Fatigue Behavior, Monotonic Properties

and

Microstructure Data

for

1117, Quenched (Core) Steel

(Iteration No. 51)

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SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for 1117 Quenched (Core) steel (Iteration # 51) 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 94 Rb. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Eighteen 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 20, 1117 Quenched (Core) 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, 18 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 B 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 Quenched (Core) steel. A Type D series inclusion severity level of 2 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 Quenched (Core) steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 1117 Quenched (Core) steel was provided by the MacSteel Company, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for 1117 Quenched (Core) 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 Quenched (Core) 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 = 1131 MPa, b = -0.0744, ε'_f = 0.22 and c = -0.458. These values of the strain-life parameters were determined from fatigue testing over the range: $0.00155 < \frac{\Delta\varepsilon}{2} < 0.010$.

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' = 1399 MPa and n' = 0.168.

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 Quenched (Core) 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.

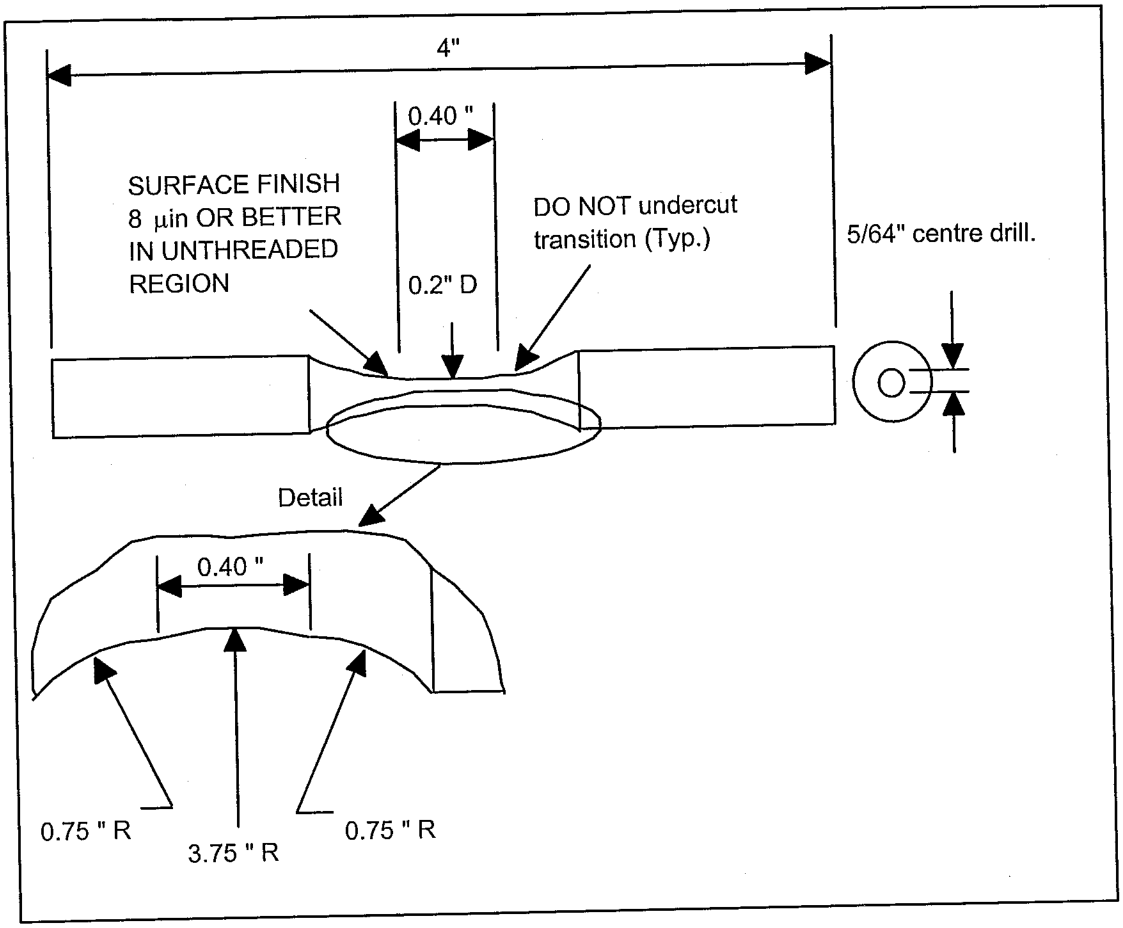
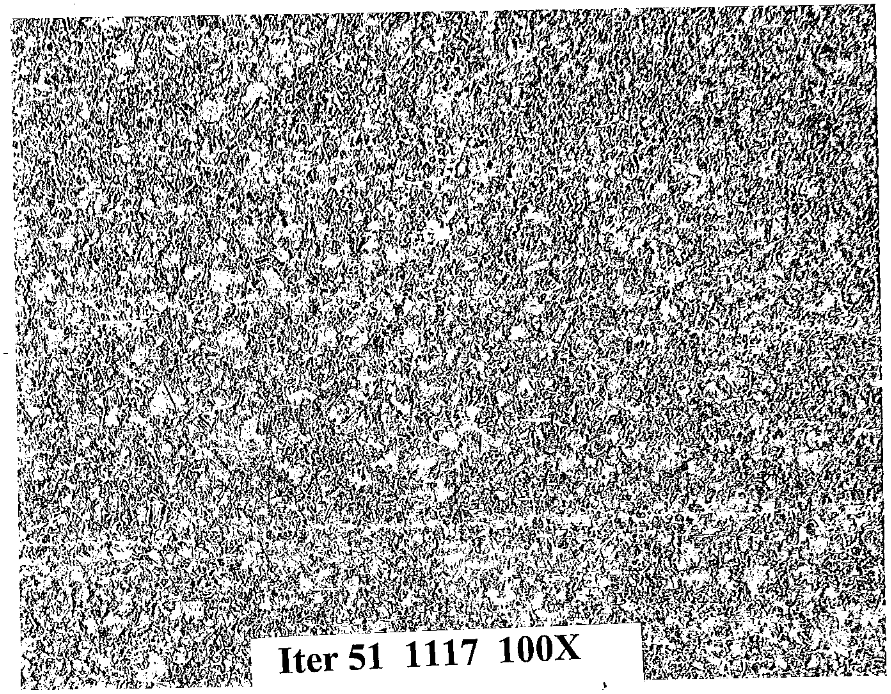


Fig. 1 Smooth cylindrical fatigue specimen



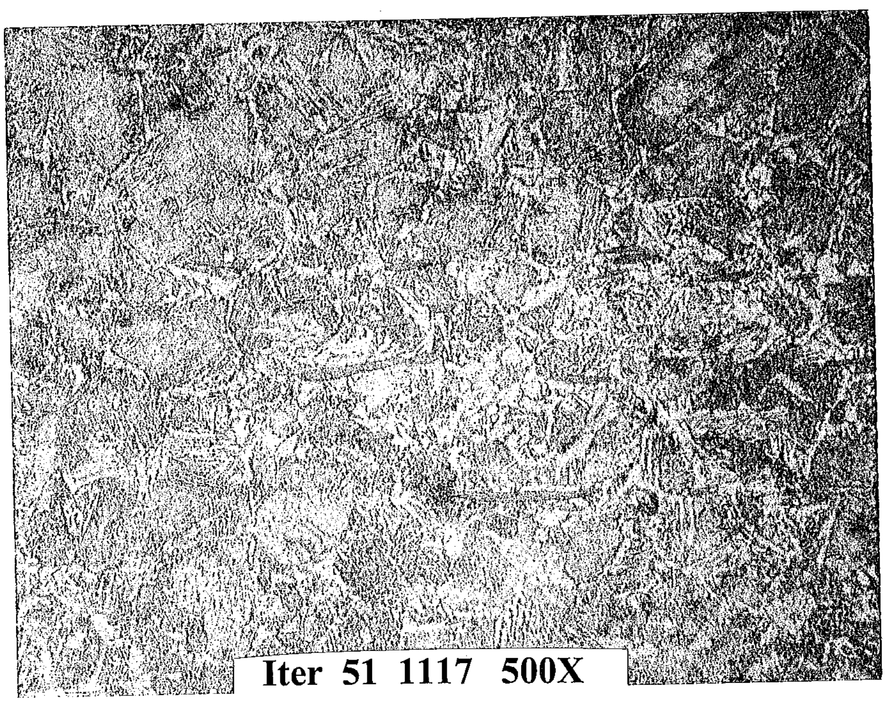
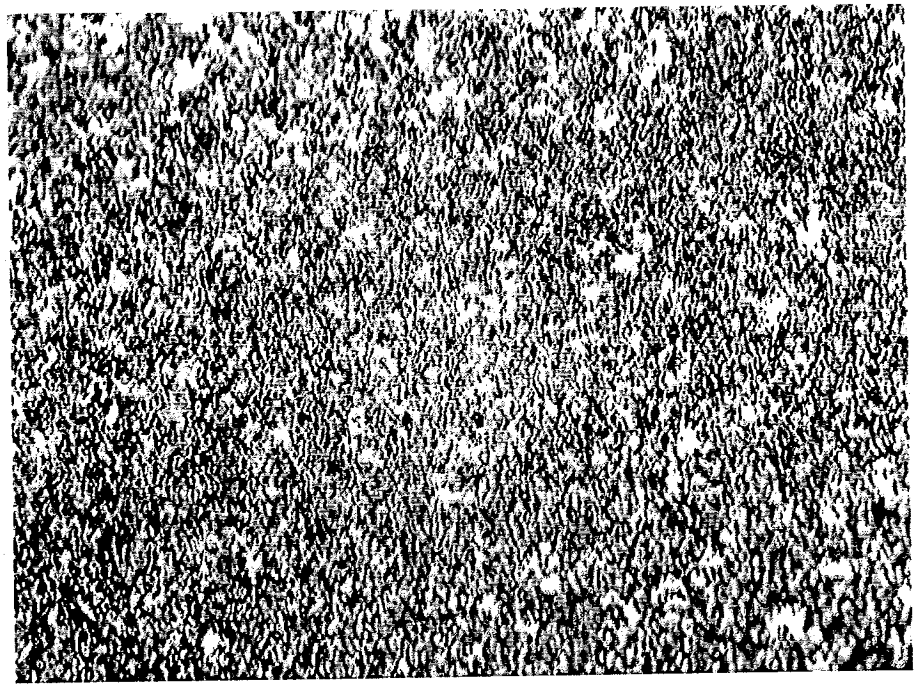
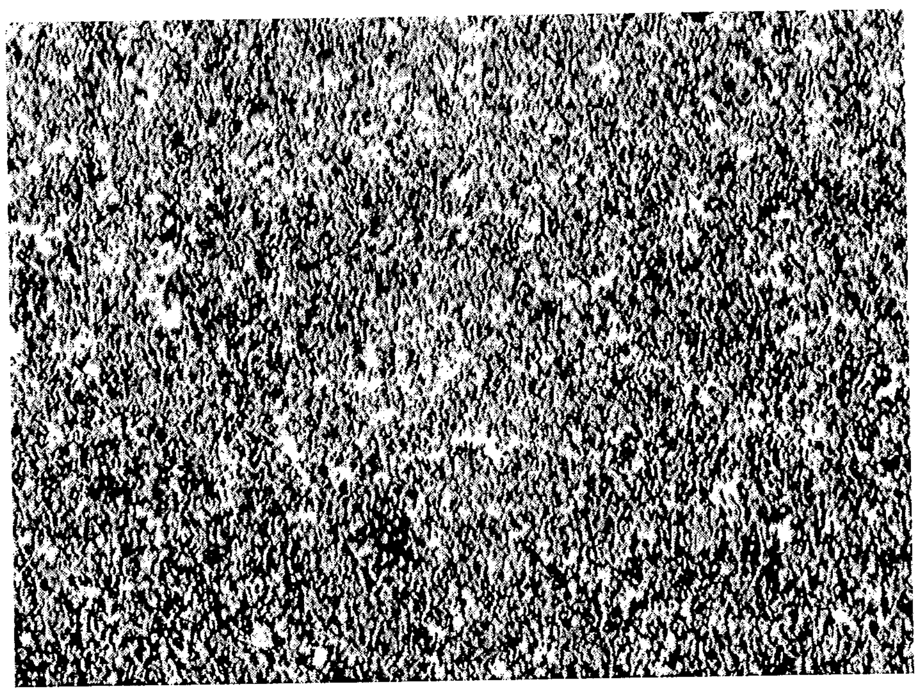


Fig. 1-2 Iter. 51, 1117 Steel, Quenched in still oil at EHT
Upper- 100X Lower 500X Nital Etched



(a) Longitudinal Direction
(b)



(c) Transverse Direction

Figure 2. Photomicrographs of 1117 Quenched (Core) steel (X500)

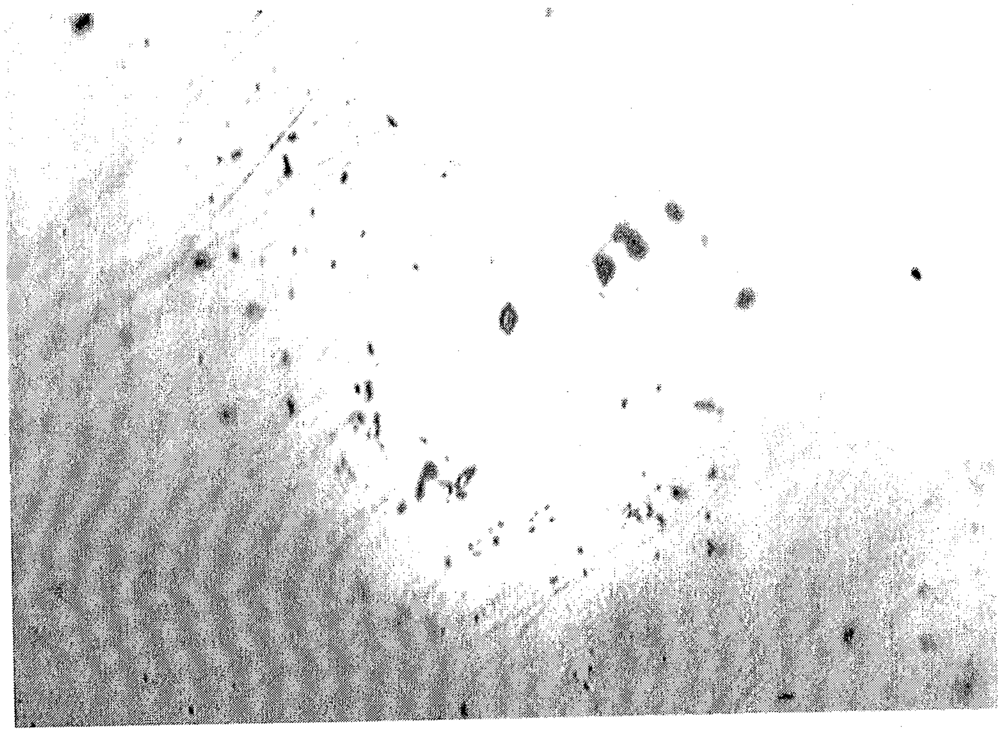


Figure 3. Inclusions photomicrograph of 1117 Quenched (Core) steel (X100)

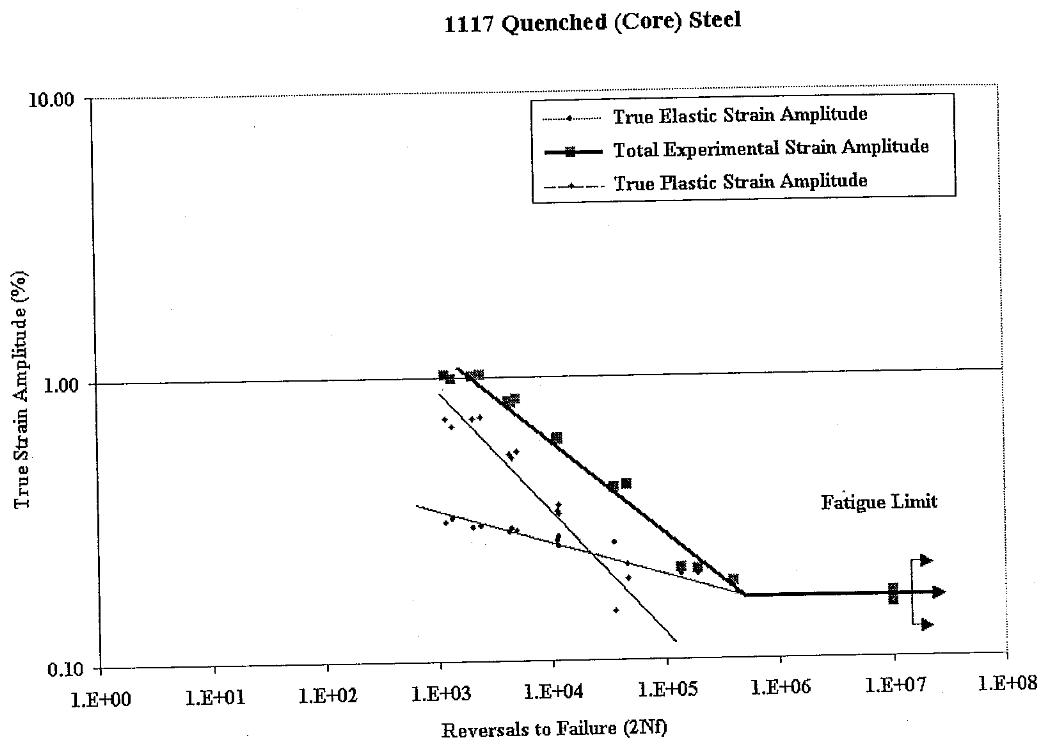


Figure 4. Constant amplitude fully reversed strain-life curve for 1117 Quenched (Core) steel.

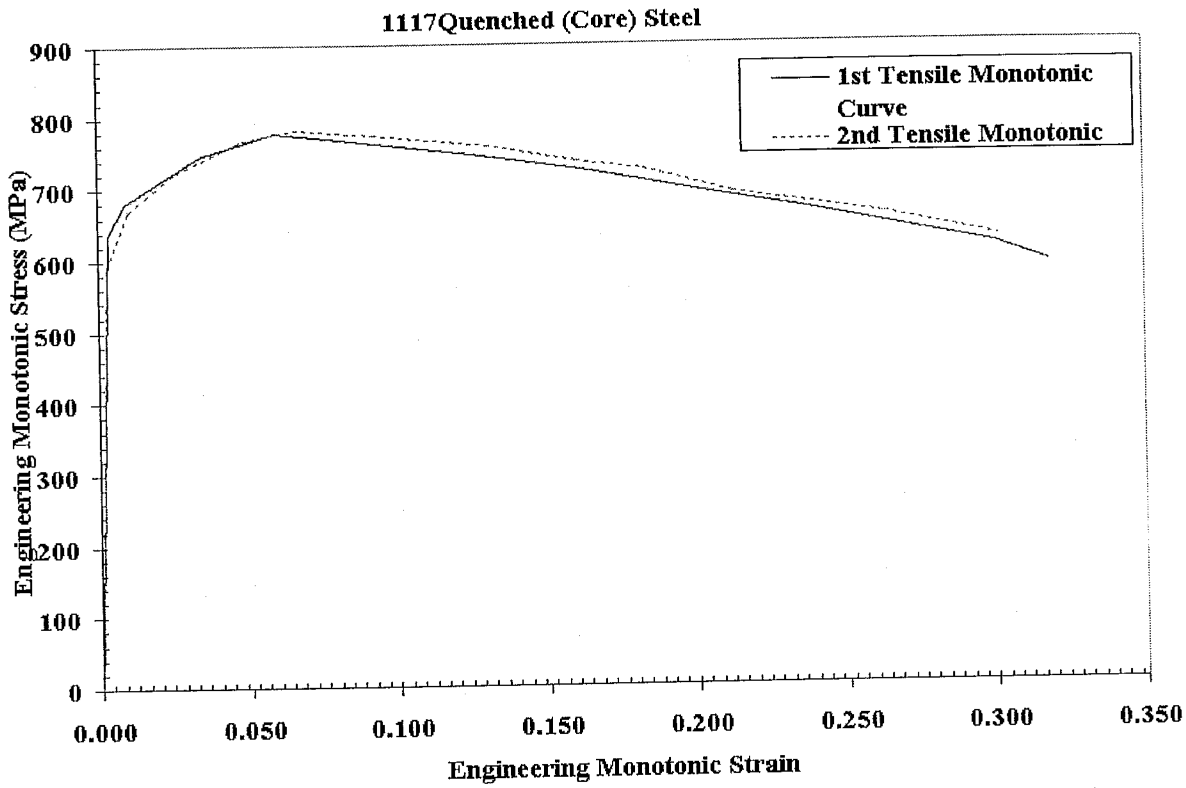


Figure 5. Monotonic stress-strain curves for two 1117 Quenched (Core) steel specimens.

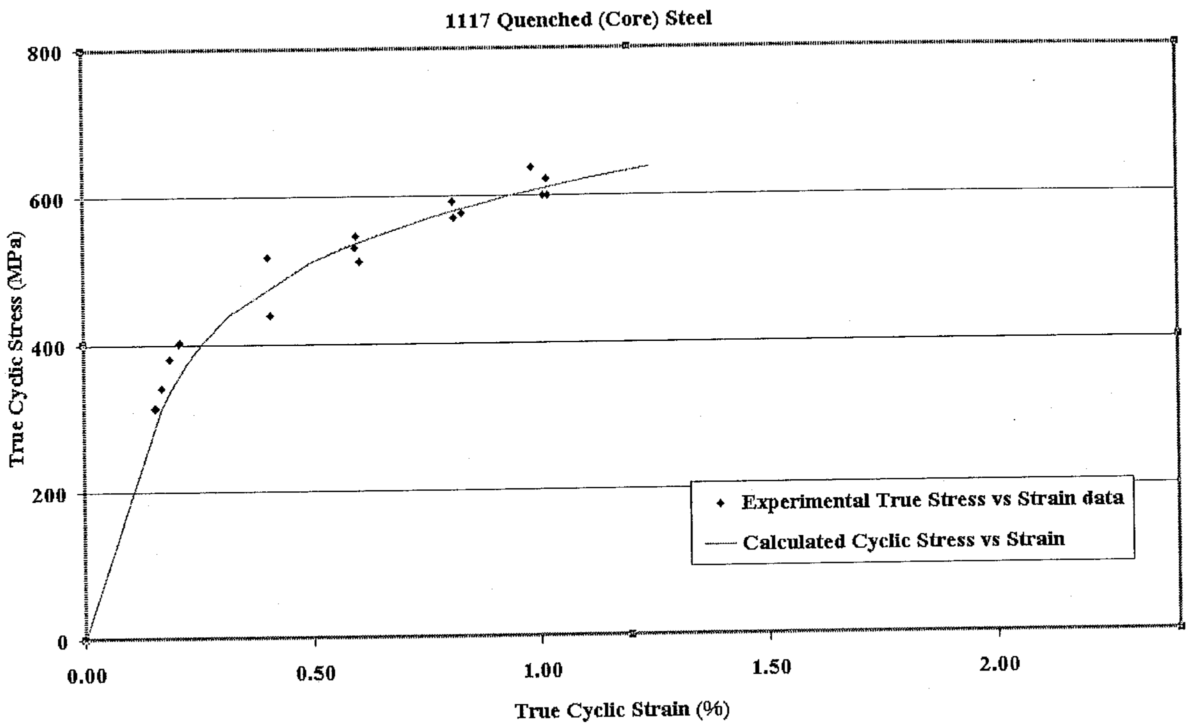


Figure 6. Cyclic stress-strain curve for 1117 Quenched (Core) steel.

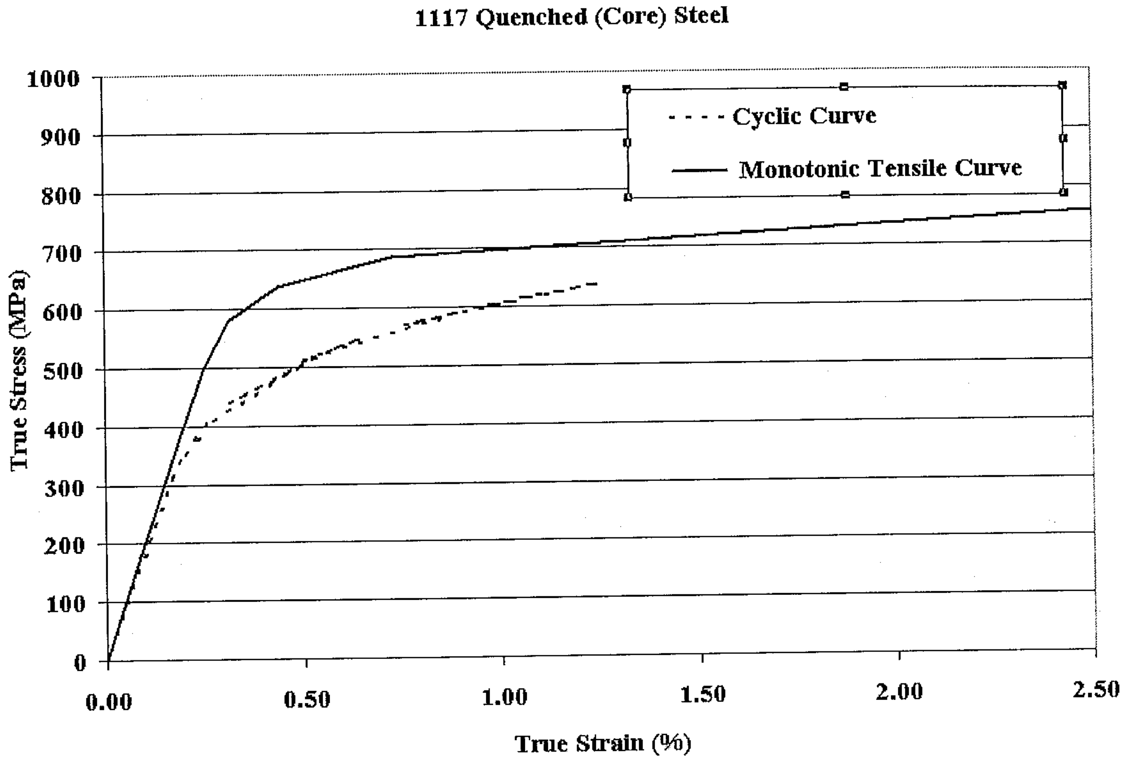


Fig. 7 Monotonic and Cyclic stress-strain curves for 1117 Quenched (Core) steel.

Table 1 Chemical composition of 1117 Quenched (Core) 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	0.12%
Molybdenum, Mo	0.02%
Sn	0.007%
Al	0.003%
Vanadium, Va	NA
N	NA
Ti	NA
N2	0.0063%
V	0.003%
Cb	0.001%
Te	NA

Table 2 Tensile and Fatigue Test Data for 1117 Quenched (Core) steel.

Sp#	Total Strain Amplitude(%)	Stress Amplitude (MPa)	Plastic Strain Amplitude(%)	Elastic Strain Amplitude(%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	MONOTONIC Young's Modulus(GPa)	Hardness (HRB)
16	1.021	599	0.724	0.296	2400	203	93
15	1.018	621	0.710	0.307	1200	201	92
6	1.009	599	0.713	0.296	2080	203	94
5	0.985	638	0.670	0.315	1362	204	99
17	0.831	576	0.546	0.285	5066	202	92
4	0.813	570	0.531	0.282	4264	201	90
9	0.810	592	0.517	0.293	4570	204	99
18	0.606	511	0.353	0.253	11660	201	99
3	0.598	547	0.328	0.271	11780	204	92
10	0.595	530	0.333	0.262	11520	204	93
12	0.410	438	0.193	0.217	47782	201	92
2	0.404	518	0.148	0.256	36140	203	92
7	0.207	402	0.008	0.199	195908	203	94
1	0.210	402	0.011	0.199	137420	191	94
11	0.187	379	0.000	0.187	401136	202	95
14*	0.169	341	0.000	0.169	10000000	201	92
8*	0.154	313	0.000	0.154	10000000	203	96
13*	0.156	313	0.000	0.156	10000000	201	94

* Run out

Appendix 1

Monotonic Properties for 1117 Quenched (Core) steel.

Average Elastic Modulus, E	=	202	GPa
Yield Strength	=	655	MPa
Ultimate tensile Strength	=	777	MPa
% Elongation	=	37	%
% Reduction of Area	=	55	%
True fracture strain, $Ln\ (A_i / A_f)$	=	80	%

True fracture stress, $\sigma_f = \dfrac{P_f}{A_f}$ = 1412 MPa

Bridgman correction, $\sigma_f = \dfrac{P_f}{A_f} \Big/ \left(1 + \dfrac{4R}{D_f}\right) Ln\left(1 + \dfrac{D_f}{4R}\right)$ =1238 MPa

Monotonic strength coefficient, K	=	973	MPa
Monotonic strain hardening exponent, n	=	0.626	
Hardness, Rockwell B (HRB)	=	94	
Hardness, Brinell	=	193	

Cyclic Properties for 1117 Quenched (Core) steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$	=	492	MPa
Cyclic strength coefficient, K'	=	1399	MPa
Cyclic strain hardening exponent, n'	=	0.168	
Fatigue Strength Coefficient, σ'_f	=	1131	MPa
Fatigue Strength Exponent, b	=	-0.074	
Fatigue Ductility Coefficient, ε'_f	=	0.22	
Fatigue Ductility Exponent, c	=	-0.458	

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.