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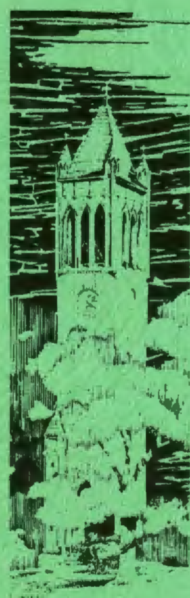

IOWA STATE UNIVERSITY

TENSILE TEST TO FIND ENDURANCE LIMIT OF STRAIN-AGEABLE METALS

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Knud Pedersen and Glenn Murphy

AMES LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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ABSTRACT

Fatigue curves for steel C-1118 were constructed for room temperature and 100°C from data collected from a number of fatigue tests. The endurance limit of the steel was estimated at the same temperatures from additional fatigue tests.

Cyclic tensile tests were performed on several specimens at each of the two temperatures, with each specimen receiving many cycles of loading and unloading. The proportional limits obtained from the cyclic curves were averaged for each temperature. The value thus obtained for the proportional limit was compared with the endurance limit and there appears to be good agreement.

I. INTRODUCTION

The authors previously investigated the fatigue and tensile properties of zirconium at temperatures ranging from 150 to 750°C. They found that for temperatures up to 450°C, which is approximately the recrystallization temperature for zirconium, the proportional limit as obtained from a series of tensile cycles fell within the range of determination of the endurance limit obtained from fatigue tests.

Zirconium is similar to low-carbon steel in many respects. When tested in tension it displays a yield point and when subjected to fatigue testing it displays an endurance limit. Although its fatigue strength is relatively low it has a high fatigue ratio (unnotched fatigue strength/tensile strength) similar to steel. The authors hypothesized that these similarities in mechanical properties of zirconium and steel were due to the strain-ageability of the two.

This investigation was undertaken to see if the proportional limit might also be used to approximate the endurance limit for steel.

II. MATERIAL AND EXPERIMENTAL PROCEDURE

A. Material

The steel was received as $\frac{1}{2}$ in. diameter cold-rolled bars which were cut into 4 in. lengths and machined to the specifications shown in Fig. 1. Since the grain structure appeared uniform no heat-treatment was performed on the specimens.

B. Equipment

The fatigue machines were all of the simply supported rotating beam type with a motor driving each end to eliminate torsional loads. The ends of the specimen were free to travel in the axial direction to eliminate shear loads along the test section. Marshall furnace controllers regulated the temperature in the split type Multiple Unit furnaces to within ± 2°C.

The number of cycles to failure was recorded on a revolution counter which indicated every 100 revolutions of the specimen and which shut off with the motors at the instant of failure.

Because the maximum test temperature was 100°C it was felt unnecessary to protect the specimens from atmospheric corrosion.

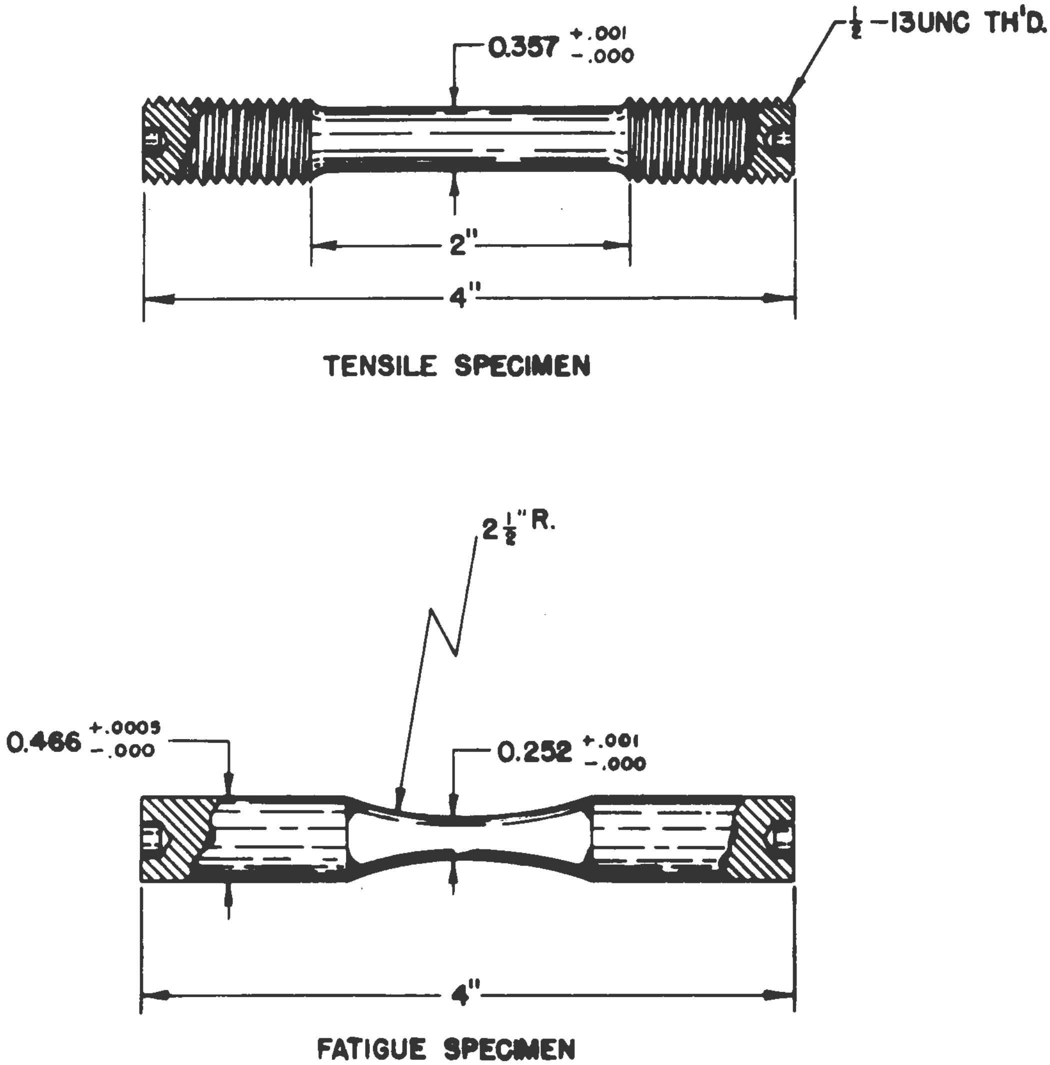

Fig. 1. Specimen dimensions.

The tensile machine was a 60,000-lb Baldwin-Southwark hydraulic unit. A linear variable differential transformer (LVDT) transferred the strain readings from the knife edges to the x-axis of a Mosley Autograf recorder and another LVDT connected to the Tate-Emery load indicator transferred the load readings to the y-axis of the recorder. In this manner a direct recording of load vs strain was obtained.

C. Testing Procedure

Half of the fatigue machines were calibrated to 100°C under dynamic conditions over a 12-h period to observe possible temperature fluctuations.

All of the fatigue machines were balanced while they were running at test speed. The balancing was done by placing two specimen halves in the grips and then adding or subtracting lead shot in the load pans until the specimen halves were aligned when viewed through a telescope. This procedure eliminated any bending moment on the specimen due to the weight of the structural numbers and the specimen itself.

The fatigue tests were performed at 4500 rpm. A specimen was started rotating when the power for the furnace was supplied, but the bending moment was not applied until after a steady-state temperature had been reached.

The tensile tests were performed at room temperature and 100°C with the latter temperature controlled electronically. The specimens were loaded slightly beyond the proportional limit and then unloaded; this process was repeated with continuous recording of the stress-strain diagram until the recorder paper was filled.

D. Calculations

The stress caused by the bending moment on the fatigue specimen was calculated by using the conventional formula $S = \frac{Mc}{I}$. Although this formula is valid only in the proportional range of stress it was applied in the non-proportional range for purposes of comparison.

S-N diagrams were made from least-square fitting of the fatigue data. The curves were assumed to be straight lines on log paper with the resulting equation of the form $\ln S = m \ln N + \ln b$, where S is the stress in psi, N is the number of cycles to failure, m is the slope and b is the intercept, at $N = 1$, in psi.

The proportional limit was found from an average of the cyclic tensile curves. As a result of strain hardening the proportional limit increases for the first few load applications until it attains a fairly constant value. Several load applications were made after the limiting proportional limit had been reached and the average was found from these tests.

The modulus of elasticity was found from the same curves by averaging the slopes.

III. RESULTS

The results of the fatigue tests are presented as S-N curves in Figs. 2 and 3 for room temperature and 100°C respectively. Autograf tracings of stress-strain diagrams from ordinary tensile tests are shown for the two temperatures in Figs. 4 and 5, and typical Autograf tracings

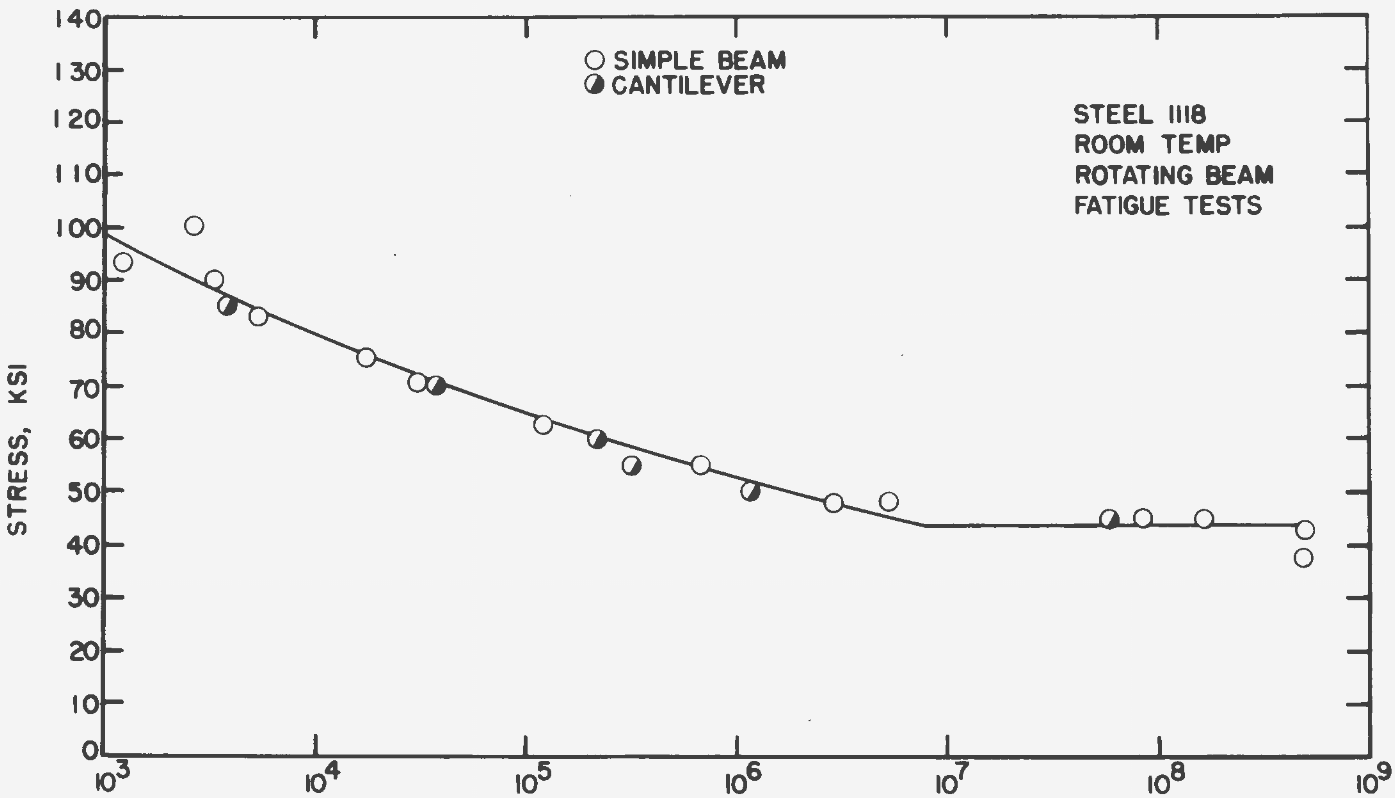

Fig. 2. S-N curve for steel 1118 at room temperature.

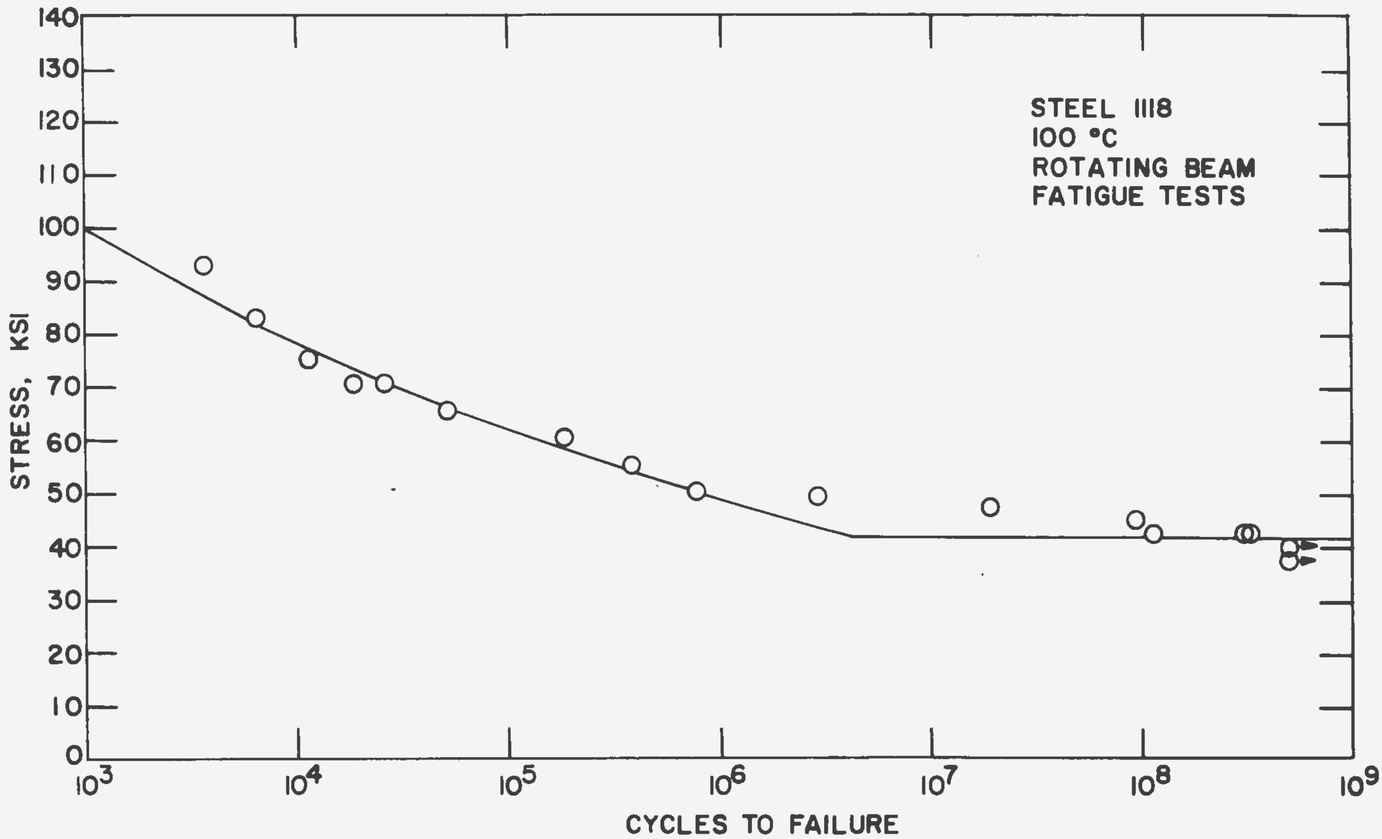

Fig. 3. S-N curve for steel 1118 at 100° C.

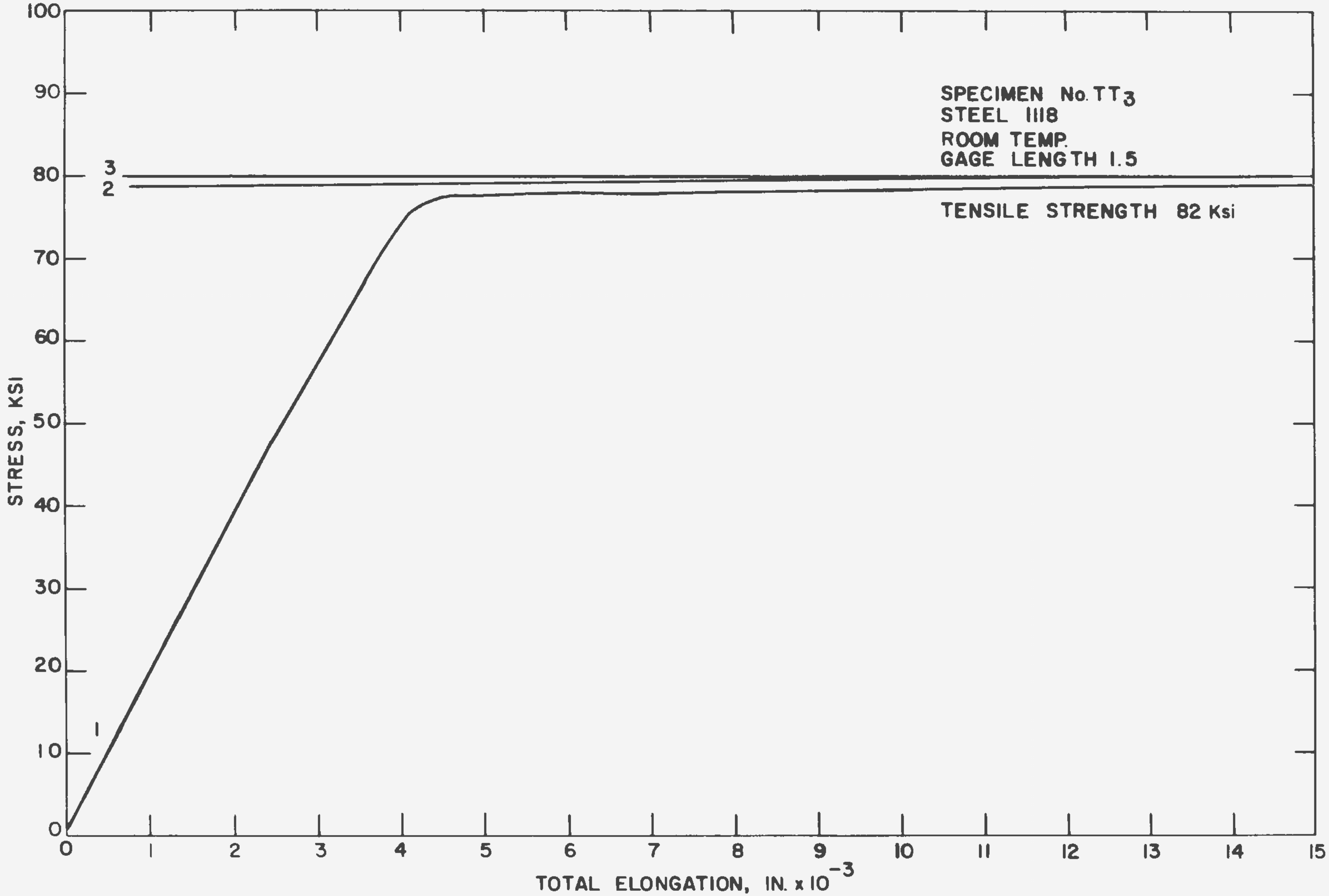

Fig. 4. Tensile curve for steel 1118 at room temperature.

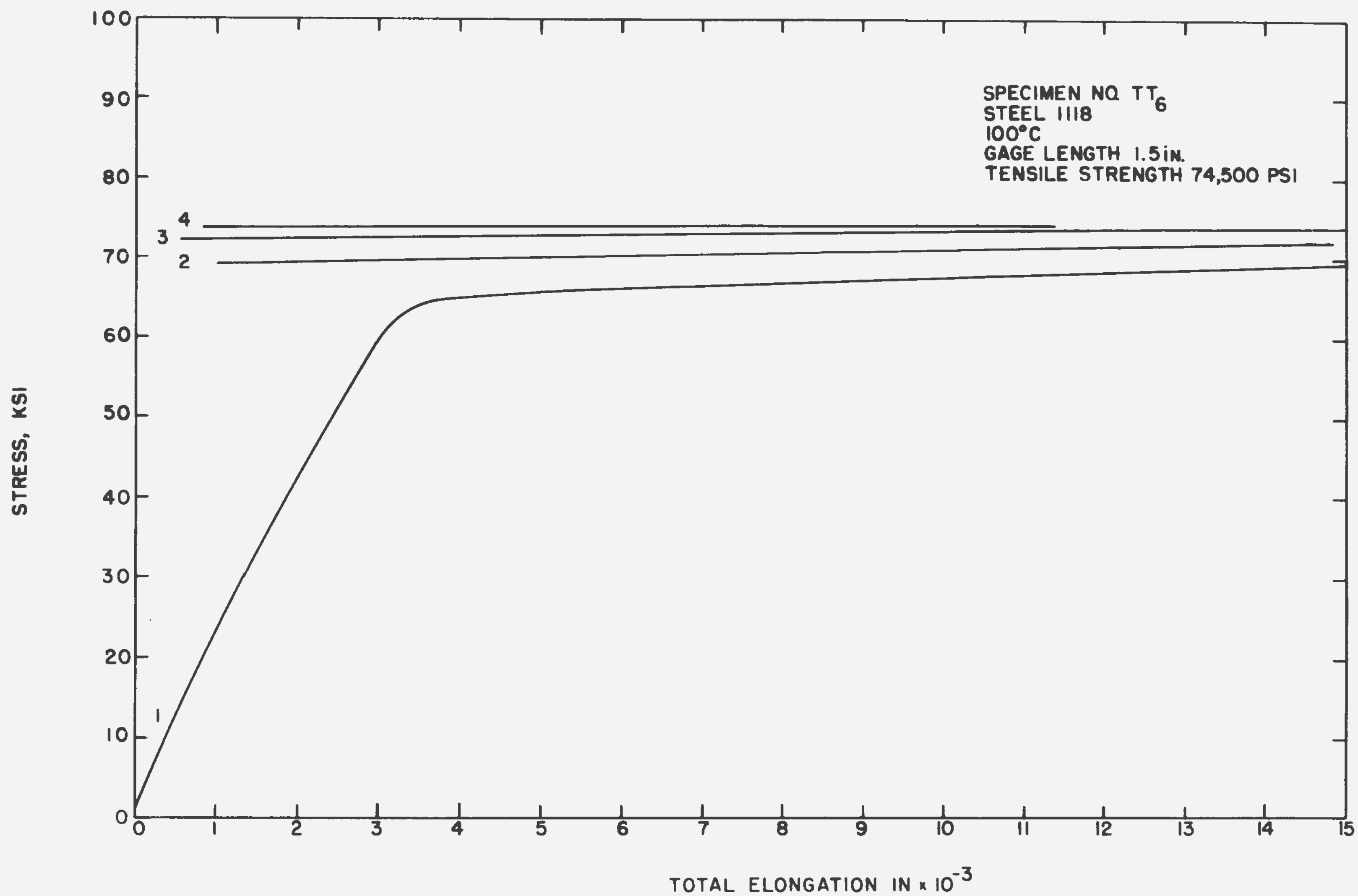

Fig. 5. Tensile curve for steel 1118 at 100° C.

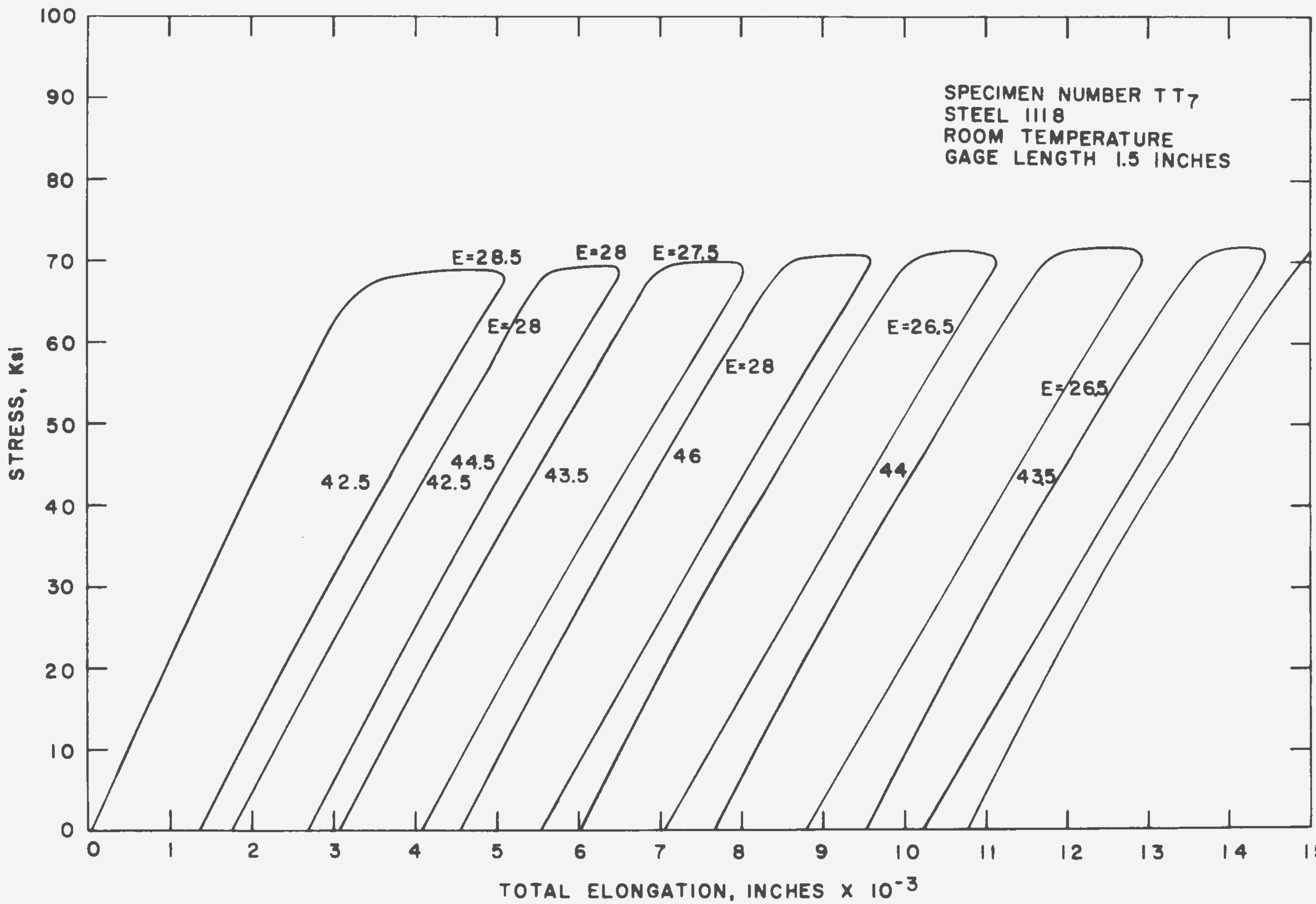

Fig. 6. Autograph recording of cyclic tensile loading at room temperature.

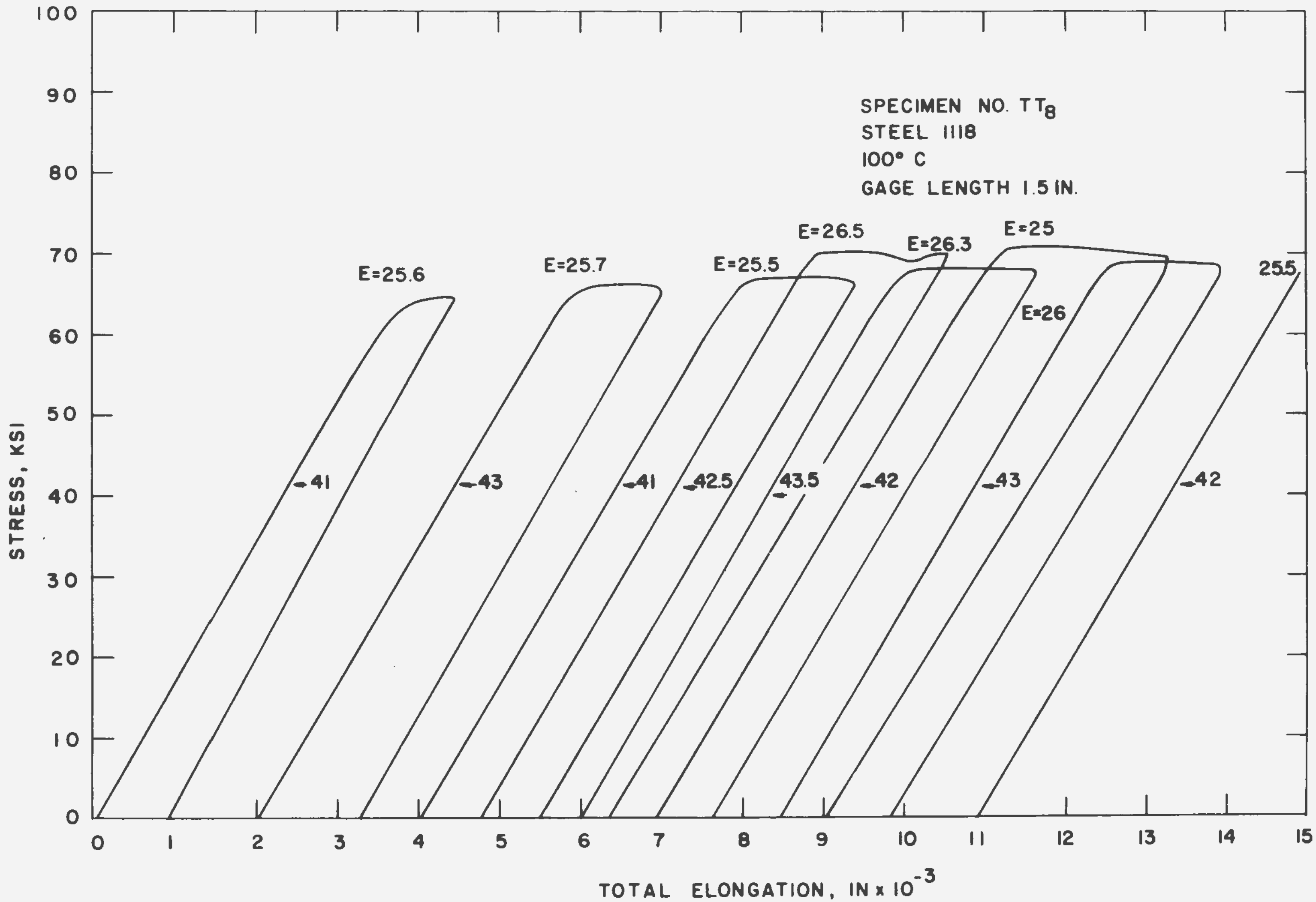

Fig. 7. Autograph recording of cyclic tensile loading at 100° C.

of cyclic tensile curves are shown in Figs. 6 and 7.

Table I lists fatigue and tensile properties of the material at the two test temperatures. The two columns headed "intercept" and "slope" are for the empirical equations describing the S-N curves, where ln b is the intercept and m is the slope.

The reason for this investigation was to compare the endurance limit with the proportional limit as obtained from cyclic tensile testing. The appropriate columns in Table I shows these results. It appears that the agreement between the two columns is sufficiently good that the proportional limit may be used to approximate the endurance limit.

IV. DISCUSSION

When a tensile specimen is cycled through a few cycles of loading and unloading the proportional limit will gradually increase due to strain hardening until a fairly constant value has been reached. If the specimen is never stressed beyond the proportional limit there will be no hysteresis loop, and energy being absorbed by the specimen upon loading will be released upon unloading. If the specimen were stressed in that manner it could withstand infinitely many cycles, and the endurance limit would be equal to the proportional limit.

With an increase in the environmental temperature the effect of annealing will play a role in the fatigue life. It is possible that the rearrangement and cancellation of the dislocations taking place during repeated reversed deformation, together with an elevated temperature

Table I

Average Tensile and Fatigue Properties of Steel 1118

Temp. °C	Tensile strength ksi	Young's Modulus psi x 10^6	Proportional limit ksi	Endurance limit ksi	Fatigue ratio	Intercept $\log_e b$	Slope $-m$
25	80.5	27.6	43.4	44	0.547	12.126	0.091
100	74.5	25.0	42.1	42	0.564	12.217	0.102

that allows easier movement of the dislocations, would allow the material to be stressed indefinitely above its proportional limit. With a further increase in temperature, recrystallization will take place and delay failure of the material, so the amount above the proportional limit which the material could be stressed indefinitely would increase due to the increased mobility of the dislocations and the increased rate of recrystallization.

This effect was found in the investigation of zirconium which was carried well beyond the recrystallization temperature. Up to the recrystillization temperature the proportional limit and the endurance limit were similar, but above that temperature the endurance limit was greater and became more so with increasing temperatures.

V. CONCLUSION

The endurance limit of steel 1118 may be approximated by the proportional limit found from cyclic tensile tests at least room temperature and 100° C. Based on tests performed on zirconium it is believed that this approximation will hold up to the recrystallization temperature.