FATIGUE BEHAVIOR OF COLD WORKED PLAIN CARBON STEEL

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ABSTRACT

The fatigue behavior of previously cold worked specimens of a low carbon steel was studied. The specimens were subjected to various tensile plastic strain amplitudes and then fatigue loaded until fracture. It is shown that the cyclic plastic strain amplitude presents characteristic changes as a function of previous cold work. At low prestrain, the specimens first exhibited softening and then hardening or saturation. The high prestrained specimens did not show hardening nor saturation, they simply showed a continuous softening until fracture. Specimen shortening was also measured. All cold worked specimens shorten their lengths as a function of the previously imposed plastic strain and the fatigue load amplitude. Finally, fatigue life decreases and then increases as the cold work goes from 0 to 15%.

KEYWORDS

Cyclic plastic strain amplitude; mean plastic strain amplitude; softening; hardening; shortening.

INTRODUCTION

The mechanism of fatigue has been well studied in recent years encompassing the three aspects: a) cyclic deformation, b) crack initiation and c) crack propagation to fracture. The first one, cyclic deformation, has been largely studied in annealed or normalized metals (1-3) and to a lesser extent in cold worked specimens (4-9).

In these works it is asserted that, depending on the initial state (annealed, cold worked, tempered) and test conditions, a metal may cyclically harden, soften, be stable or have a mixed behavior. It is also accepted that annealed pure metals harden and cold worked pure metals soften but always a more or less saturated behavior is achieved and a cyclic stress-strain curve is

defined with the stable strain and stress (10).
Macroscopic changes of length of strained specimens under cyclic loading has also been reported (11). It was shown that medium steel specimens prestrained 1.7% reduce their length when they were cyclically loaded.

EXPERIMENTAL PROCEDURE

Experiments were carried out on cylindrical specimens with a gauge diameter of 8 mm, made of a AISI 1020 steel (0.2% C, 0.5% Mn, 0.2% Si, 0.02% S and 0.03% P.). Specimens were annealed and furnace cooled. The tensile properties were: Rel=250 MPa., Reh= 265 MPa., Rm=420 MPa., Am=25% and Z=69%.
The experiments were performed on a servo-hydraulic testing machine and the procedure was as follows: first, the specimens were tensile strained under displacement control and with a strain rate of 0.004 (1/seg) until desired plastic strain was achieved. Afterwards, and without dismounting the specimen, the machine was changed to load control and a sinusoidal tension-compresion load with a frequency of 5 Hz was applied until failure occurred.The mean load was always zero (R=-1). The plastic strain amplitude and the mean strain, the last one defined as the middle point of the hysteresis loop, were recorded as a function of the number of cycles.

RESULTS

In fig. 1 the plastic strain amplitude is shown as a function of the number of cycles for the annealed specimens. As observed, the specimens cyclic loaded with a stress amplitude lower than the lower yield stress show a initial phase in which the cyclic deformation is aproximately zero (elastic behavior), followed by a sharp increase of the plastic strain amplitude which is a consequence of the cyclically induced softening process of the material. After reaching maximum softening, tha plastic strain amplitude decreases until fracture.
Fig. 2 shows the cyclic behavior of the specimens with 2% prestrain. As compared with the annealed specimens, the prestrained ones do not show the initial elastic phase but they have plastic deformation from the beginning of the test. This initial plastic strain amplitude remains constant for a number of cycles and then follow the softening and hardening as in the annealed specimens. The plastic strain amplitude reached by these specimens are close to the plastic strain amplitude from the annealed specimens.
The high prestrained specimens showed a completely different behavior. As an example, fig. 3 shows the plastic strain amplitude from the 15% prestrained specimens. The width of the hysteresis loops for these specimens were closed at the beginning of the test and remain closed for a large number of cycles, depending of the stress amplitude.After this incubation phase, a softening process appears, the plastic strain amplitude becomes larger.Unlike from the annealed and the low strained specimens, the high prestrained specimens do not show hardening but they keep softening until fracture occurs. Specimens with 6 and 8% prestrain showed the same qualitative behavior. It is important to note

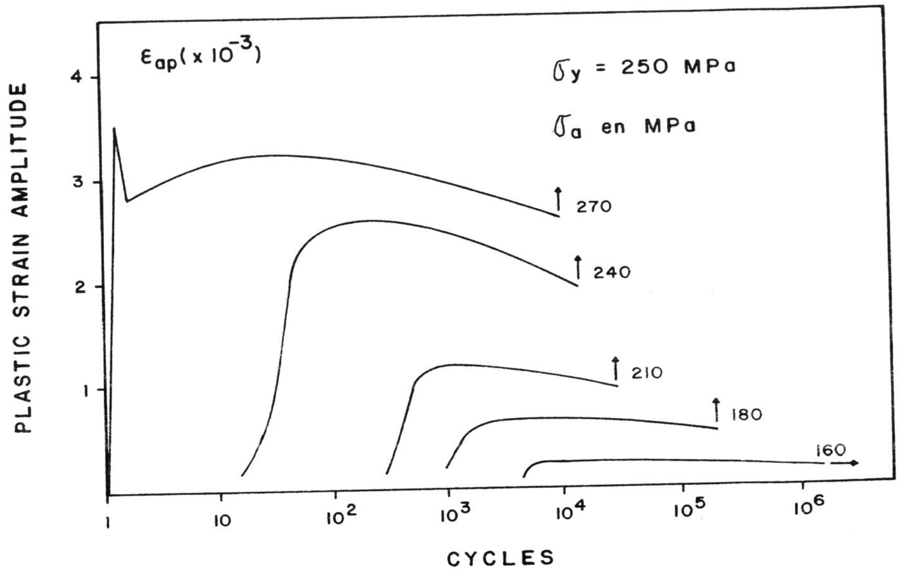

Figure 1.- Plastic strain amplitude as a function of the number of cycles for the annealed specimens.

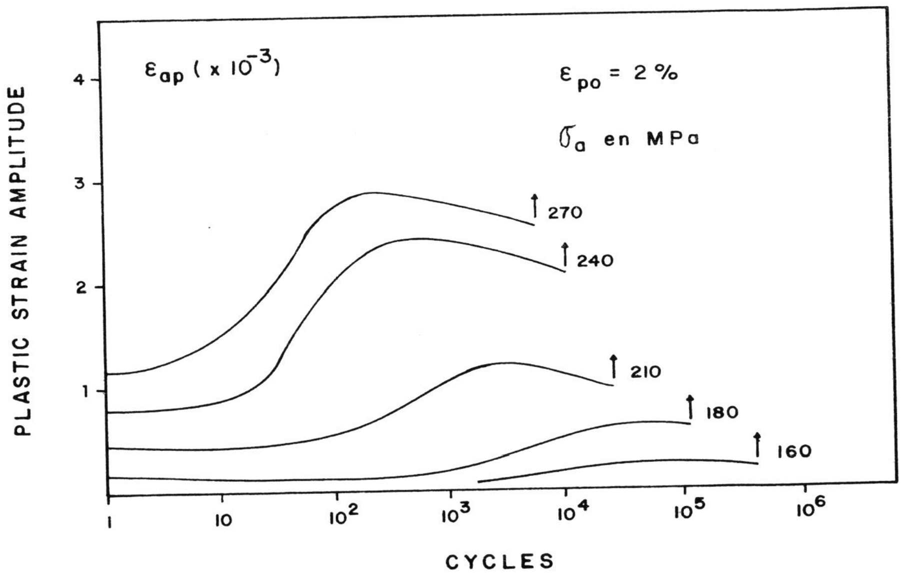

Figure 2.- Plastic strain amplitude as a function of the number of cycles for the 2% prestrained specimens.

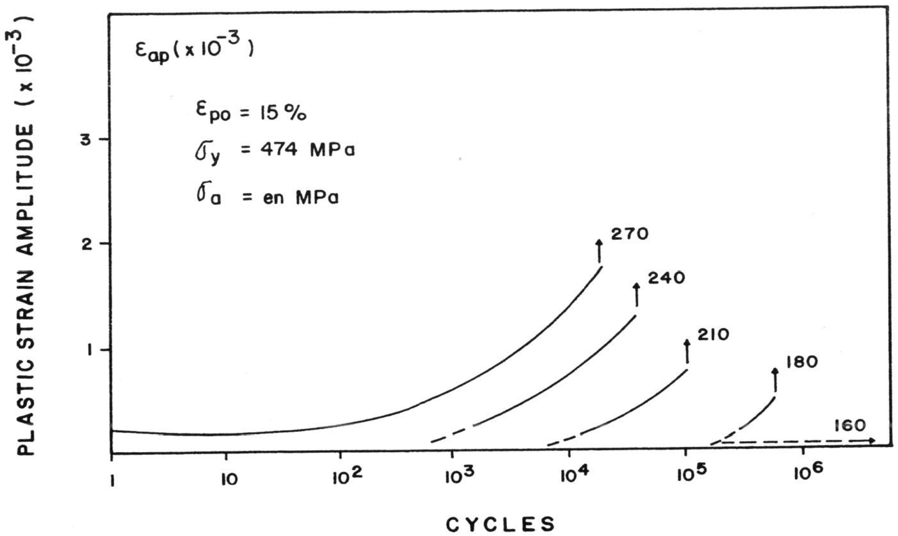

Figure 3.- Plastic strain amplitude as a function of the number of cycles for the 15% prestrained specimens.

that this softening is not due to crack opening. Observations of the hysteresis loop and specimen surface showed that the crack influenced the plastic strain amplitude aproximately in the last 10% of fatigue life.

With this behavior, obviously, it is impossible to apply the traditional method to determine the cyclic stress-strain curve, simply because there is no stable stress and strain. In order to calculate these curves, it was necesary to define a "mean plastic strain amplitude" calculated as the area under the curve of strain vs. the number of cycles divided by the number of cycles to fracture. This mean plastic strain amplitude is used in fig. 4, where the cyclic stress-strain curved of all specimens is showed.In this figure it can be observed that prestrain raises the cyclic curve to higher stresses, except in the case of 2% prestrain.

The behavior of the mean strain for the 2% prestrained specimens as a function of the number of cycles is shown in fig. 5. In the first cycle a shortening occurs due to the Bauschinger effect. Afterwards, the hysteresis loop keeps moving in the direction of zero deformation.That means that the specimens reduced their length.For example, a 2% prestrained specimen, cyclically loaded with a stress amplitude of 240 MPa, ends up with a prestrain of 0.5%. Similary, the 15% prestrained specimen loaded with 240 MPa, ended up with 9% prestrain, as shown in fig. 6. The cyclically shortening from all prestrained specimens as a function of the prestrain and the load amplitude is shown in fig 7.

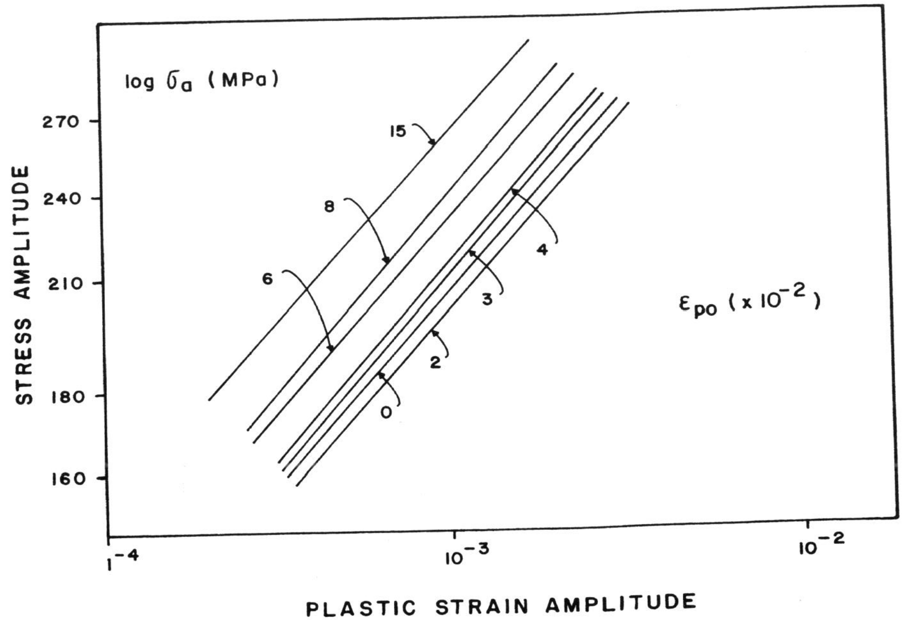

Figure 4.- Cyclic stress-strain curves for the annealed and prestrained specimens.

Finally, the fatigue life of the prestrained specimens was compared with the life of annealed specimens. Fig. 8 represents the relative life (number of cycles to fracture of the prestrained specimen divided by the number of cycles to fracture of the annealed specimen for the same load amplitude) as a function of prestrain. As shown, prestrains until aprox. 3.5% reduce the fatigue life of specimens. Higher prestrain increases the number of cycles to fracture.

CONCLUSIONS

The cyclic load behavior of prestrained low carbon steel was studied and it was shown that:

1.- Plastic strain amplitude as a function of the number of cycles is influenced by prestrain.

2.- Low prestrained specimens (6%) show a plastic strain amplitude from the beginning of the test and then follow a softening and a hardening.

3.- High prestrained specimens (6%) do not show saturation nor hardening. They keep softening until fracture occurs.

4.- The prestrain is reduced during the fatigue load, that means the specimens reduced their length along the cycles.

5.- Low prestrain reduces the fatigue life of specimens.High prestrain increases it.

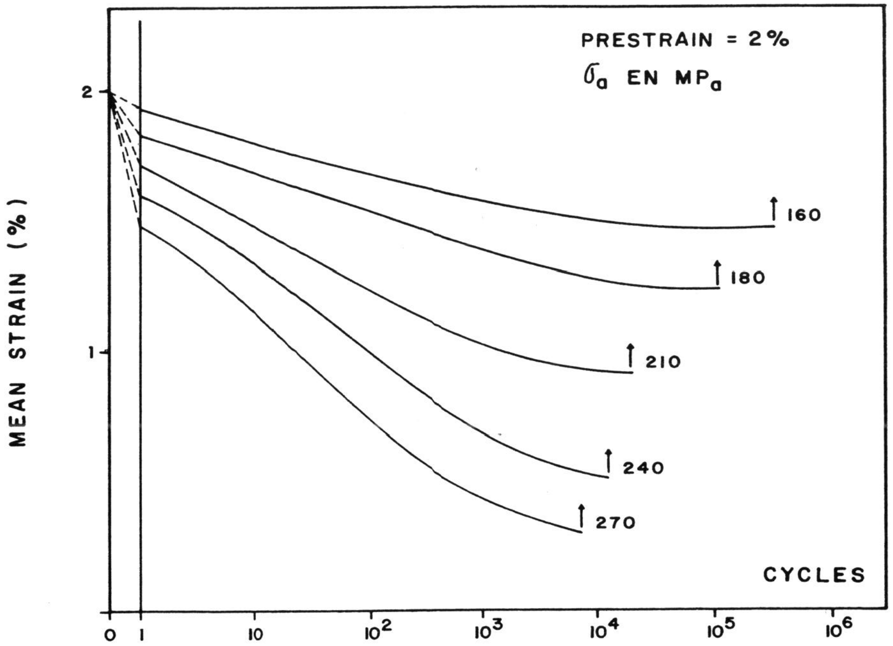

Figure 5.- Mean strain (middle point of the hysteresis loop) as a function of number of cycles for the 2% prestrained specimens.

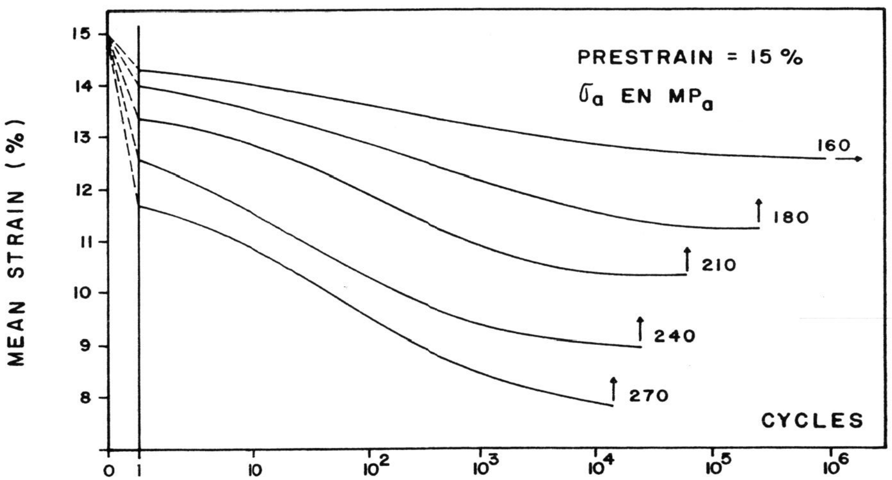

Figure 6.- Mean strain as a function of number of cycles for the 15% prestrained specimens.

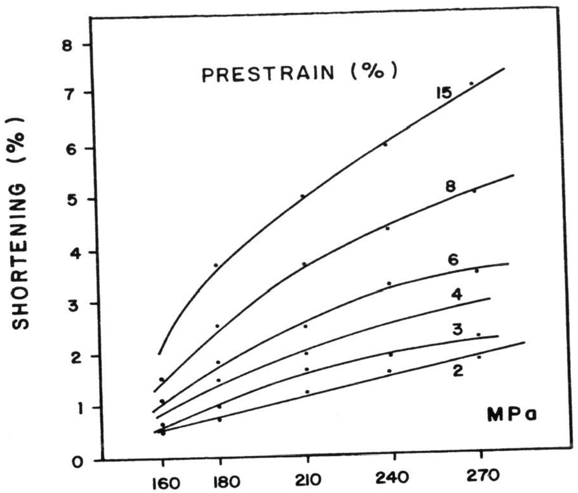

Figure 7.- Cyclical shortening as a function of prestrain and load amplitude for all prestrained specimens.

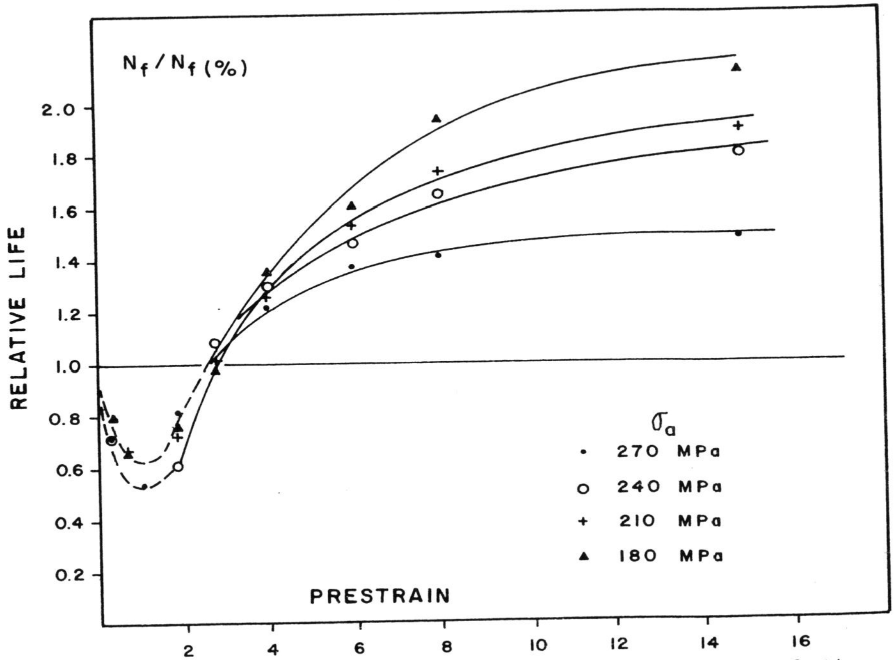

Figure 8.- Relative life (number of cycles to fracture of the prestrained divided by the of the annealed specimens for the same load amplitude)vs. prestrain.

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