Fatigue Behavior, Monotonic Properties

and

Microstructure Data

for

5120, Quenched (Core) Steel

(Iteration No. 55)

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SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for 5120 Quenched (Core) steel (Iteration # 55) have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of 1.339" 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 24 Rc. 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, 5120 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 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 5120 Quenched (Core) steel. A Type D thick series inclusion severity level of 3 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 5120 Quenched (Core) steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 5120 Quenched (Core) steel was provided by the MacSteel Company, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for 5120 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 5120 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 = 1284 MPa, b = -0.069, ε'_f = 0.39 and c = -0.562. These values of the strain-life parameters were determined from fatigue testing over the range: $0.002 < \frac{\Delta\varepsilon}{2} < 0.010$.

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' = 1784 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 5120 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.

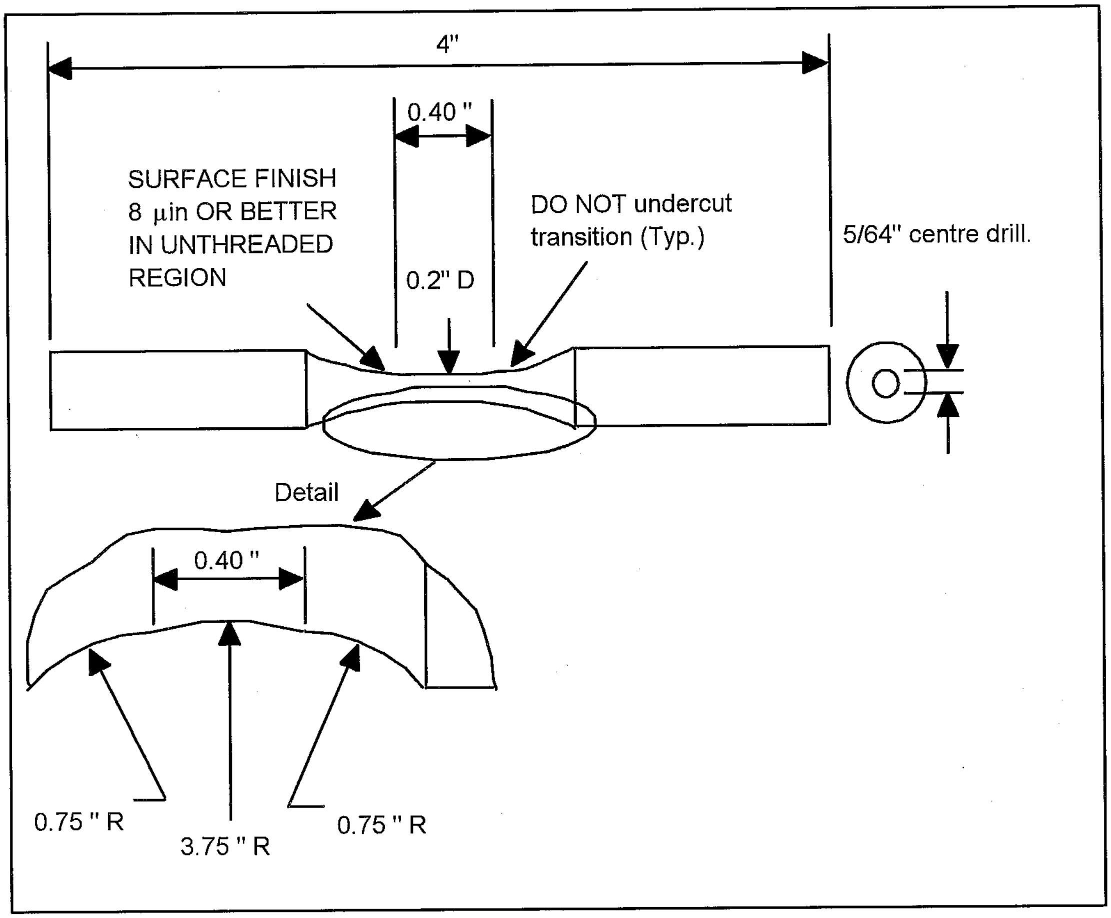
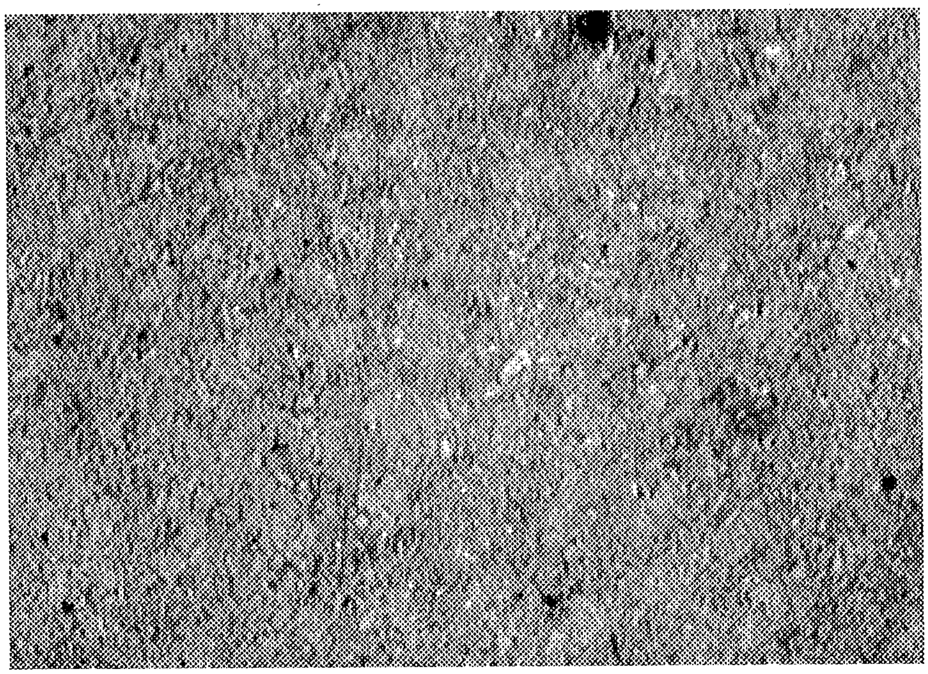
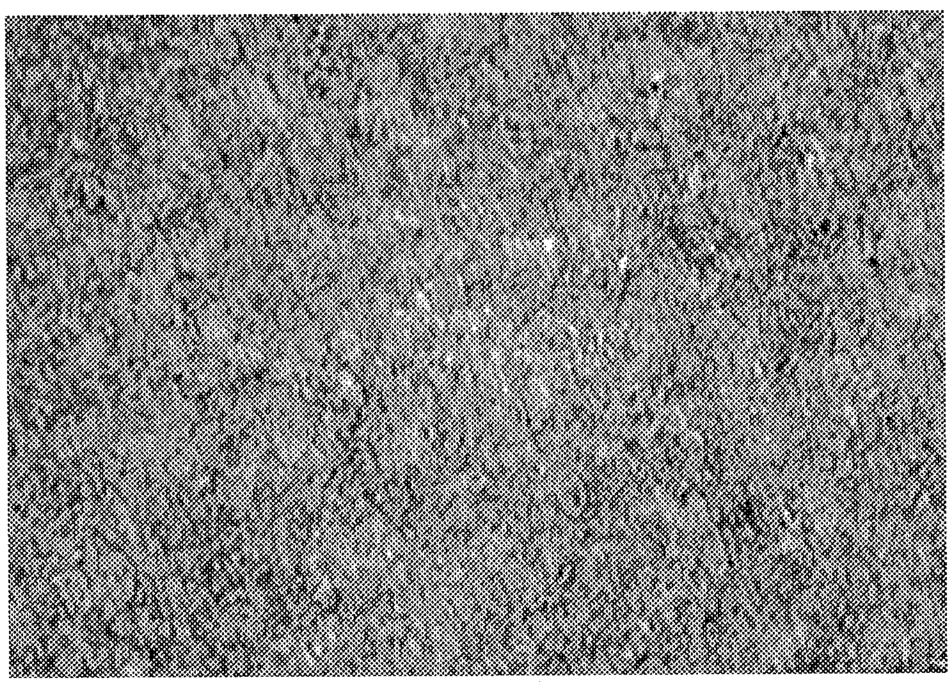


Fig. 1 Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2. Photomicrographs of 5120 Quenched (Core) steel (X500)

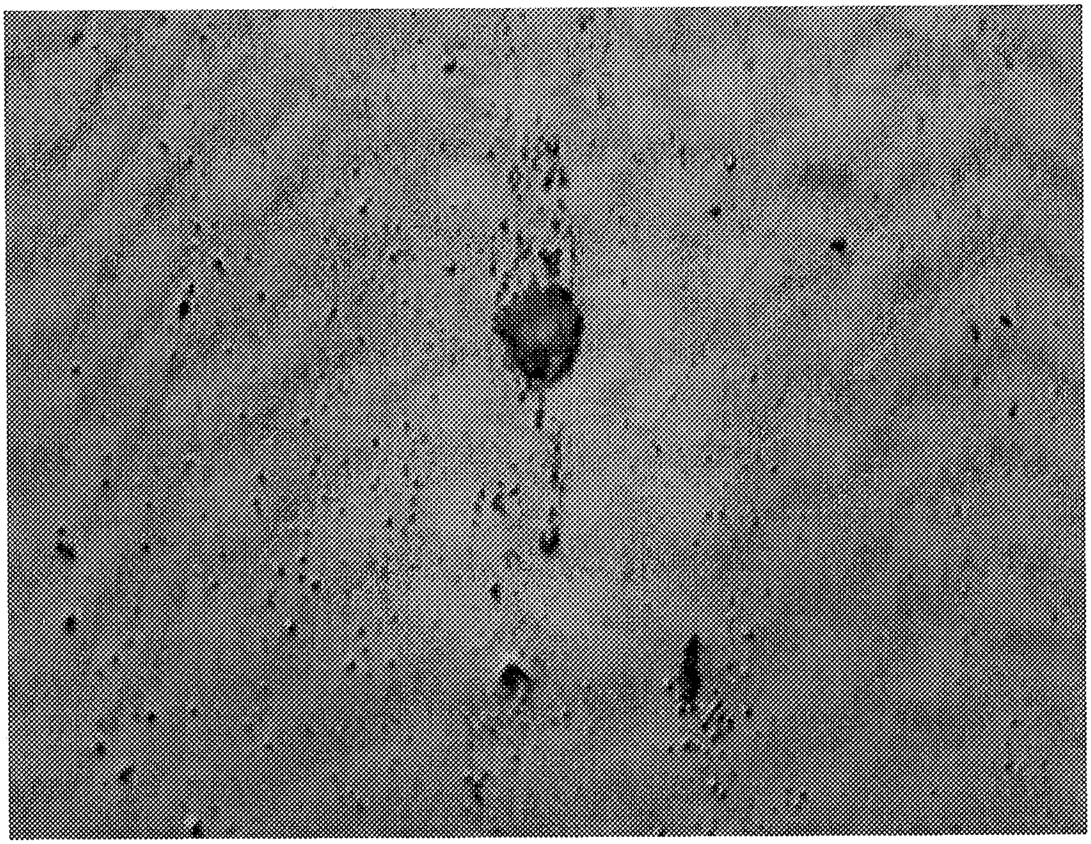


Figure 3. Inclusions photomicrograph of 5120 Quenched (Core) steel (X100)

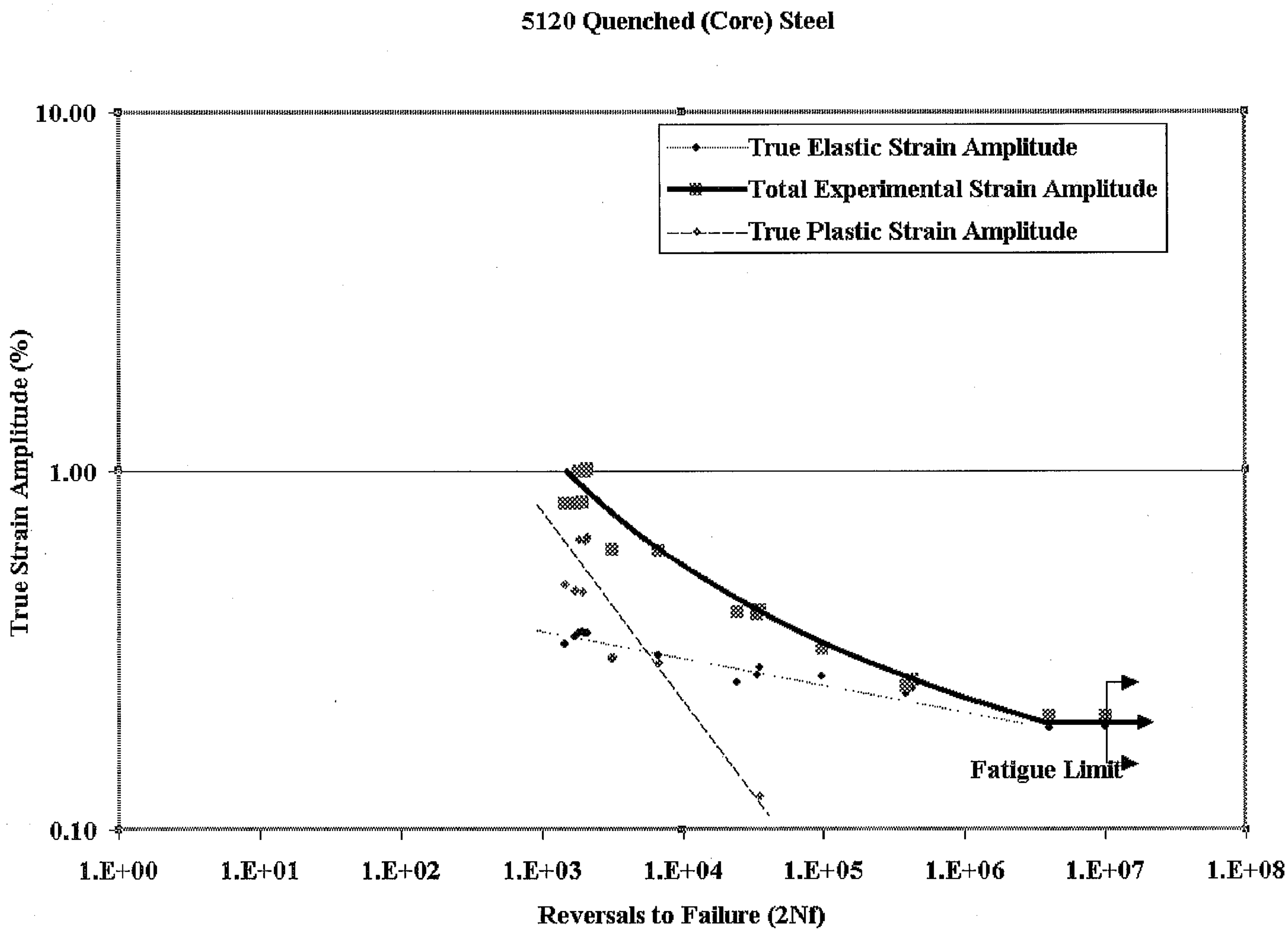


Figure 4. Constant amplitude fully reversed strain-life curve for 5120 Quenched (Core) steel.

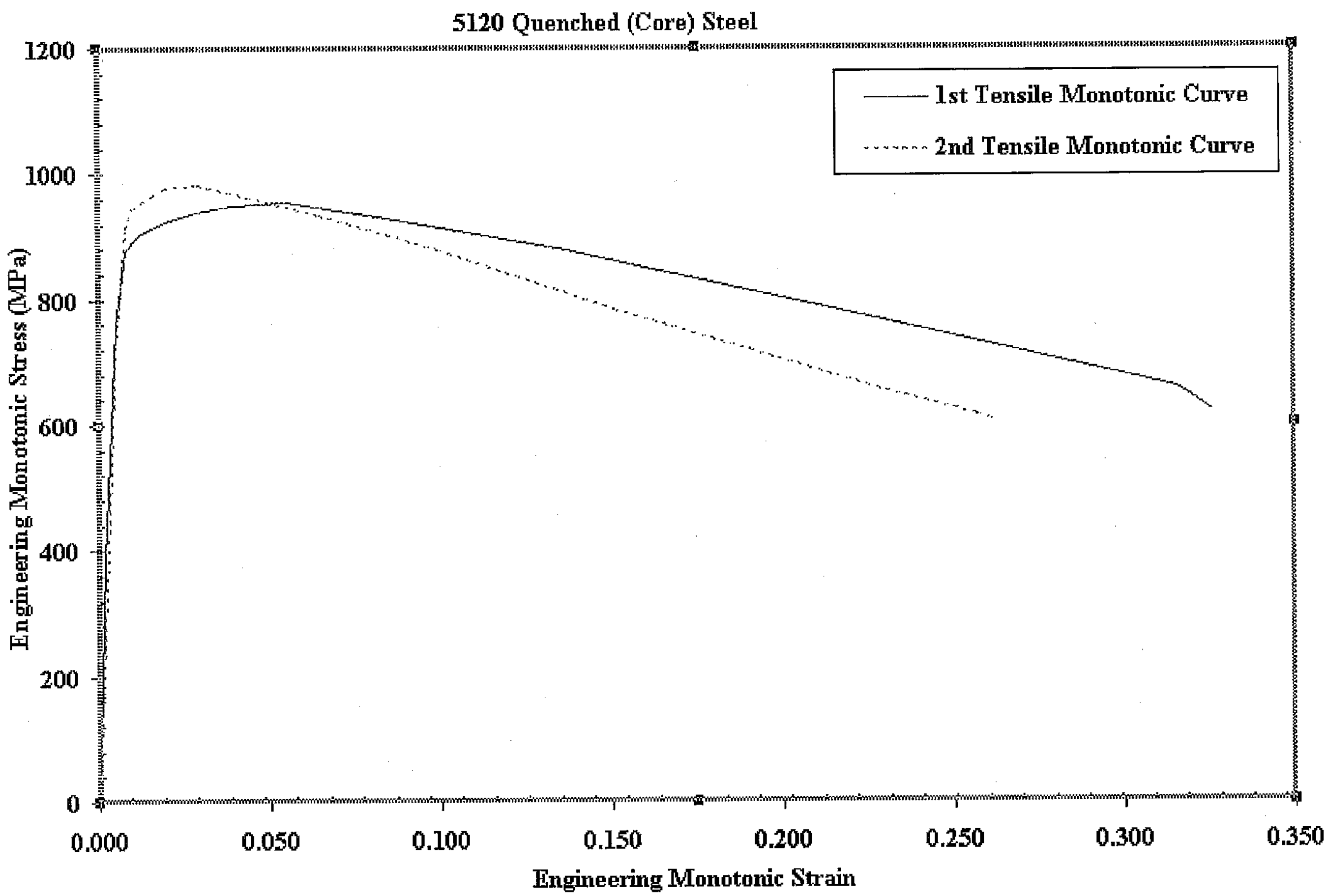


Figure 5. Monotonic stress-strain curves for two 5120 Quenched (Core) steel specimens.

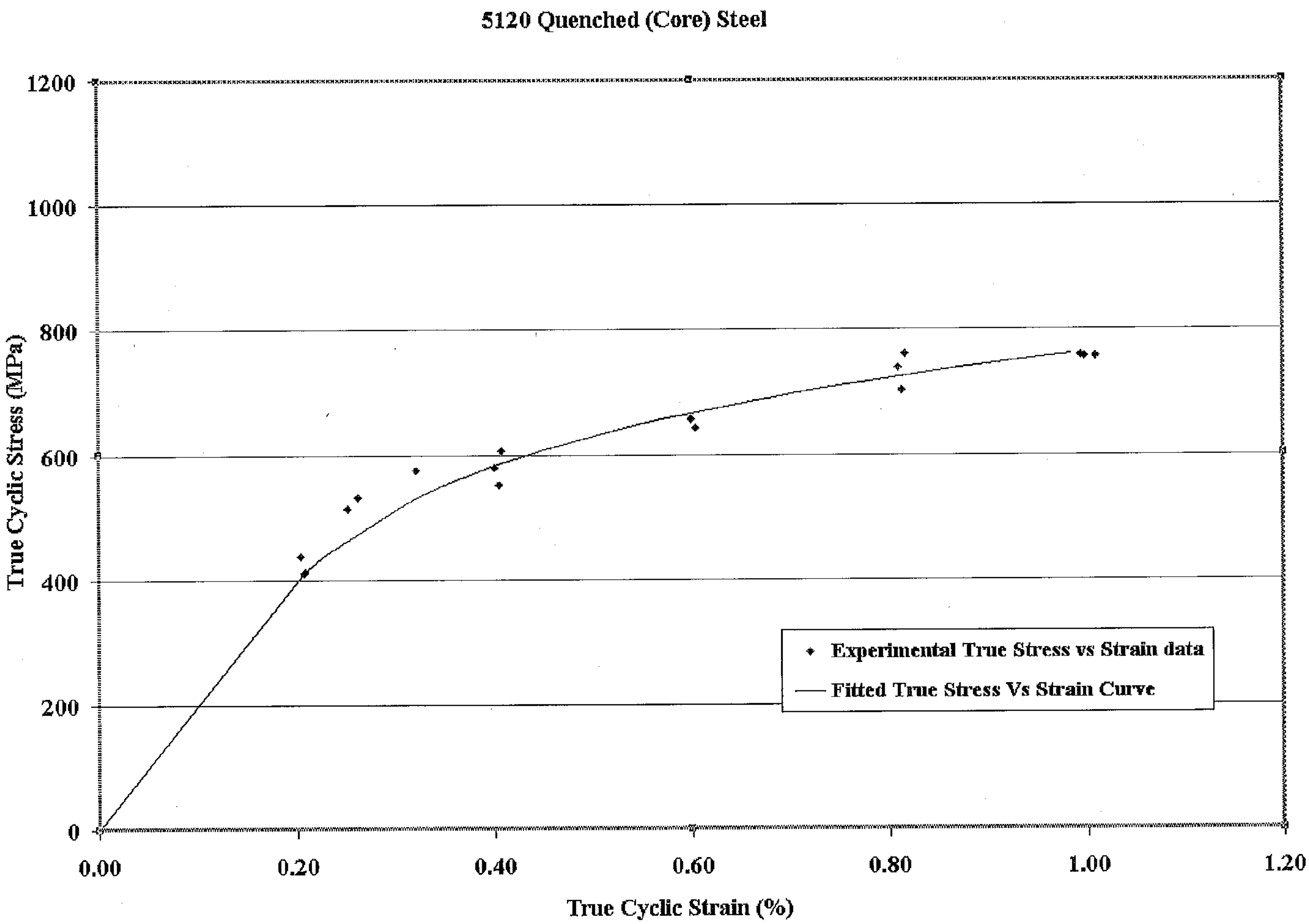


Figure 6. Cyclic stress-strain curve for 5120 Quenched (Core) steel.

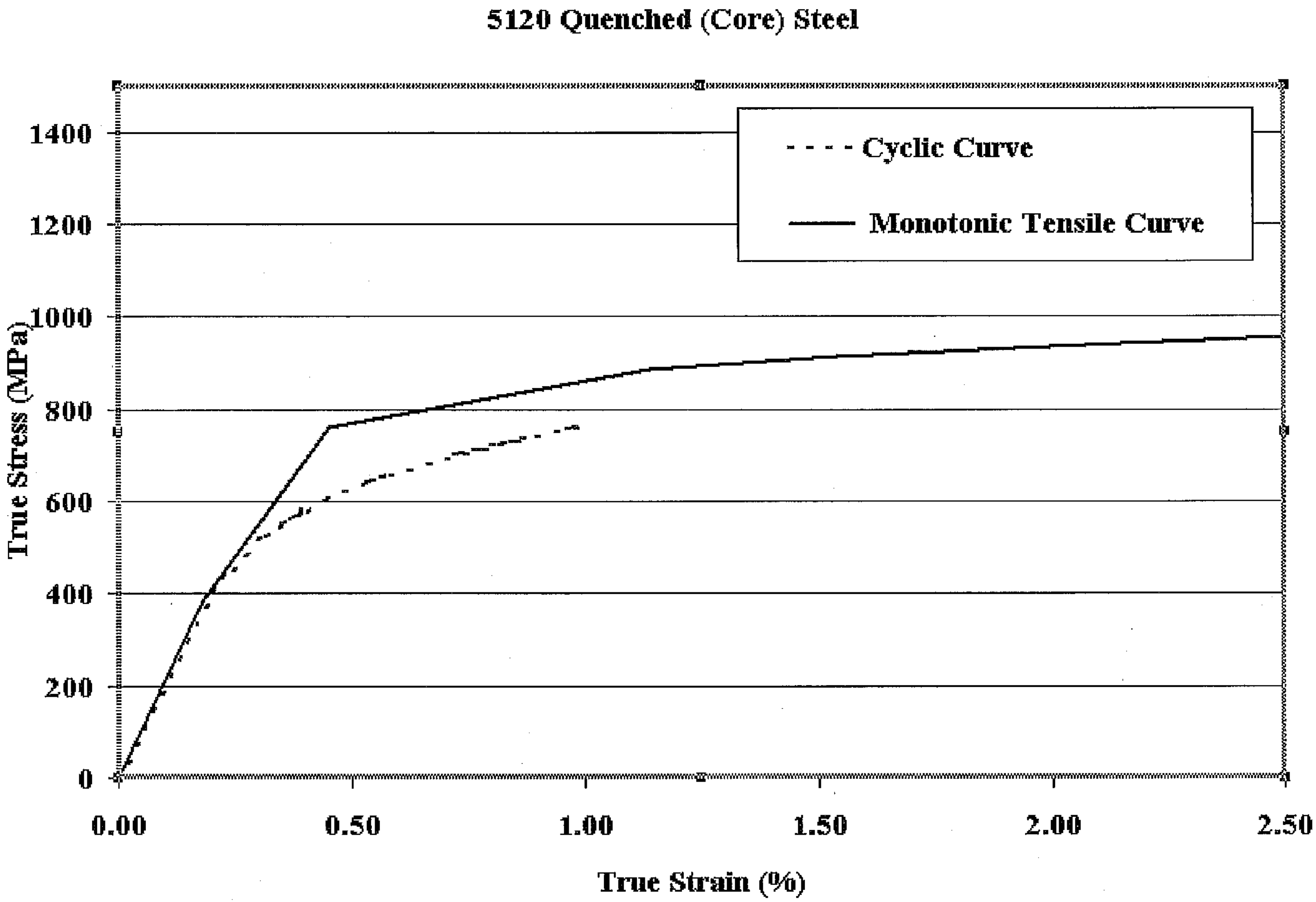


Fig. 7 Monotonic and Cyclic stress-strain curves for 5120 Quenched (Core) steel.

Table 1 Chemical composition of 5120 Quenched (Core) steel.

Carbon, C	0. 19%
Manganese, Mn	0.79%
Phosphorous, P	0.013%
Sulfur, S	0.025%
Silicon, Si	0.17%
Copper, Cu	0.18%
Nickel, Ni	0.06%
Chromium, Cr	0.77%
Molybdenum, Mo	0.01%
Sn	0.006%
Al	0.01%
Vanadium, Va	NA
N2	0.005%
Ti	0.001%
Nb	NA
V	0.064%
Cb	0.002%
Te	NA

Table 2 Tensile and Fatigue Test Data for 5120 Quenched (Core) 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)
5	1.009	757	0.655	0.354	NA	2100	210	23
4	0.997	757	0.643	0.354	NA	1800	216	24
3	0.994	760	0.639	0.355	NA	2000	216	24
6	0.816	761	0.460	0.356	NA	1940	214	23
14	0.813	703	0.485	0.328	NA	1438	214	25
7	0.810	739	0.465	0.345	NA	1700	215	26
11	0.605	643	0.304	0.301	NA	3150	214	22
9	0.600	657	0.293	0.307	NA	6760	212	24
17	0.600	649	0.297	0.303	NA	5122	211	23
13	0.407	606	0.124	0.283	NA	35242	210	25
12	0.405	551	0.147	0.258	NA	24324	216	22
1	0.400	579	0.130	0.270	NA	33940	210	24
15	0.321	576	0.052	0.269	NA	97840	216	24
2	0.262	531	0.014	0.248	NA	424862	214	23
8	0.251	515	0.011	0.240	NA	387124	216	23
10*	0.205	437	0.000	0.205	NA	10000000	214	25
5*	0.208	413	0.000	0.208	NA	10000000	213	22
16	0.208	410	0.000	0.208	NA	3945000	214	24

* Run out

2.4
42

Appendix 1

Monotonic Properties for 5120 Quenched (Core) steel.

Average Elastic Modulus, E	=	214	GPa
Yield Strength	=	780	MPa
Ultimate tensile Strength	=	1008	MPa
% Elongation	=	46 %	
% Reduction of Area	=	58 %	
True fracture strain, $Ln\ (A_i / A_f)$	=	87 %	
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$	=	1476	MPa

Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \Big/ \left(1 + \frac{4R}{D_f}\right) Ln\left(1 + \frac{D_f}{4R}\right)$ =1287 MPa

Monotonic strength coefficient, K	=	1277	MPa
Monotonic strain hardening exponent, n	=	0.074	
Hardness, Rockwell C (HRC)	=	24	
Hardness, Brinell	=	252	

Cyclic Properties for 5120 Quenched (Core) steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$	=	628	MPa
Cyclic strength coefficient, K'	=	1784	MPa
Cyclic strain hardening exponent, n'	=	0.168	
Fatigue Strength Coefficient, σ'_f	=	1284	MPa
Fatigue Strength Exponent, b	=	-0.069	
Fatigue Ductility Coefficient, ε'_f	=	0.39	
Fatigue Ductility Exponent, c	=	-0.562	
FATIGUE STR		425	

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.