SAE 9310
Quenched Core Steel
Iteration #57

Fatigue Behavior, Monotonic Properties and Microstructural Data

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Prepared for:
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May 2005 (revised)

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TABLE OF CONTENTS

SUMMARY

The required microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for 9310 Quenched Core steel (Iteration # 57) have been obtained. The bars supplied by MacSteel were machined into smooth axial fatigue specimens. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Nineteen 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 9310 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 round 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, 19 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 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 voltmeter. 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) to be determined.

RESULTS

A) Microstructure Data

Figure 2 presents the martensite microstructure of the 9310 Quenched Core 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 9310 Quenched Core steel. The inclusion area was measured using a JAVA image analysis system.

B) Strain-Life Data

The fatigue test data for 9310 Quenched Core steel obtained in this investigation are given in Table 1. 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 9310 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 = 1015.5 MPa, b = -0.054, ε'_f = 0.721 and c = -0.640. These values of the strain-life parameters were determined from fatigue testing over the range: $0.00214 < \frac{\Delta\varepsilon}{2} < 0.01$.

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' = 1034.6 MPa and n' = 0.0832.

The true monotonic and true cyclic stress-strain curves plotted together are given in Figure 6.

D) Mechanical Properties

The engineering monotonic tensile stress-strain curves are given in Figure 7. The monotonic and cyclic properties are included in Appendix 1. The Hardness of the 9310 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 1.

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.

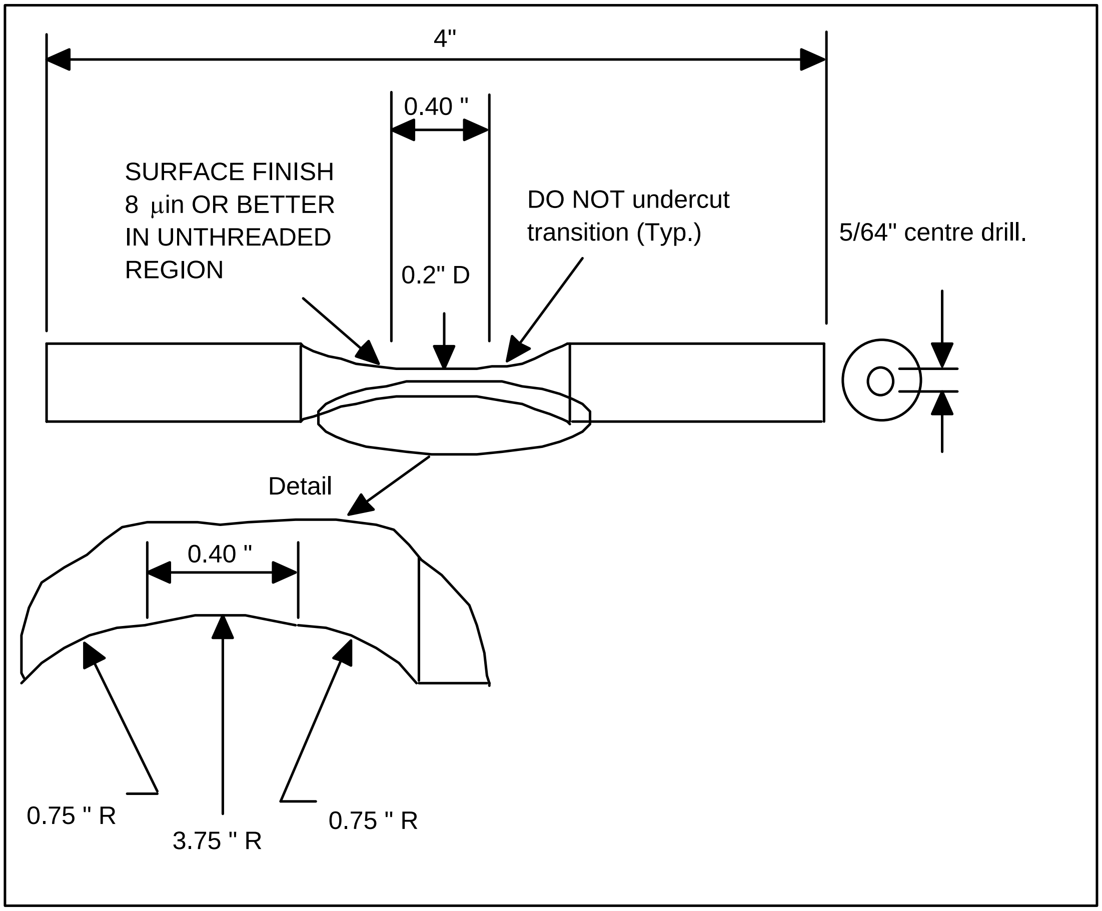
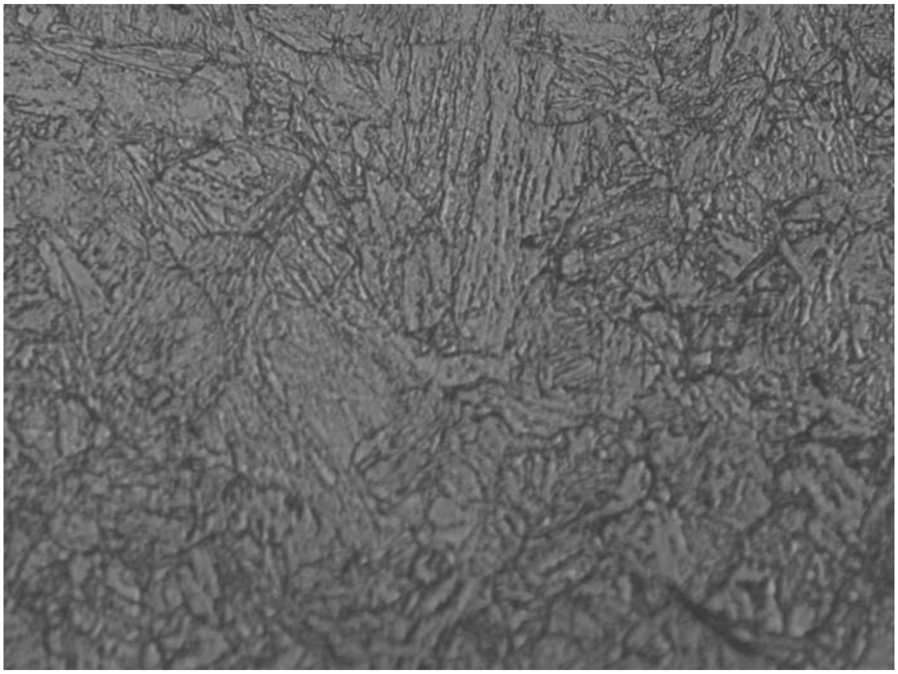
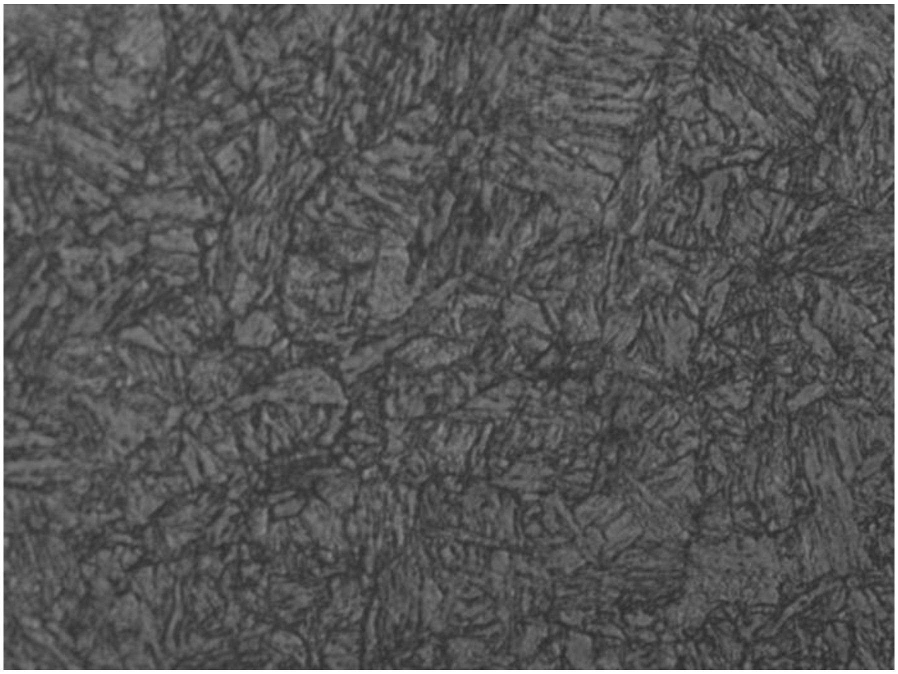


Figure 1 Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2 Photomicrographs of 9310 Quenched Core steel (X500)

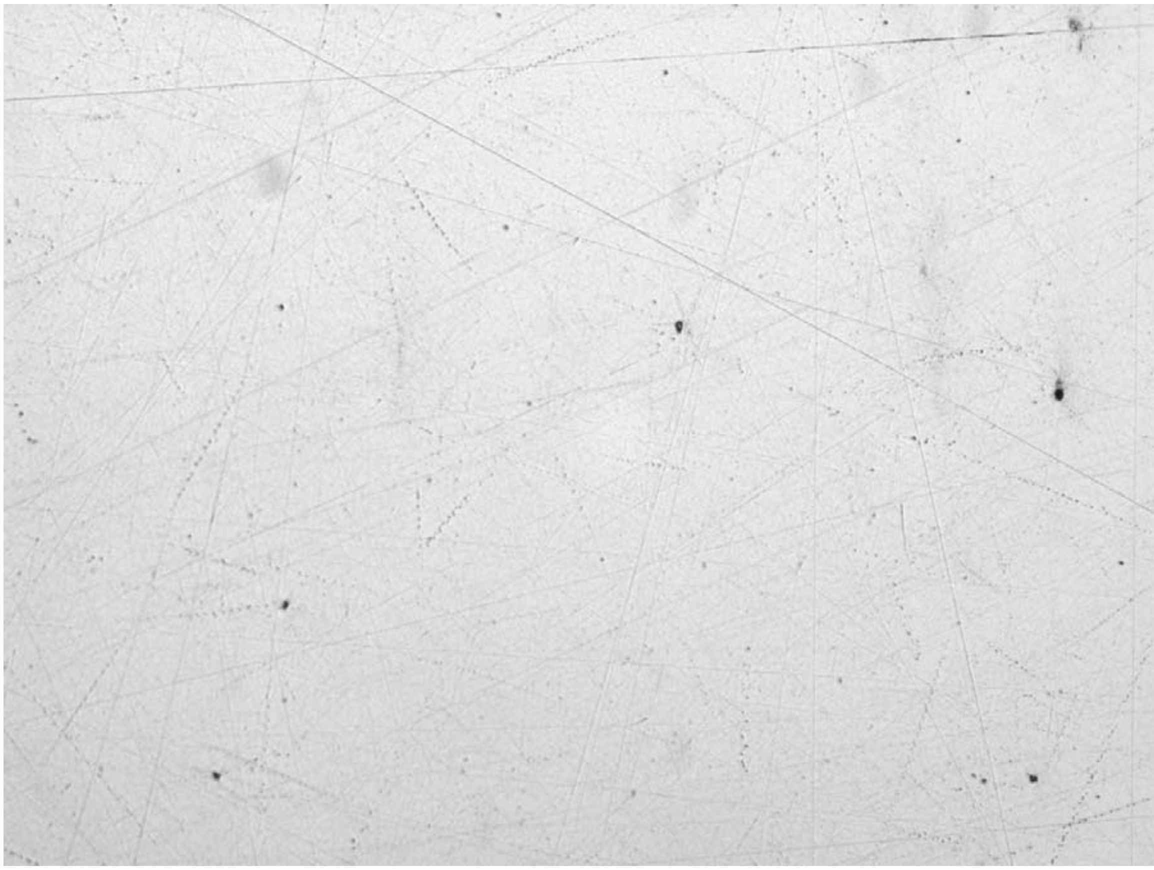


Figure 3 Inclusions photomicrograph of 9310 Quenched Core steel (X100)

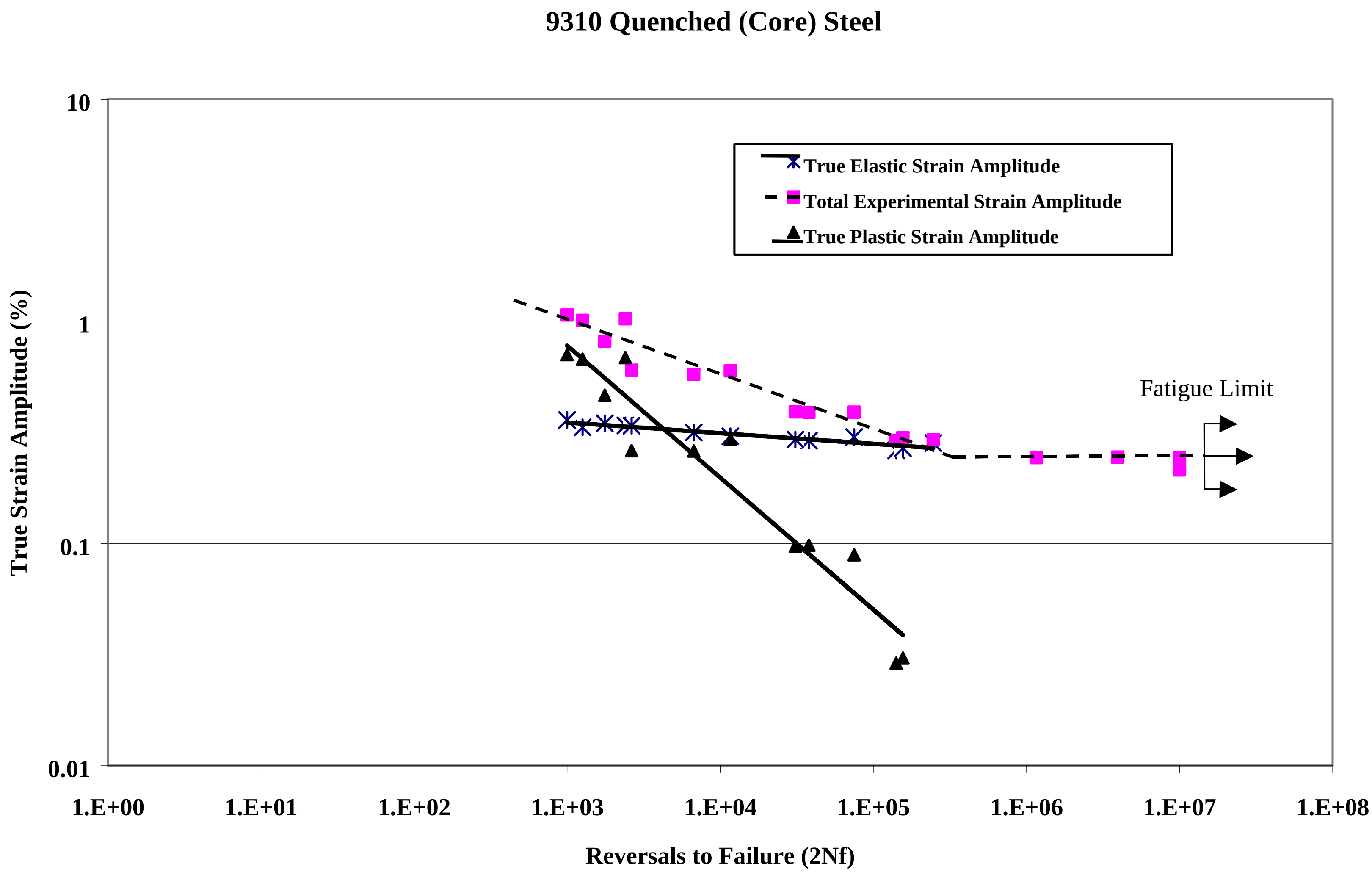


Figure 4. Constant amplitude fully reversed strain-life curve for 9310 Quenched Core steel.

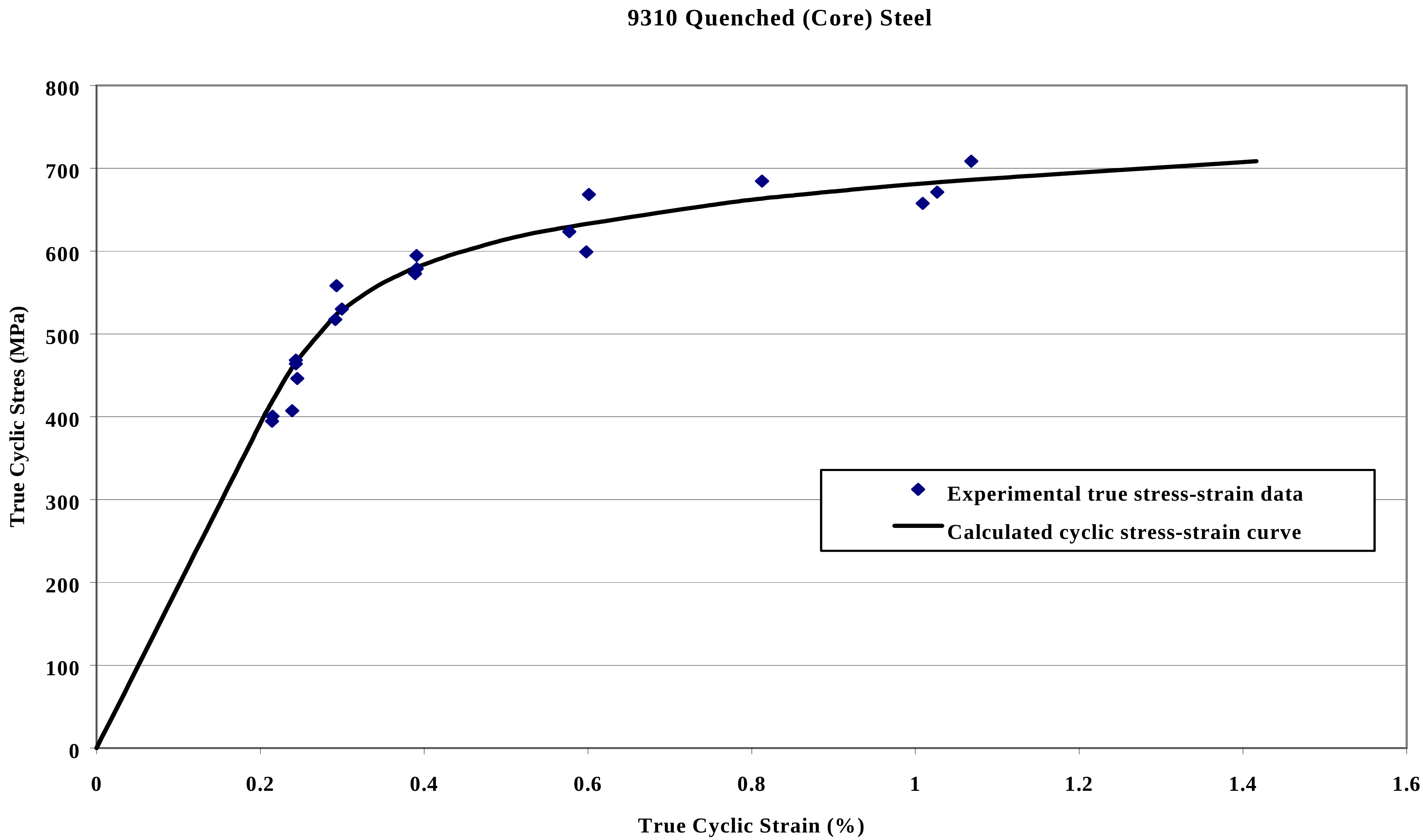


Figure 5. Cyclic stress-strain curve for 9310 Quenched Core steel.

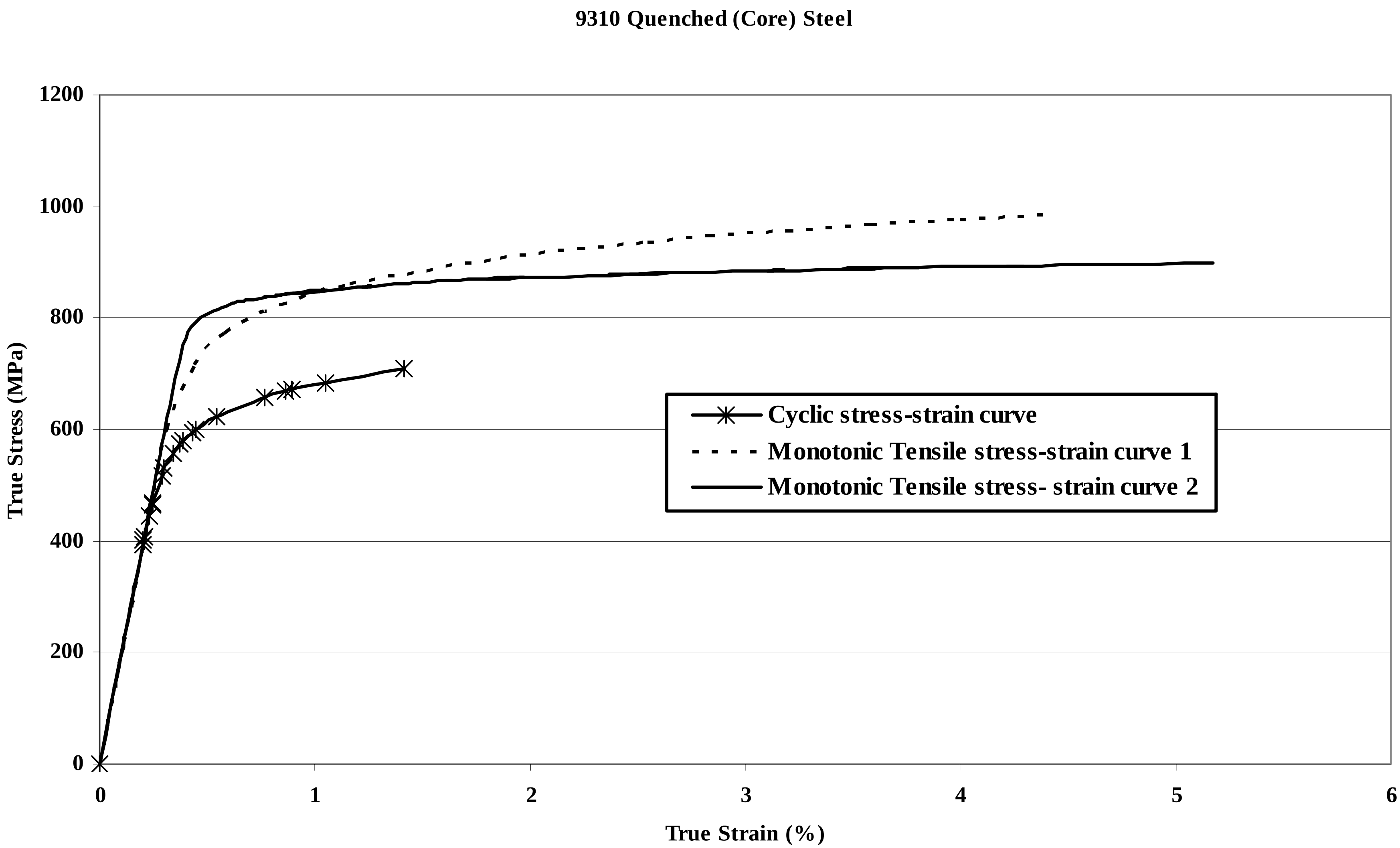


Figure 6. Monotonic and Cyclic stress-strain curves for 9310 Quenched steel.

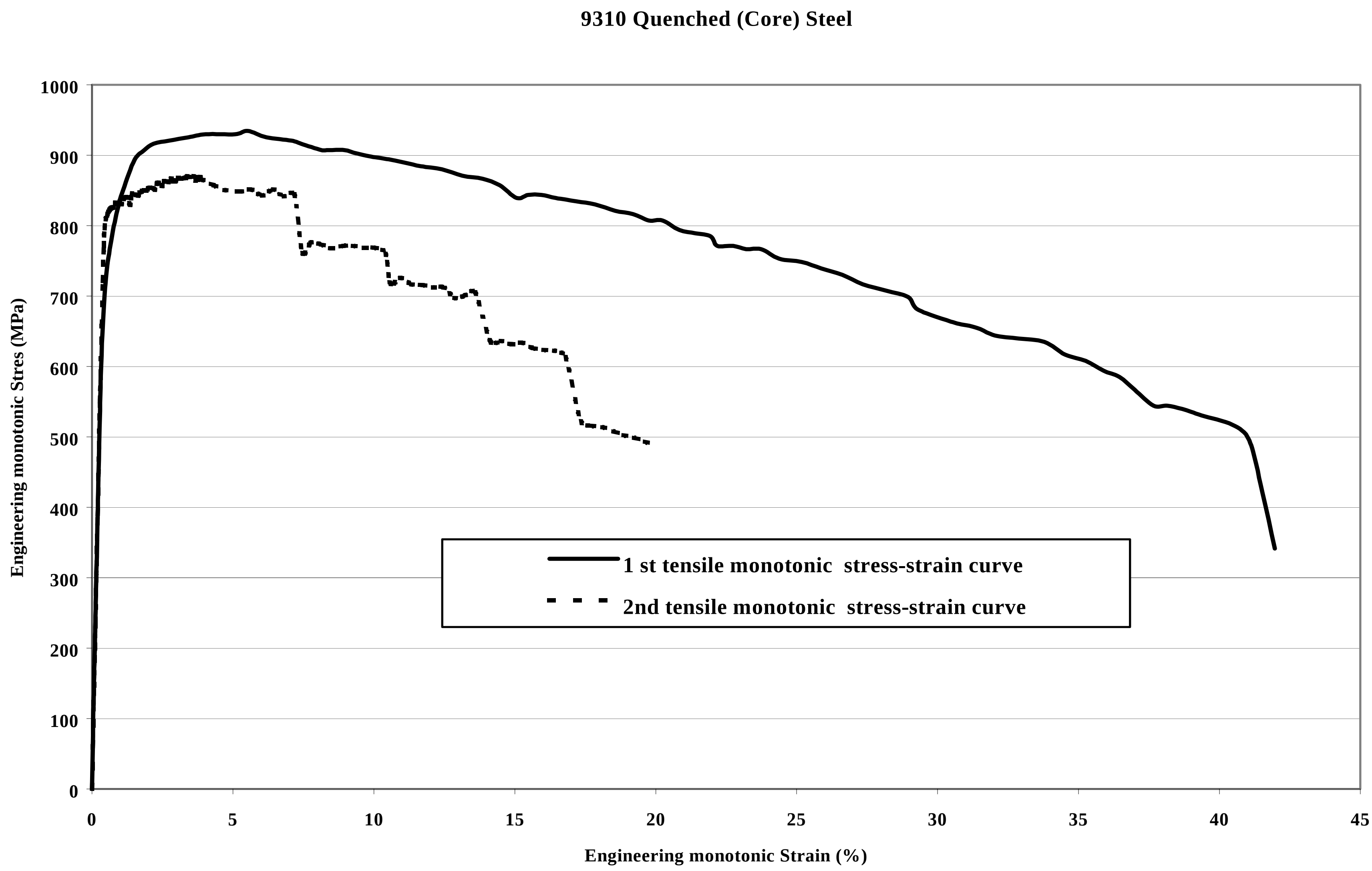


Figure 7. Tensile monotonic stress-strain curves for two 9310 Quenched Core steel specimens.

Table 1 Fatigue Data for 9310 Quenched Core Steel (Iteration 57)

Sp#	Total Strain Amplitude(%)	Stress Amplitude (MPa)	Plastic Strain Amplitude(%)	Elastic Strain Amplitude(%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	Hardness (Rockwell C)	Monotonic Young's Modulus (MPa)
1	1.009	658	0.675	0.334	1262	--	-
2	1.027	671	0.686	0.341	2400	27	-
3	1.068	709	0.708	0.360	1000	--	196
4	0.813	685	0.465	0.348	1762	--	195
5	0.577	623	0.261	0.316	6700	--	197
6	0.598	599	0.294	0.304	11628	25	198
7	0.601	668	0.262	0.339	2640	--	198
8	0.389	573	0.098	0.291	37920	--	197
9	0.391	579	0.097	0.294	30900	--	200
10	0.391	595	0.089	0.302	74890	--	195
11	0.292	518	0.029	0.263	141094	--	195
12	0.300	530	0.031	0.269	155654	--	197
13	0.293	558	0.010	0.283	246530	--	196
14	0.245	446	0.019	0.226	3926860	26	200
15*	0.243	464	0.000	0.243	10000000	--	200
16	0.243	468	0.000	0.243	1157110	--	197
17*	0.239	407	0.000	0.239	10000000	--	195
18*	0.215	400	0.000	0.215	10000000	--	196
19*	0.214	395	0.000	0.214	10000000	--	197

* Run out

Appendix 1

Monotonic Properties for 9310 Quenched Core Steel (Iteration 57).

Average Elastic Modulus, E	=	197	GPa
Yield Strength	=	804	MPa
Ultimate tensile Strength	=	902	MPa
% Elongation	=	31	%
% Reduction of Area	=	70.8	%
True fracture strain, $Ln\ (A_i / A_f)$	=	123	%
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$	=	1417.5	MPa
Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \Big/ \left(1 + \frac{4R}{D_f}\right) Ln\left(1 + \frac{D_f}{4R}\right)$	=	1260.8	MPa
Monotonic tensile strength coefficient, K	=	1135.7	MPa
Monotonic tensile strain hardening exponent, n	=	0.055	
Hardness, Rockwell C (HRC)	=	26	
Hardness, Brinell	=		

Cyclic Properties for 9310 Quenched Core Steel (Iteration 57).

Cyclic Yield Strength, (0.2% offset) $= K'(0.002)^{n'}$	=	616	MPa
Cyclic strength coefficient, K'	=	1034.6	MPa
Cyclic strain hardening exponent, n'	=	0.0832	
Fatigue Strength Coefficient, σ'_f	=	1015.5	MPa
Fatigue Strength Exponent, b	=	-0.054	
Fatigue Ductility Coefficient, ε'_f	=	0.721	
Fatigue Ductility Exponent, c	=	-0.640	

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.