6150 Quenched and Tempered
Iteration #85

Fatigue Behavior, Monotonic Properties and Microstructural Data

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July 2006

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SUMMARY

This report presents the monotonic and fatigue test results obtained for 6150 quenched and tempered (iteration 85) steel. The material was provided by the American Iron and Steel Institute (AISI). Monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Strain-controlled constant-amplitude fatigue tests were to obtain the strain-life curve, cyclic stress-strain curve and fatigue data for this material. Also the microstructure data was obtained.

INTRODUCTION

This report presents the results of tensile and fatigue tests performed on a group of 6150 quenched and tempered steel samples (Iteration 85). The material was provided by the American Iron and Steel Institute. The objectives of this investigation were to obtain the microstructure 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 1.00" round bars. Smooth cylindrical fatigue specimens, shown in Figure 1, were machined from the metal bars and then heat treated. Subsequently, the gauge sections of the fatigue specimens were mechanically polished in the loading direction. Before testing, the specimens had a final polish in the loading direction in the gauge sections using 600-emery paper and 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.

Test Equipment and Procedure

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 electro-hydraulic 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 3 Hz while in stress-controlled tests the frequency used was up to 75 Hz.

RESULTS

Chemical composition and microstructure Data

The chemical composition as provided by the supplier is shown in Table 1. Figure 2 presents the martensite microstructure of the 6150 quenched and tempered. Figure 3 shows the inclusions observed in this material.

Strain-Life Data

Constant amplitude test data obtained in this investigation are given in table 2. The stress amplitude corresponding to the strain amplitude was calculated from the peak load amplitude at the specimen half-life.

A fatigue strain life curve is shown in Figure 4, and is described by the following equation:

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

where $\frac{\Delta e}{2}$ = 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

The values of the strain-life parameters were determined from the best fit curve of the fatigue testing data and presented in table 3.

Cyclic Stress-Strain Curves

Stabilized, half-life stress data obtained from strain-life fatigue tests were used to obtain the companion cyclic stress-strain curve shown in Figure 5. As shown in Fig. 5, the material’s cyclic stress- strain curve is linear. Therefore, the curve was described as:

$$e = \frac{s}{E_c}$$

where E_c is the cyclic modulus of elasticity and it is given in table 3.

Mechanical Properties

The engineering monotonic tensile stress-strain curves are given in Figure 6. The true monotonic and true cyclic stress-strain curves plotted together are given in Figure 7. The monotonic properties along with the average hardness test results are included in table 3. The individual hardness measurements are given in Table 2.

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.

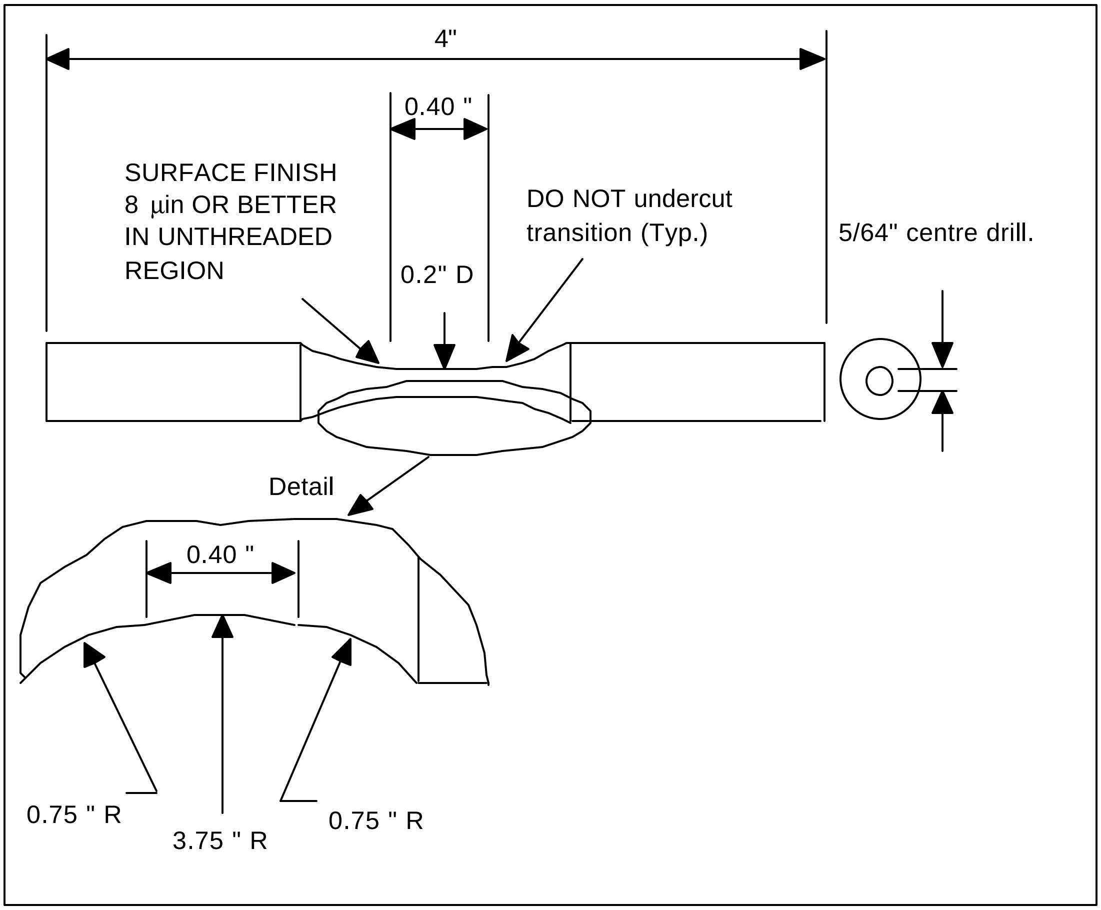

Figure 1 Smooth cylindrical fatigue specimen

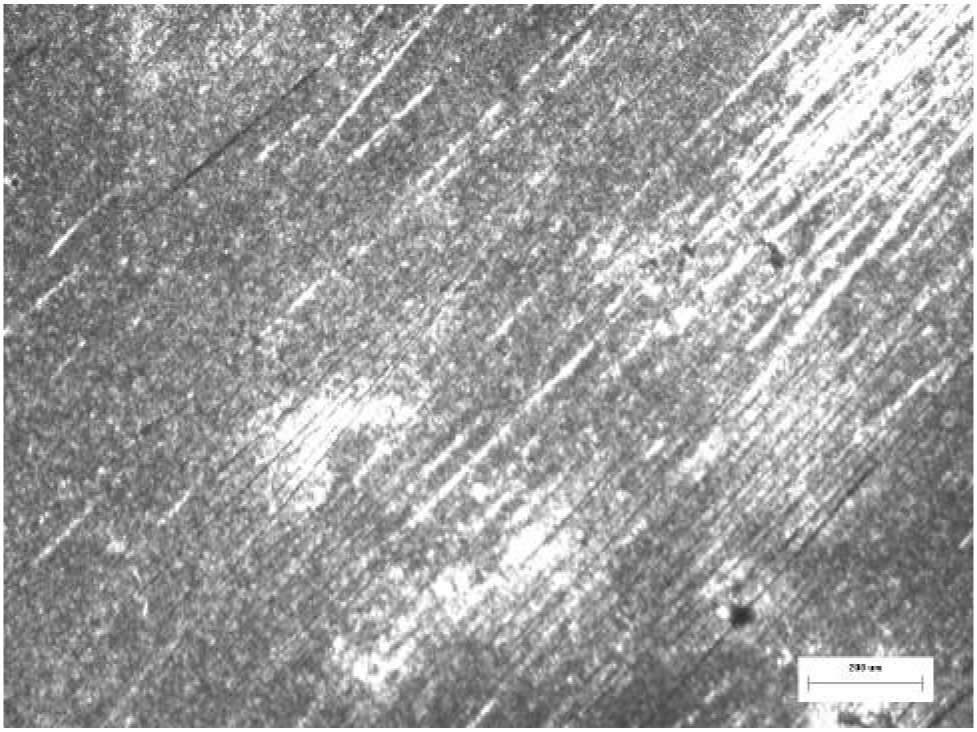

Figure 2 Photomicrographs of 6150 quenched and tempered steel (X50)

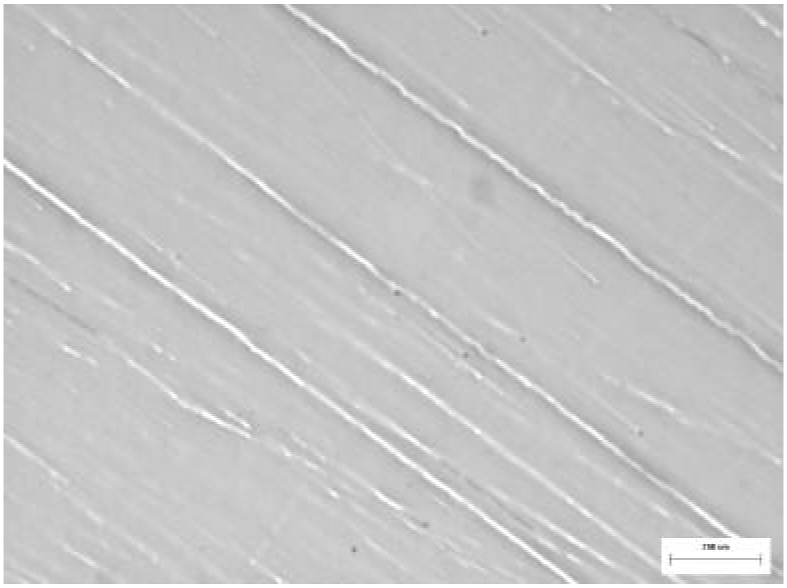

Figure 3 Inclusions (transverse direction) photomicrograph of 6150 quenched and tempered steel (X50)

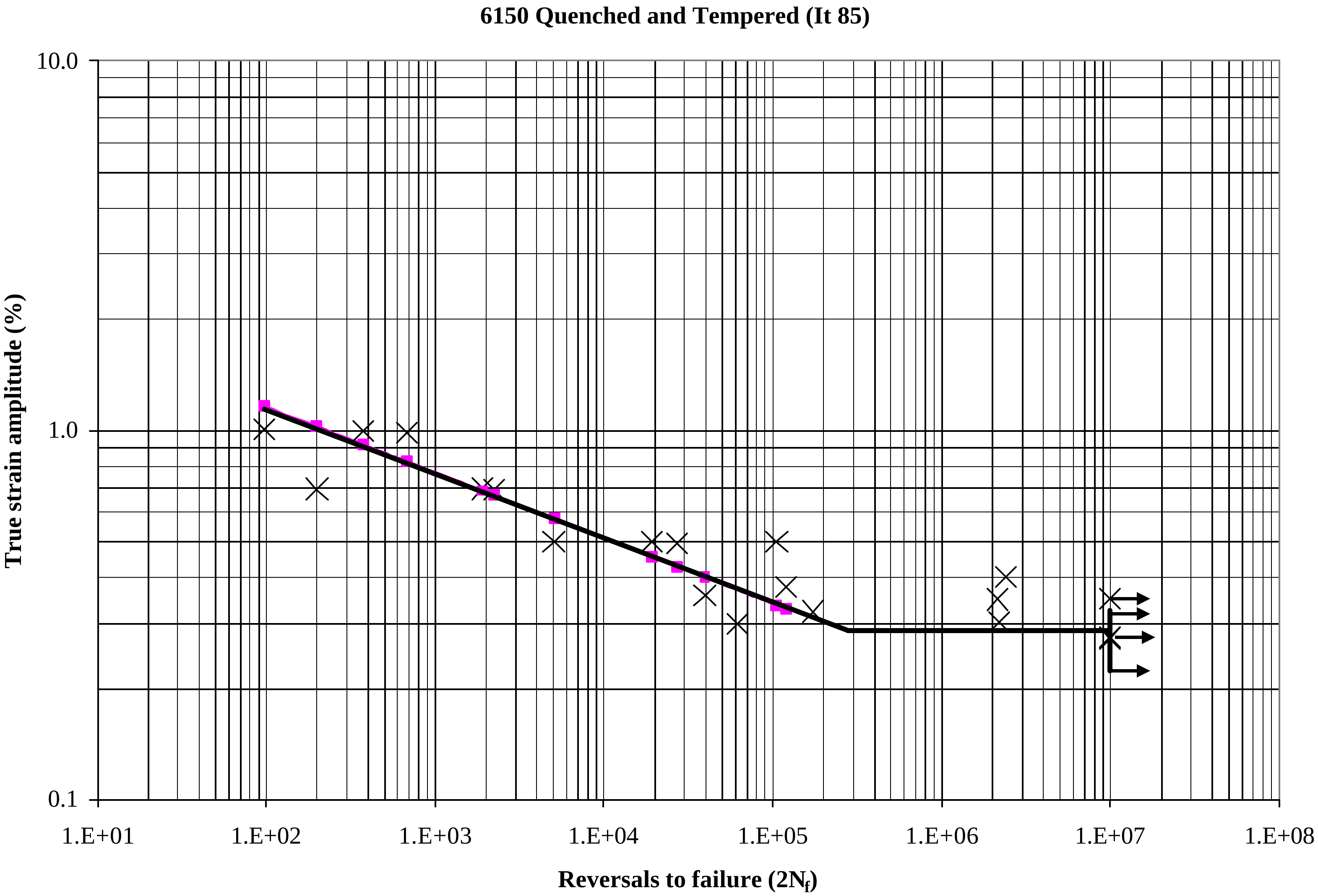

Figure 4. Constant amplitude fully reversed strain-life curve for Iteration 85

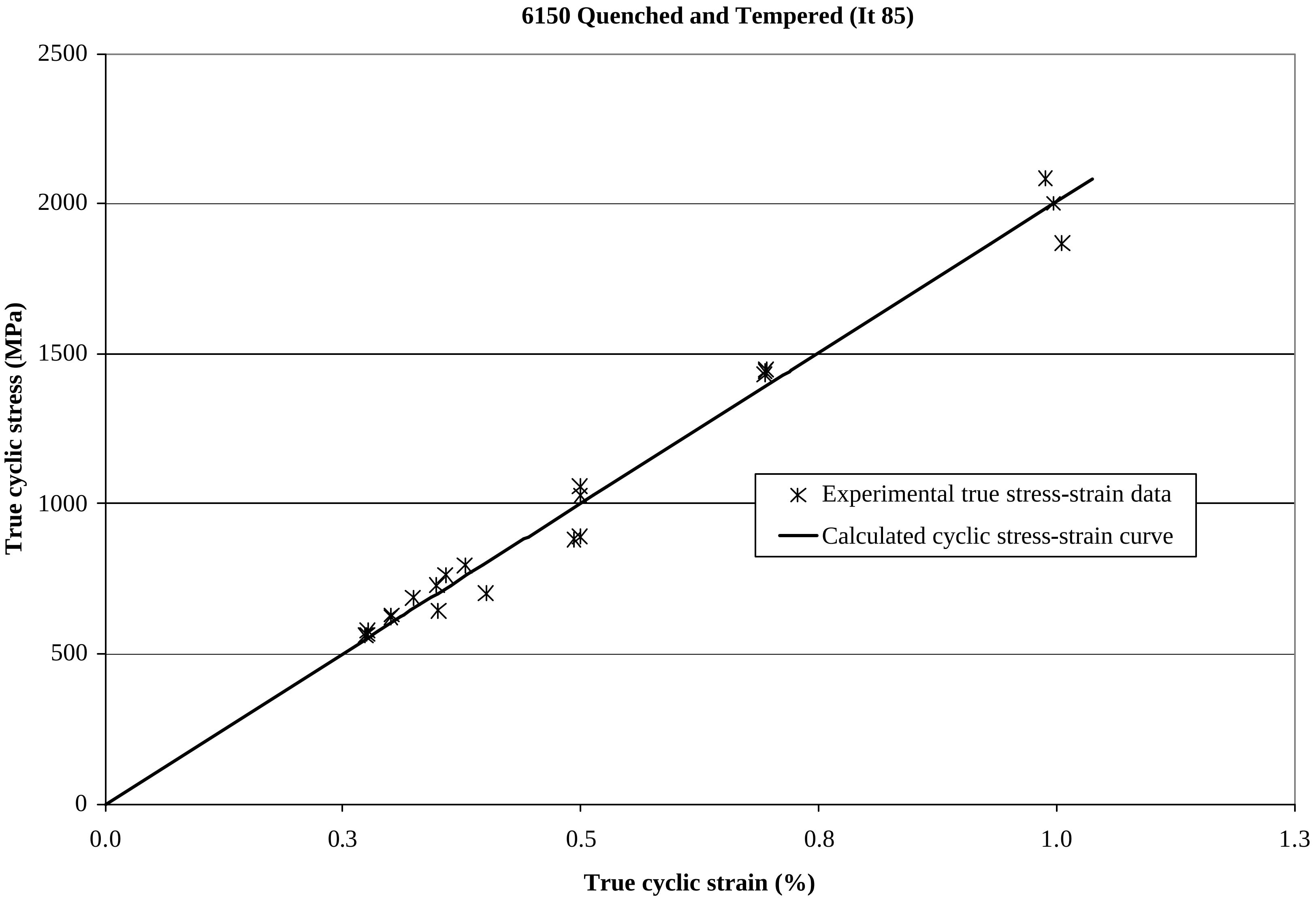

Figure 5. Cyclic true stress-strain curve for iteration 85

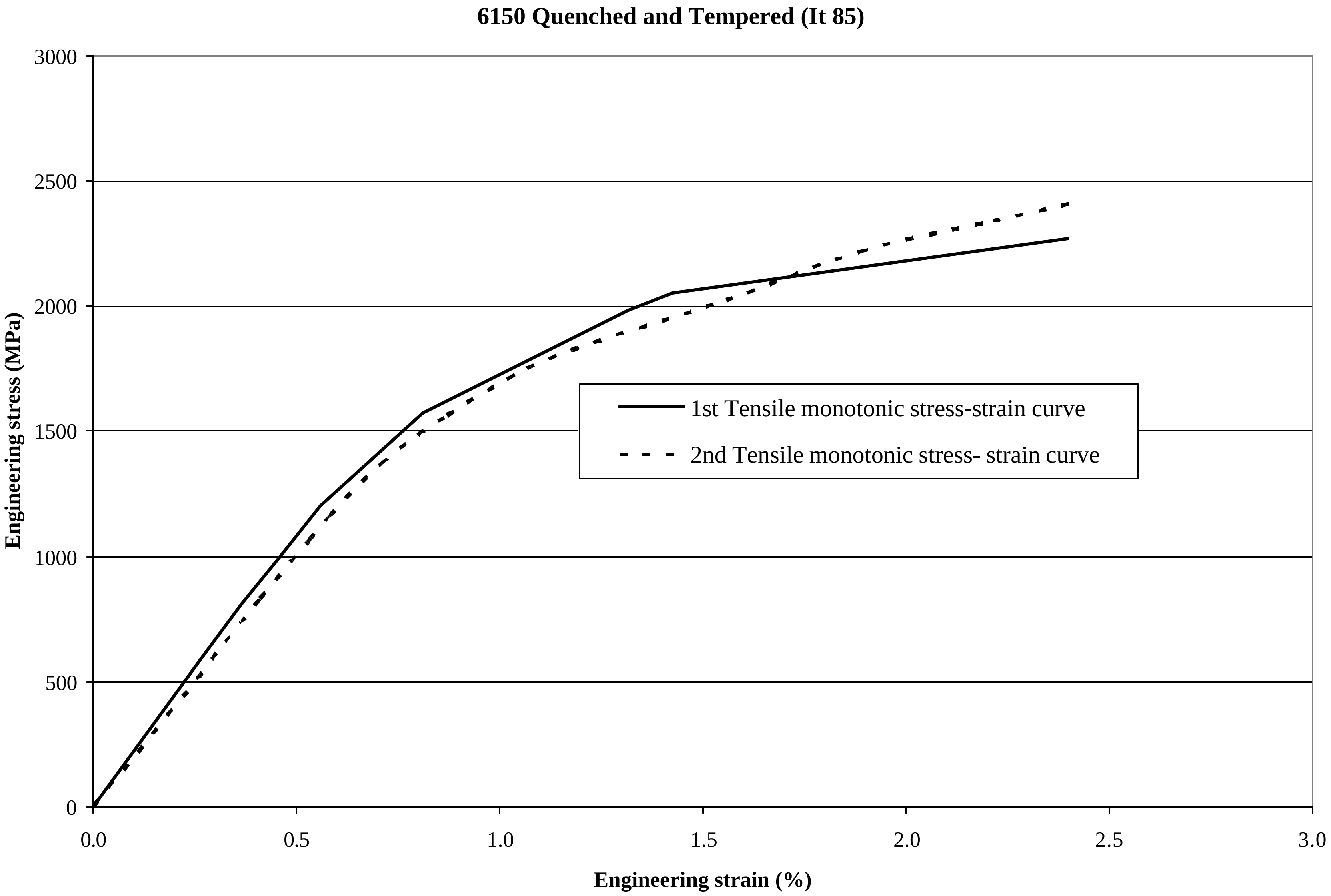

Figure 6. Tensile monotonic engineering stress-strain curves for iteration 85

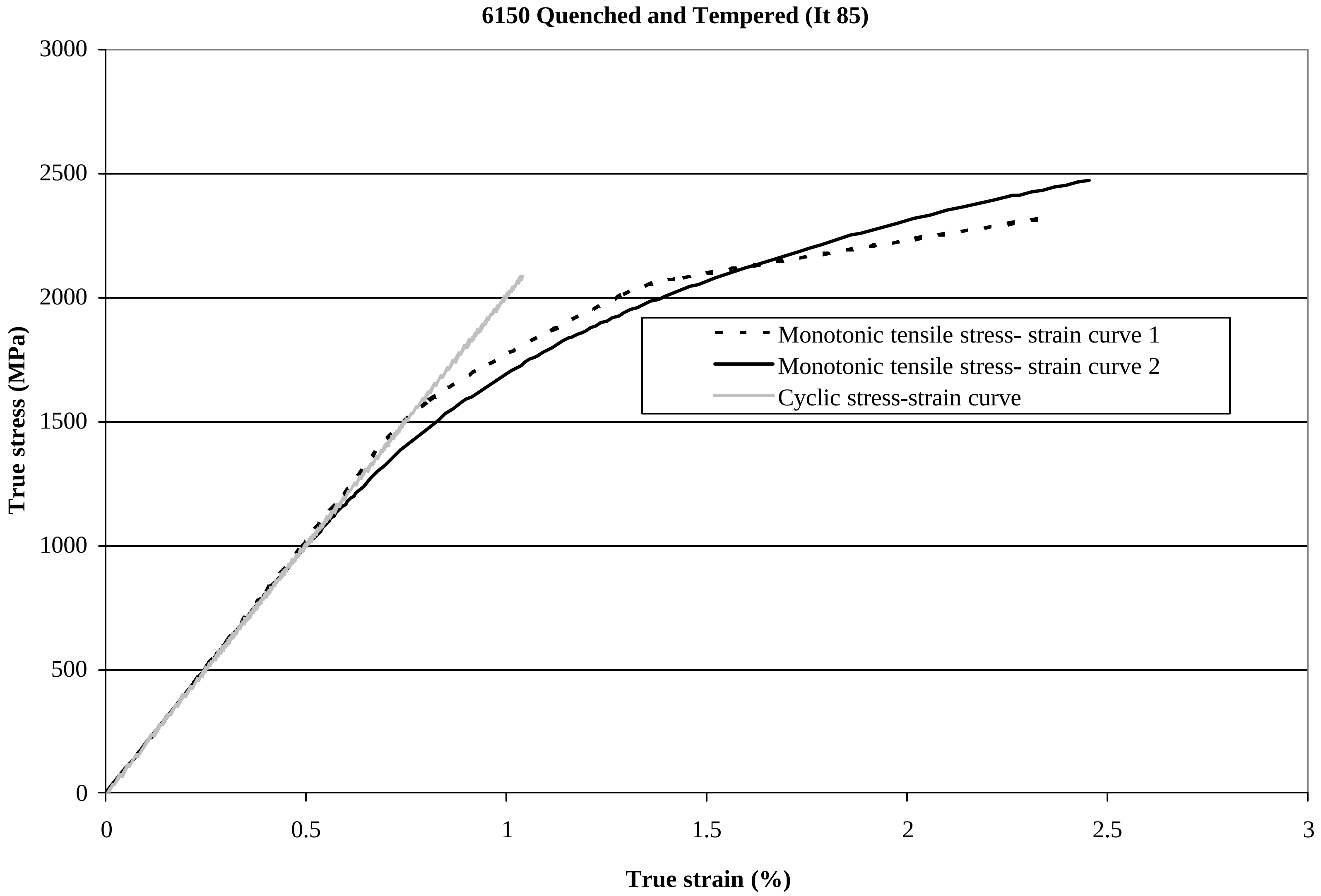

Figure 7. Monotonic and Cyclic true stress-strain curves for iteration 85

Table 1: Chemical composition for Iteration 85

Chemical element	Quantity (%)
Carbon-- C	0.51
Manganese (Mn)	0.82
Phosphorus (P)	0.012
Sulfur (S)	0.026
Silicon (Si)	0.25
Copper (Cu)	0.22
Nickel (Ni)	0.1
Chromium (Cr)	0.96
Molybdenum (Mo)	0.03
Tin (Sn)	0.00
Aluminum (Al)	0.038
Vanadium (V)	0.18
Columbium/Niobium (Nb)	0.00
Titanium (Ti)	0.00
Boron (B)	0.00
Calcium (Ca)	0.00
Zirconium (Zr)	0.00
Nitrogen (ppm) (N)	0.00
Oxygen (ppm) (O)	0.00

Table 2: Fatigue Data for Iteration 85

Sp#	Total Strain Amplitude (%)	Stress Amplitude (MPa)	Plastic Strain Amplitude (%)	Elastic Strain Amplitude (%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	Hardness (Rockwell C)
1	1.006	1867.7	0.000	1.006	98	
4	0.988	2083.5	0.000	0.988	684	
14	0.997	2000.5	0.000	0.997	374	
18	0.695	1447.5	0.000	0.695	1910	
19	0.693	1430.9	0.000	0.693	2244	
21	0.694	1442.0	0.000	0.694	200	54
2	0.499	891.6	0.000	0.499	5058	55
3	0.493	882.2	0.000	0.493	27010	
7	0.499	1058.2	0.000	0.499	105806	
16	0.500	1028.4	0.000	0.500	19280	55
5	0.400	701.3	0.000	0.400	2417554	
8	0.378	795.8	0.000	0.378	119060	
6	0.350	644.2	0.000	0.350	10000000*	
9	0.358	763.2	0.000	0.358	39576	
20	0.348	729.5	0.000	0.348	2150408	
11	0.324	688.1	0.000	0.324	172720	
10	0.301	630.1	0.000	0.301	2187246	
12	0.300	623.5	0.000	0.300	61302	
13	0.274	561.2	0.000	0.274	10000000*	
15	0.275	565.0	0.000	0.275	10000000*	
17	0.276	576.6	0.000	0.276	10000000*	

* Run out

Table 3: Monotonic and cyclic properties for iteration 85

Monotonic Properties	
Average Elastic Modulus, E (GPa)	204.32
Yield Strength (MPa)	1878.2
Ultimate tensile Strength (MPa)	2342.8
% Elongation (%)	2.4%
% Reduction of Area (%)	0.0%
True fracture strain, $Ln\ (A_i / A_f)$ (%)	2.4%
True fracture stress, $s_f = \frac{P_f}{A_f}$ (MPa)	2342.8
Bridgman correction $= \frac{P_f}{A_f} \Big/ \left(1 + \frac{4R}{D_f}\right) Ln \left(1 + \frac{D_f}{4R}\right)$ (MPa)	1926.0
Monotonic tensile strength coefficient, K (MPa)	4682.6
Monotonic tensile strain hardening exponent, n	0.1470
Hardness, Rockwell C (HRC)	55
Cyclic Properties	
Cyclic Elastic Modulus, E_c (GPa)	200.68
Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ (MPa)	N/A
Cyclic strength coefficient, K' (MPa)	N/A
Cyclic strain hardening exponent, n'	N/A
Fatigue Strength Coefficient, σ'_f (MPa)	5379.2
Fatigue Strength Exponent, b	-0.178
Fatigue Ductility Coefficient, ε'_f	N/A
Fatigue Ductility Exponent, c	N/A

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