Fatigue Behavior, Monotonic Properties

and

Microstructure Data

for

1117, Carburized (Case) Steel

(Iteration No. 52)

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SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for 1117 Carburized (Case) steel (Iteration # 52) have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of 1.75" bars. These bars were machined into smooth axial fatigue specimens. The specimens were heat treated by the AISI group to reach a hardness of about 62 Rc. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Twenty specimens were fatigue tested in laboratory air at room temperature to establish a strain-life curve.

INTRODUCTION

This report presents the results of tensile and fatigue tests performed on a group of 22, 1117 Carburized (Case) steel samples. The material was provided by the American Iron and Steel Institute.

The objectives of this investigation were to obtain the chemical analysis, and microstructural data, mechanical properties, cyclic stress-strain data and strain-life fatigue data requested by the AISI bar group.

EXPERIMENTAL PROCEDURE

Specimen Preparation

The material for the study was received in the form of bars. Smooth cylindrical fatigue specimens, shown in Figure 1, were machined from the metal bars. The gauge sections of the fatigue specimens were mechanically polished in the loading direction using 240, 400, 500, and 600 emery paper. After polishing, a thin band of M-coat D acrylic coating was applied along the central gauge section. The purpose of the M-coat D application was to prevent scratching of the smooth surface by the knife-edges of the strain extensometer, thus reducing the incidence of knife-edge failures. In total, 20 fatigue data points were generated.

Test Equipment and Procedure

Two monotonic tension tests were performed to determine the yield strength, the tensile strength, the percent of elongation and the percent reduction of area. Hardness tests were performed on the surface of three fatigue specimens using a Rockwell C scale. The hardness measurements were repeated three times for each specimen and the average value was recorded.

All fatigue tests were carried out in a laboratory environment at approximately 25 ^{o}C using an MTS servo-controlled closed loop electrohydraulic testing machine. A process control computer, controlled by FLEX software [1] was used to output constant strain and stress amplitudes in the form of a sinusoidal wave.

Axial, constant amplitude, fully reversed (R=-1) strain-controlled fatigue tests were performed on smooth specimens. The stress-strain limits for a given cycle of each specimen were recorded at logarithmic intervals throughout the test via a peak reading oscilloscope. Failure of a specimen was defined as a 50 percent drop in tensile peak load from the peak load observed at one half the expected specimen life. For fatigue lives greater than 100,000 reversals, the specimens were tested in stress-control once the stress-strain loops had stabilized. For the stress-controlled tests, failure was defined as the separation of the smooth specimen into two pieces. For strain-controlled tests the loading frequency varied from 0.03 Hz to 5 Hz while in stress-controlled tests the frequency used was up to 110 Hz.

The first reversal of each fatigue test was recorded on a x-y plotter, allowing the elastic modulus (E) and the monotonic yield strength to be determined.

RESULTS

A) Microstructure Data

Figure 2 presents the martensite microstructure of the 1117 Carburized (Case) steel. A Type D series inclusion severity level of 1 was obtained based on ASTM E45 (Method A). Inclusions of types A, B and C were not observed. Figure 3 shows the inclusions observed in the 1117 Carburized (Case) steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 1117 Carburized (Case) steel was provided by the MacSteel Company, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for 1117 Carburized (Case) steel obtained in this investigation are given in Table 2. The stress amplitude corresponding to each strain-amplitude was calculated from the peak load amplitude at the specimen half-life.

A fatigue strain-life curve for the 1117 Carburized (Case) steel is shown in Figure 4, and is described by the following equation:

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c$$

where $\frac{\Delta\varepsilon}{2}$ = True total strain amplitude

$2N_f$ = Number of reversals to failure

σ'_f = Fatigue strength coefficient

b = Fatigue strength exponent

ε'_f = Fatigue ductility coefficient

c = Fatigue ductility exponent

Where σ'_f = 1474 MPa, b = -0.097, ε'_f = 0.013% and c = -0.04. These values of the strain-life parameters were determined from fatigue testing over the range: $0.0018 < \frac{\Delta\varepsilon}{2} < 0.05$.

C) Cyclic Stress-Strain Curves

Stabilized and half-life stress data obtained from strain-life fatigue tests were used to obtain the companion cyclic stress-strain curve shown in Figure 5. The cyclic stress-strain curve is described by the following equation:

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K'}\right)^{\frac{1}{n'}}$$

where ε = True total strain amplitude

σ = Cyclically stable true stress amplitude

K' = Cyclic strength coefficient

n' = Cyclic strain hardening exponent

Where K' = 17577 MPa and n' = 0.332.

D) Mechanical Properties

The engineering monotonic stress-strain curve is given in Figure 6. The monotonic and cyclic properties are included in Appendix 1. The Hardness of the 1117 Carburized (Case) steel was taken as the average of three randomly chosen fatigue specimens and is given in Appendix 1. The individual hardness measurements are also given in Table 2. The true monotonic and true cyclic stress-strain curves plotted together are given in Figure 7.

REFERENCES

[1] Pompetzki, M.A., Saper, R.A., and Topper, T.H., "Software for High Frequency Control of Variable Amplitude Fatigue Tests," Canadian Metallurgical Quarterly, Vol. 25, No. 2, pp. 181-194, 198.

[2] J. A. Bannantine, J. J. Comer, and J. L. Handrock (1990), In :Fundamentals of Metal Fatigue Analysis, Prentice Hall, London.

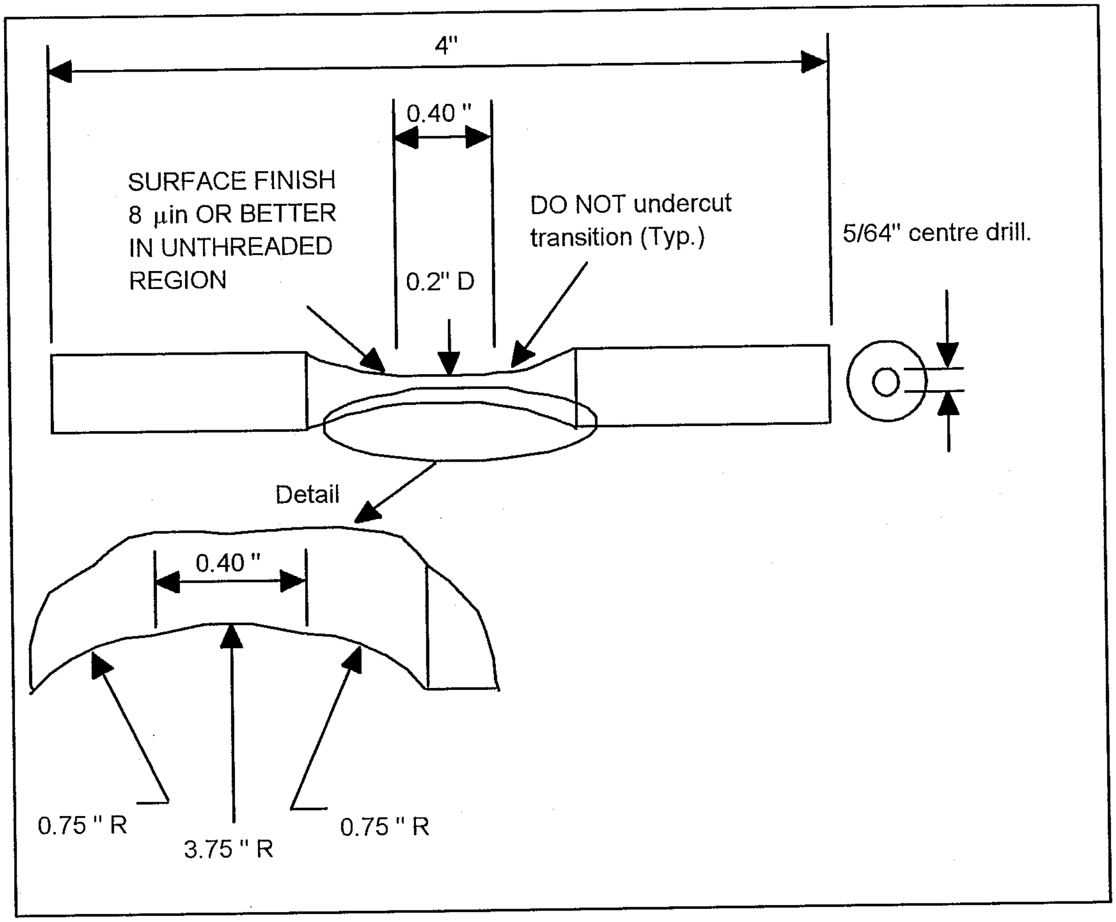
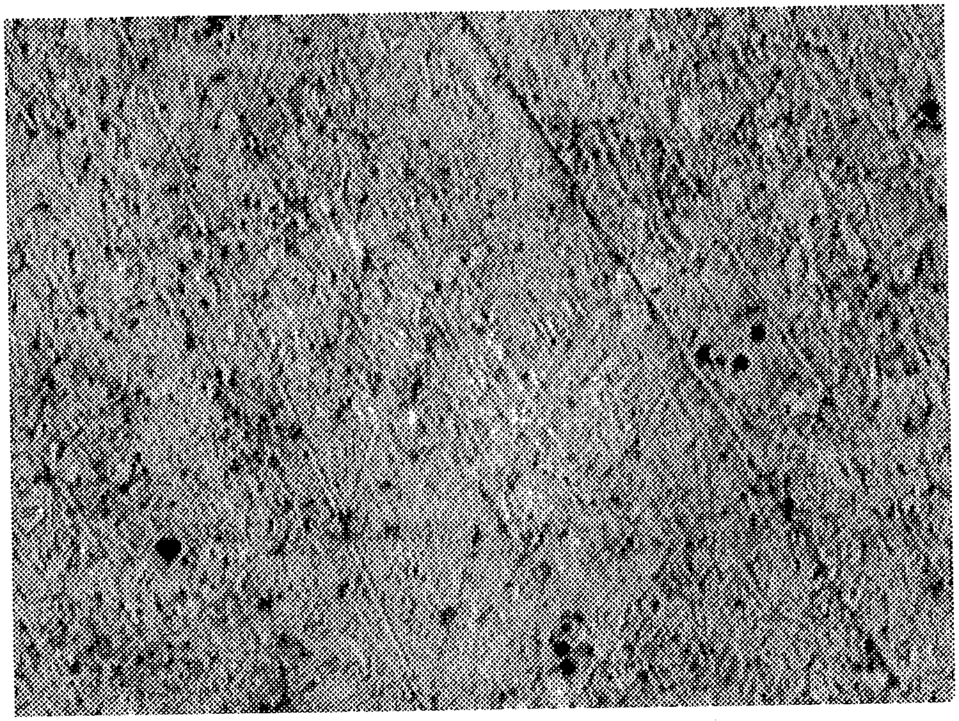
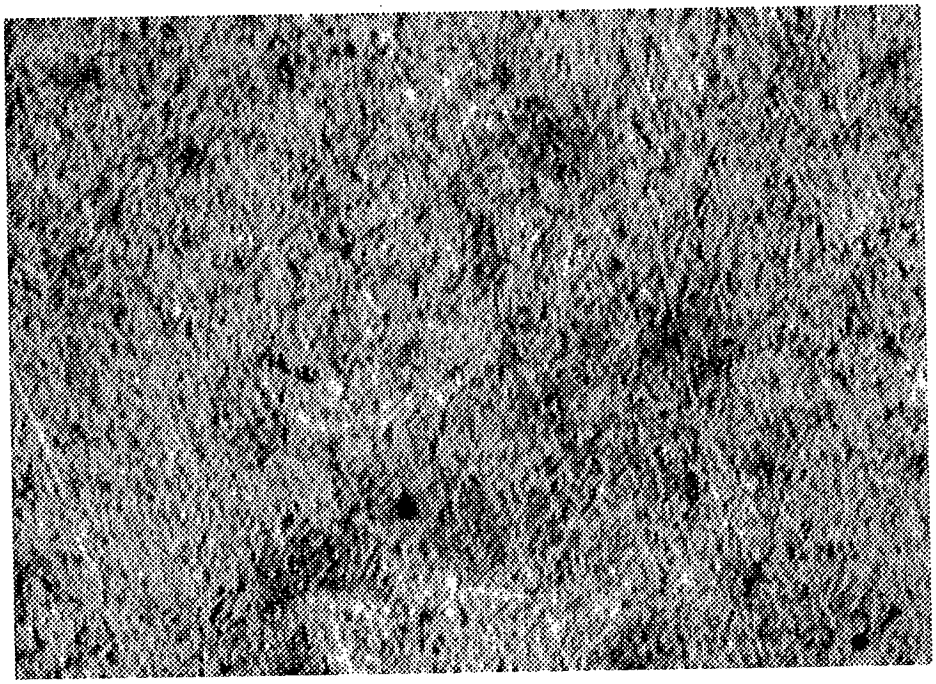


Fig. 1 Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2. Photomicrographs of 1117 Carburized (Case) steel (X500)

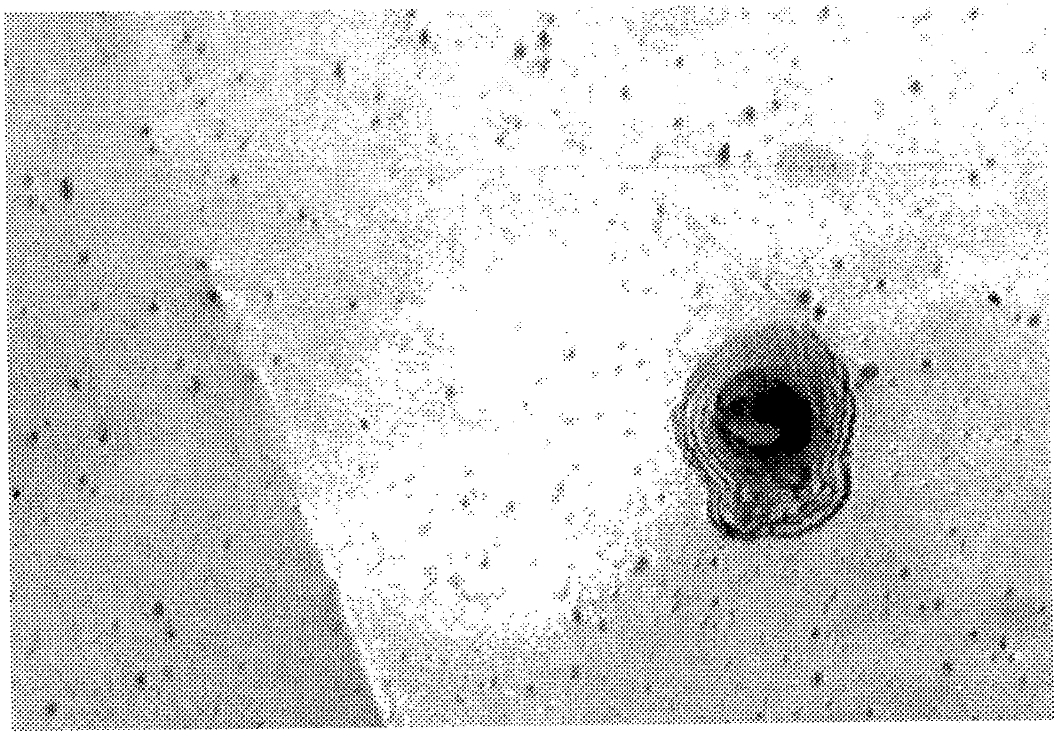


Figure 3. Inclusions photomicrograph of 1117 Carburized (Case) steel (X100)

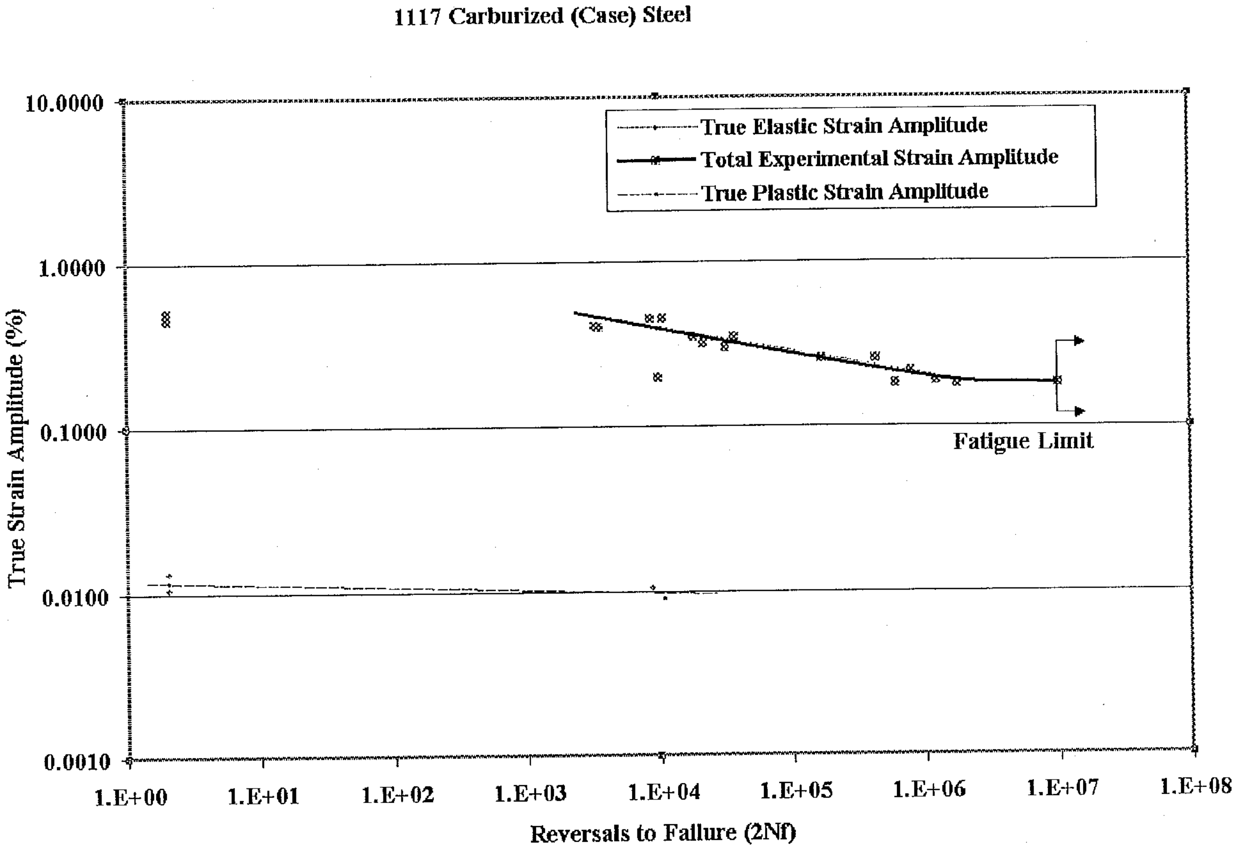


Figure 4. Constant amplitude fully reversed strain-life curve for 1117 Carburized (Case) steel.

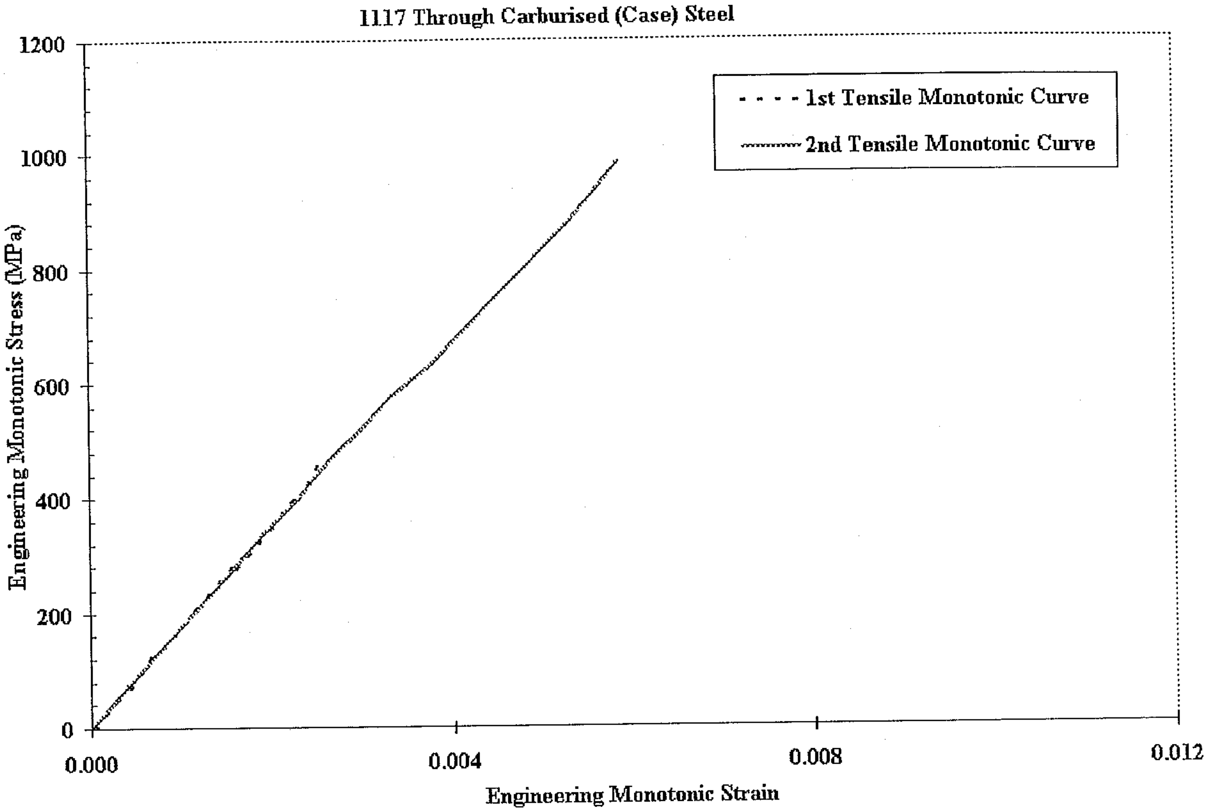


Figure 5. Monotonic stress-strain curves for two 1117 Carburized (Case) steel specimens.

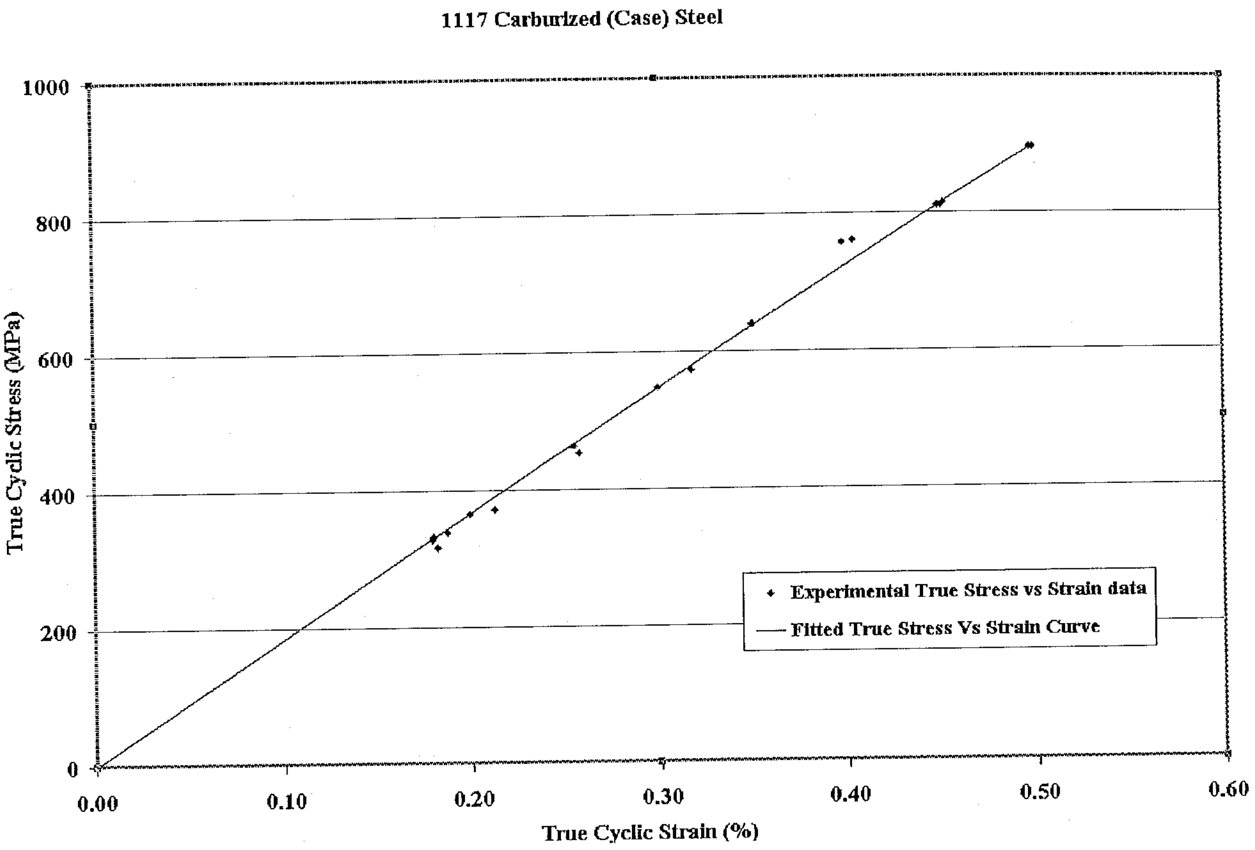


Figure 6. Cyclic stress-strain curve for 1117 Carburized (Case) steel.

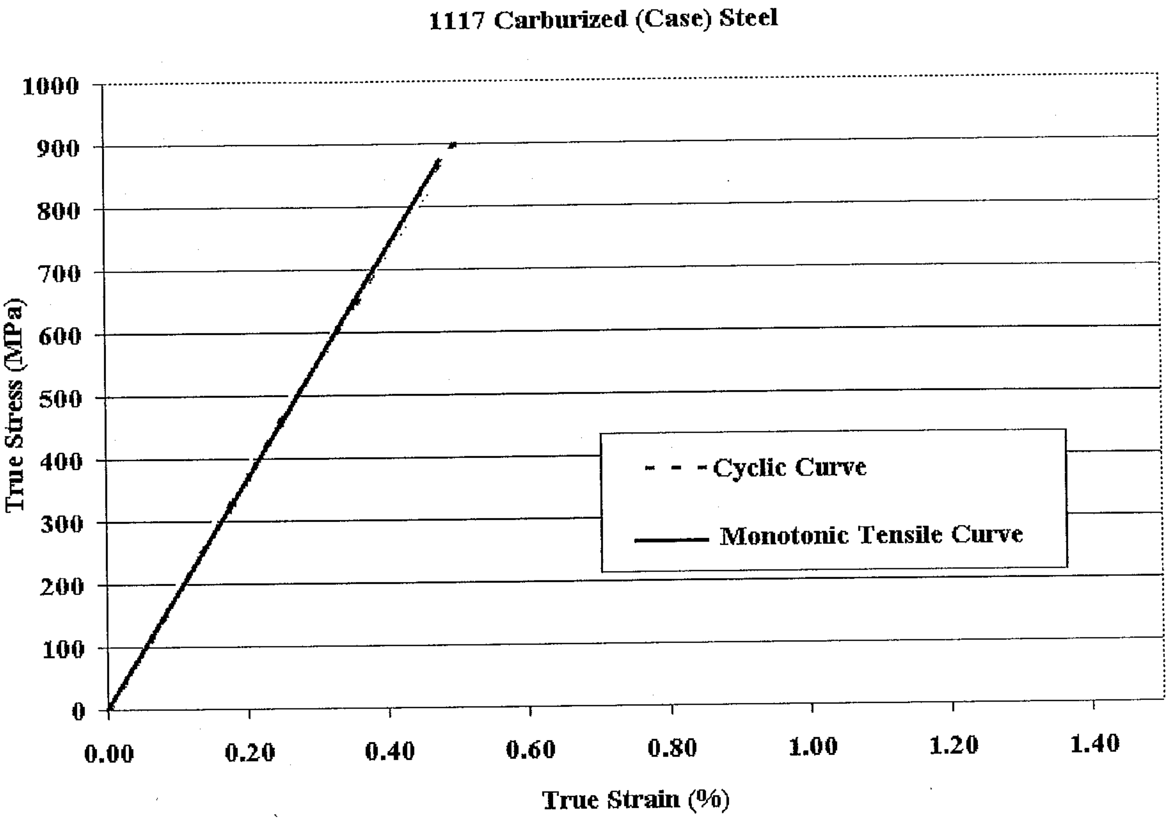


Fig. 7 Monotonic and Cyclic stress-strain curves for 1117 Carburized (Case) steel.

Table 1 Chemical composition of 1117 Carburized (Case) steel.

Carbon, C	0. 18%
Manganese, Mn	1.22%
Phosphorous, P	0.012%
Sulfur, S	0.215%
Silicon, Si	0.14%
Copper, Cu	0.11%
Nickel, Ni	0.03%
Chromium, Cr	0.45%
Molybdenum, Mo	0.33%
Sn	0.007%
Al	0.003%
Vanadium, Va	NA
N2	0.0063%
Ti	NA
Nb	NA
V	0.003%
Cb	0.001%
Te	NA

Table 2 Tensile and Fatigue Test Data for 1117 Carburized (Case) steel.

Sp#	Total Strain Amplitude(%)	Stress Amplitude (MPa)	Plastic Strain Amplitude(%)	Elastic Strain Amplitude(%)	Mean Stress Amplitude (MPa)	(50% load drop) Fatigue Life (Reversals, 2Nf)	MONOTONIC Young's Modulus(GPa)	Hardness (HRC)
3	0.500	897	0.013	0.487	NA	2	179	61
2	0.499	897	0.012	0.487	NA	2	180	62
9	0.452	813	0.011	0.441	NA	8732	180	63
11	0.450	811	0.010	0.440	NA	2	180	60
10	0.449	811	0.009	0.440	NA	10700	181	62
1	0.404	761	0.000	0.404	NA	3312	188	62
4	0.398	758	0.000	0.398	NA	3570	190	61
13	0.350	639	0.000	0.350	NA	37112	182	60
12	0.350	639	0.000	0.350	NA	18020	183	63
5	0.317	573	0.000	0.317	NA	21718	180	62
16	0.300	548	0.000	0.300	NA	32274	183	60
14	0.258	454	0.000	0.258	NA	171220	176	62
15	0.255	462	0.000	0.255	NA	434224	182	62
6	0.213	371	0.000	0.213	NA	787038	185	61
17	0.199	366	0.000	0.199	NA	9988	184	63
8	0.187	338	0.000	0.187	NA	1216000	181	60
7*	0.182	316	0.000	0.182	NA	10000000	184	62
18*	0.180	330	0.000	0.180	NA	10000000	183	62
20	0.180	333	0.000	0.180	NA	605182	185	61
19	0.179	327	0.000	0.179	NA	1755592	183	60

* Run out

Appendix 1

Monotonic Properties for 1117 Carburized (Case) steel.

Average Elastic Modulus, E = 184 GPa

Yield Strength = NA

Ultimate tensile Strength = 880 MPa

% Elongation = 0.48 %

% Reduction of Area = 0.49 %

True fracture strain, $Ln\ (A_i / A_f)$ = 0.49 %

True fracture stress, $\sigma_f = \dfrac{P_f}{A_f}$ = 904 MPa

Bridgman correction, $\sigma_f = \dfrac{P_f}{A_f} \Big/ \left(1+\dfrac{4R}{D_f}\right) Ln\left(1+\dfrac{D_f}{4R}\right)$ =745 MPa

Monotonic strength coefficient, K = 23179 MPa

Monotonic strain hardening exponent, n = 0.441

Hardness, Rockwell C (HRC) = 62

Hardness, Brinell = 625

Cyclic Properties for 1117 Carburized (Case) steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ = NA

Cyclic strength coefficient, K' = 17577 MPa

Cyclic strain hardening exponent, n' = 0.332

Fatigue Strength Coefficient, σ'_f = 1474 MPa

Fatigue Strength Exponent, b = -0.097

Fatigue Ductility Coefficient, ε'_f = 0.013%

Fatigue Ductility Exponent, c = -0.04

P_f: Load at fracture.

A_i and A_f: Specimen cross-section area before and after fracture.

R: Specimen neck radius.

D_f Specimen diameter at fracture.