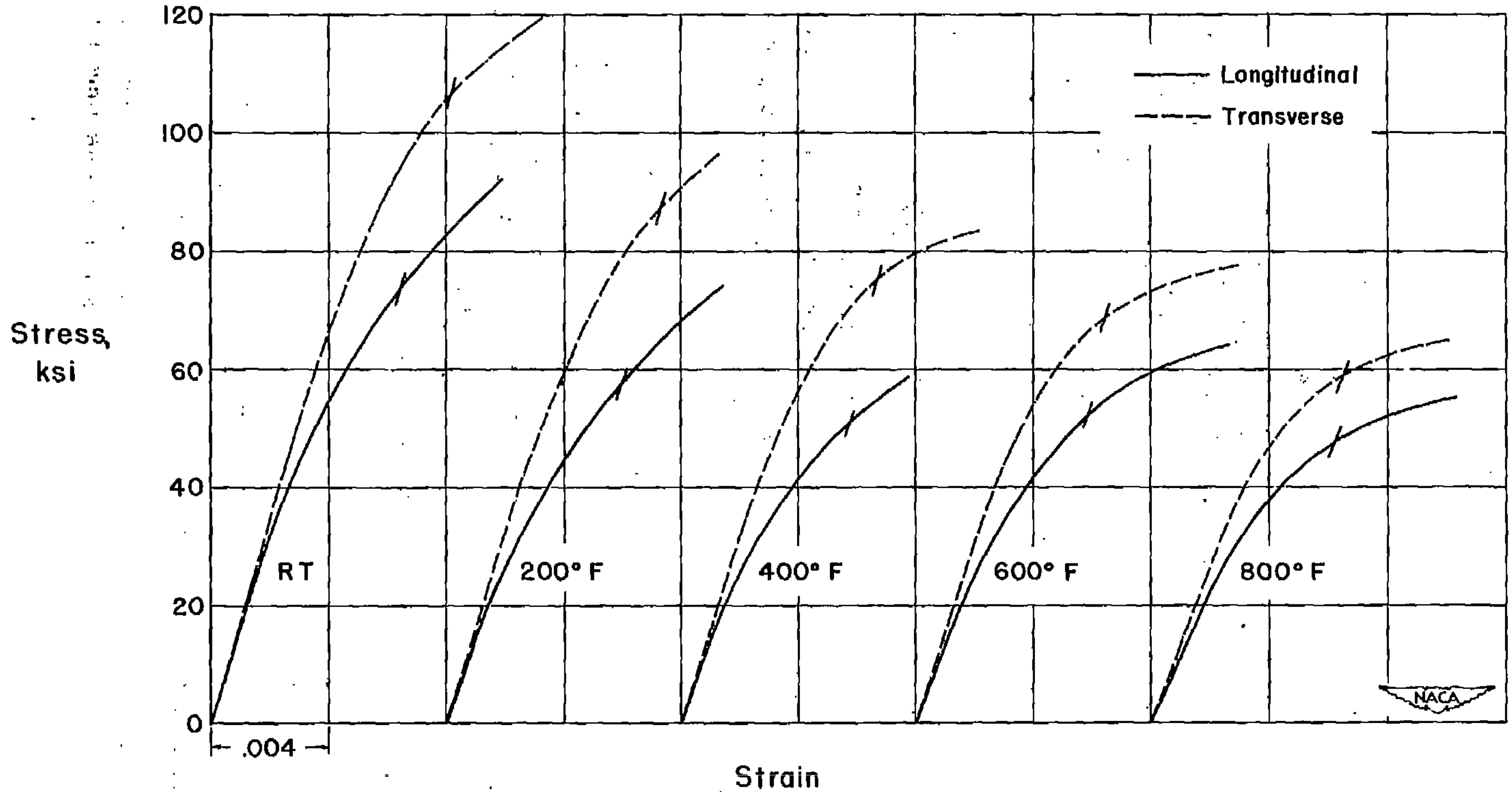



Figure 2.– Compressive stress-strain curves for 20-percent cold-worked titanium sheet for a strain rate of 0.002 per minute and an exposure time of 1 hour. (RT, Room temperature)

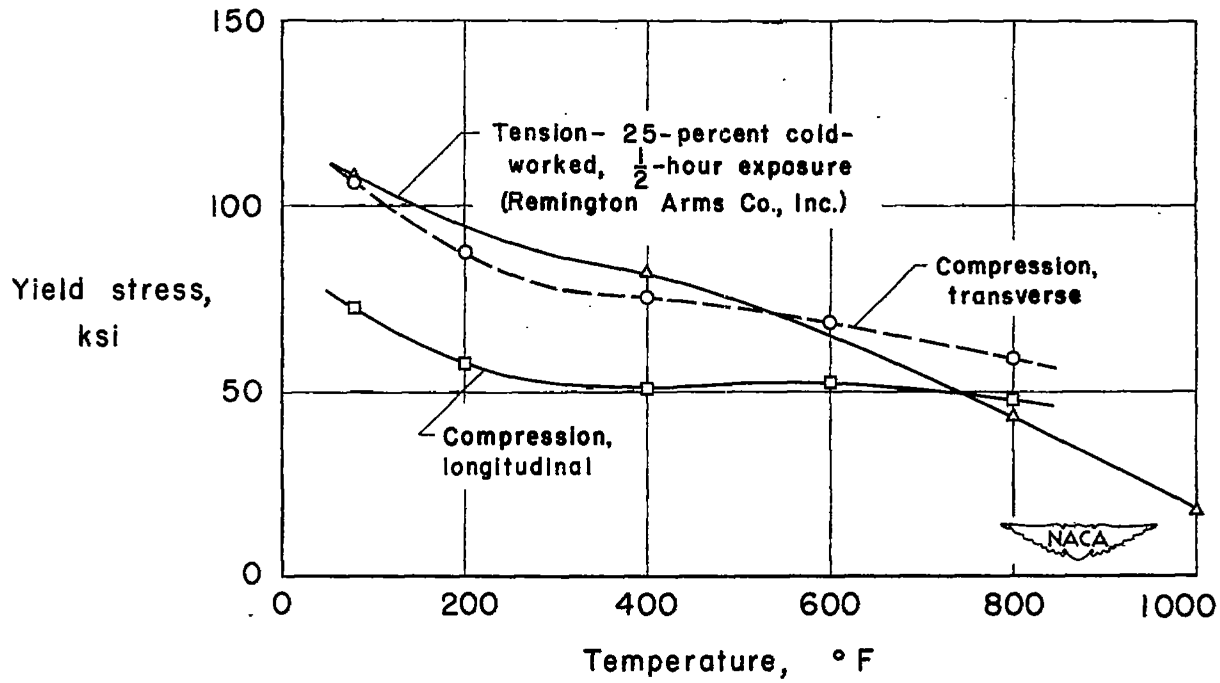



Figure 3.- Variation of yield stress (0.2 percent offset) with temperature for 20-percent cold-worked titanium sheet. For compression: exposure time 1 hour and strain rate 0.002 per minute.

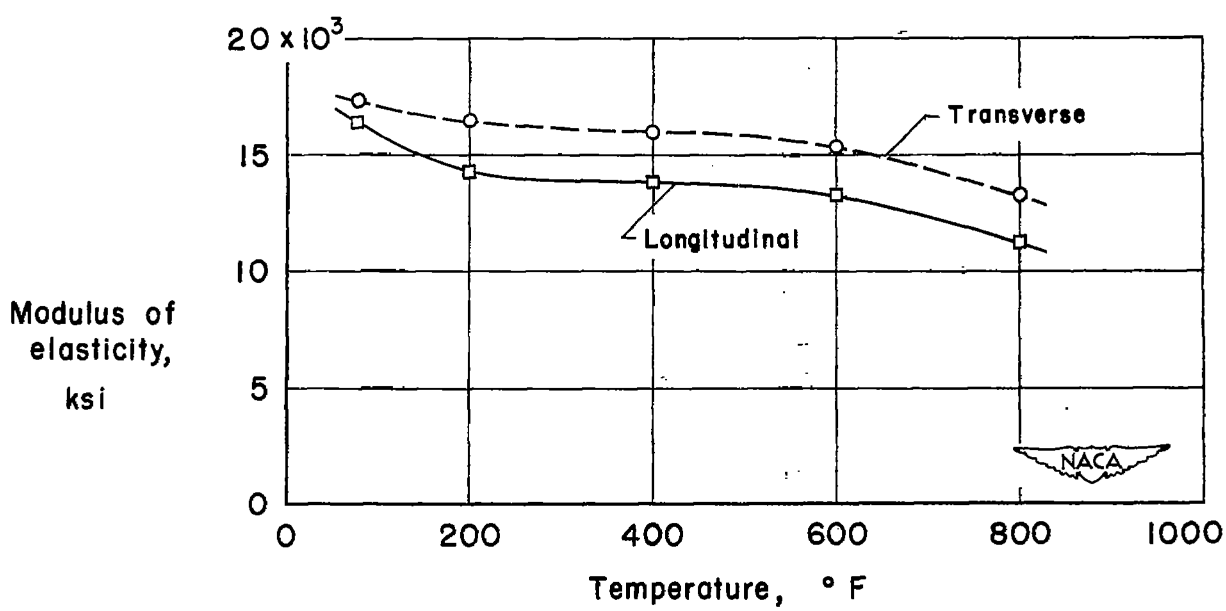



Figure 4.- Variation of modulus of elasticity in compression with temperature for 20-percent cold-worked titanium sheet. Exposure time 1 hour and strain rate 0.002 per minute.

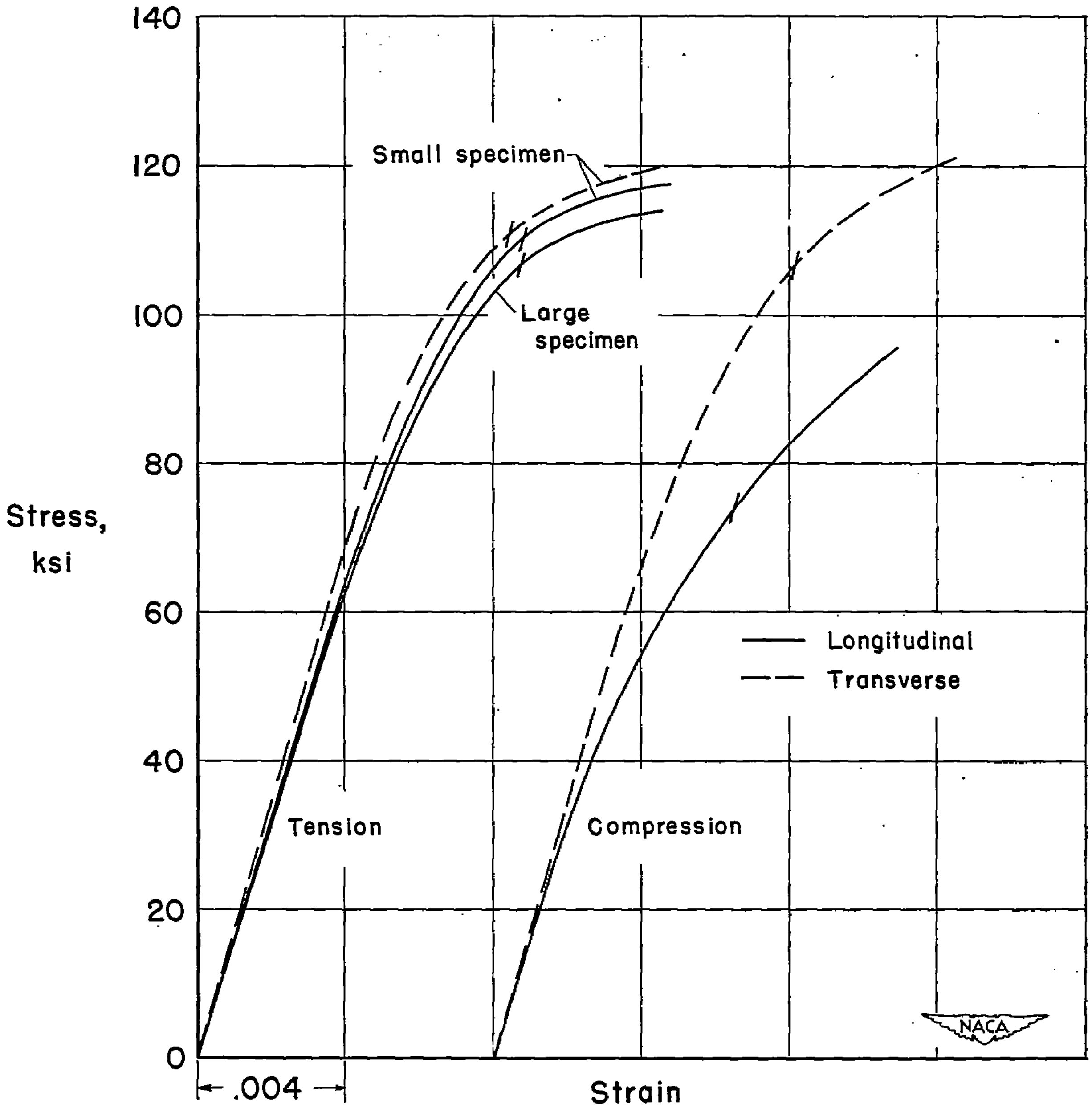



Figure 5.- Comparison of tensile and compressive properties of 20-percent cold-worked titanium sheet for both longitudinal and transverse grain directions at room temperature. (For tensile specimen dimensions, see fig. 1.)

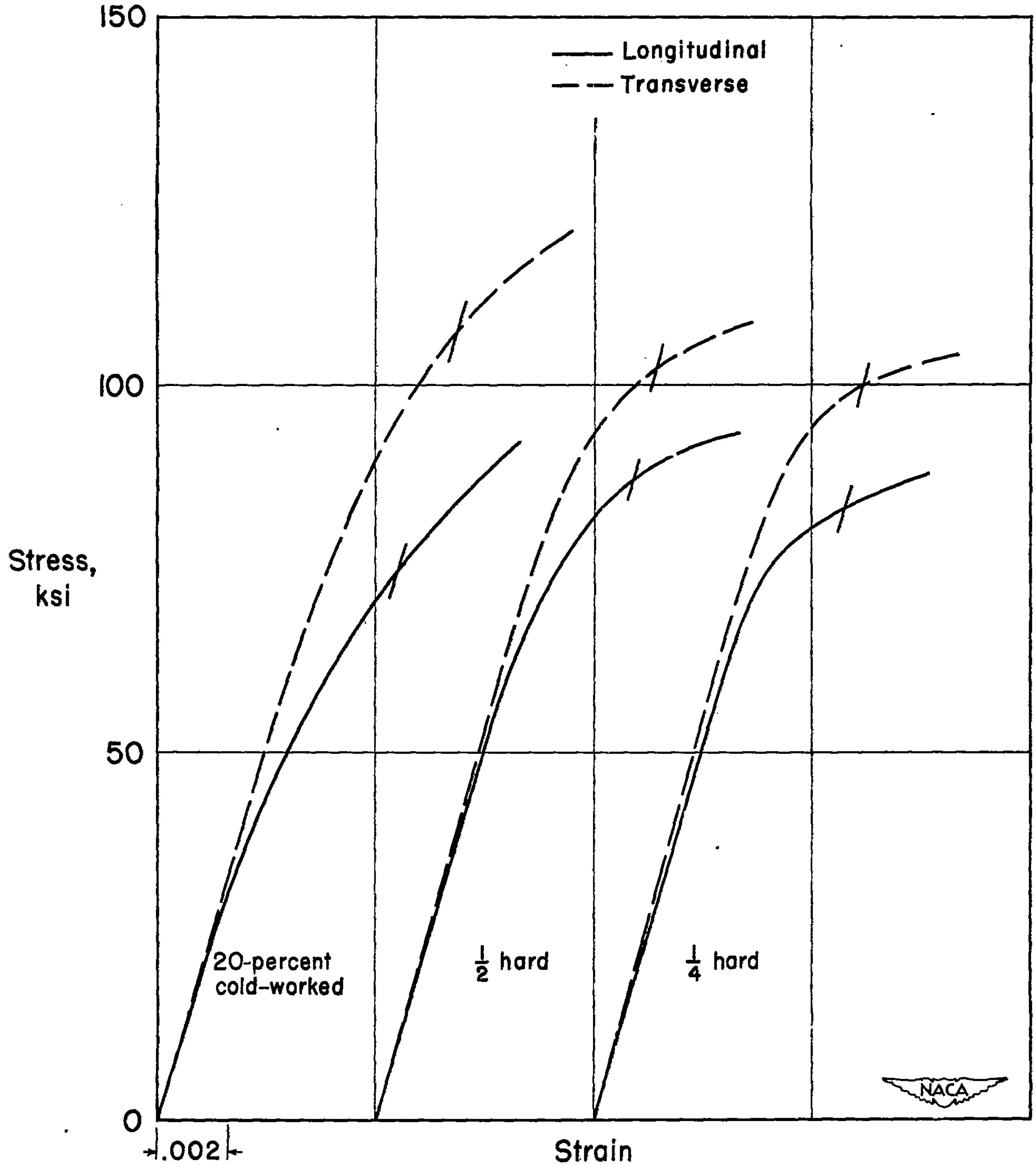



Figure 6. - Compressive stress-strain curves at room temperature for titanium sheet of various hardnesses.

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