5160H Quenched & Tempered
Iteration #84

Fatigue Behavior, Monotonic Properties and Microstructural Data

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SUMMARY

This report presents the monotonic and fatigue test results obtained for 5160H quenched and tempered (iteration 84) 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 5160H quenched and tempered steel samples (Iteration 84). 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 1.023” 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 5160H 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. The cyclic stress-strain curve is described by the following equation:

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

where ε = True total strain amplitude

σ = Cyclically stable true stress amplitude

$K^{'}$ = Cyclic strength coefficient

$n^{'}$ = Cyclic strain hardening exponent

The constants K’ and n' obtained from a best fit of the above equation to the test data are 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.

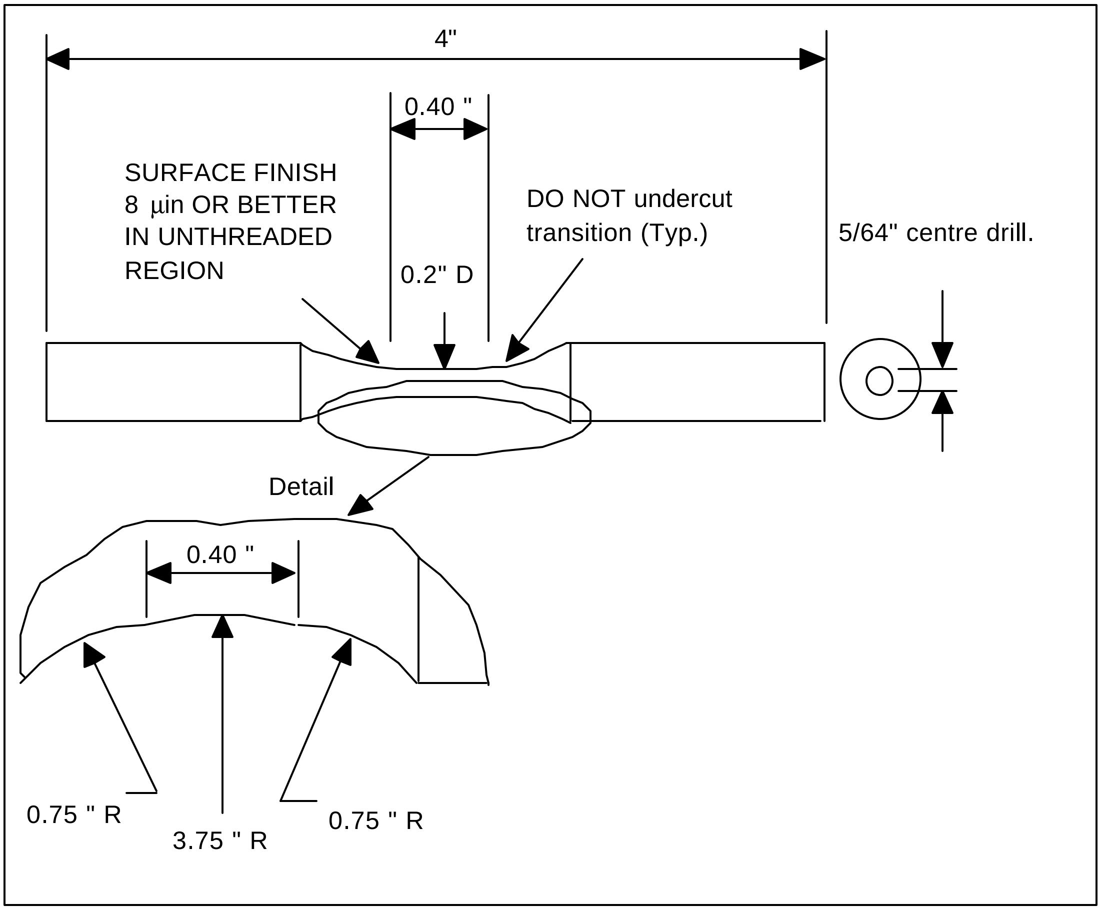

Figure 1 Smooth cylindrical fatigue specimen

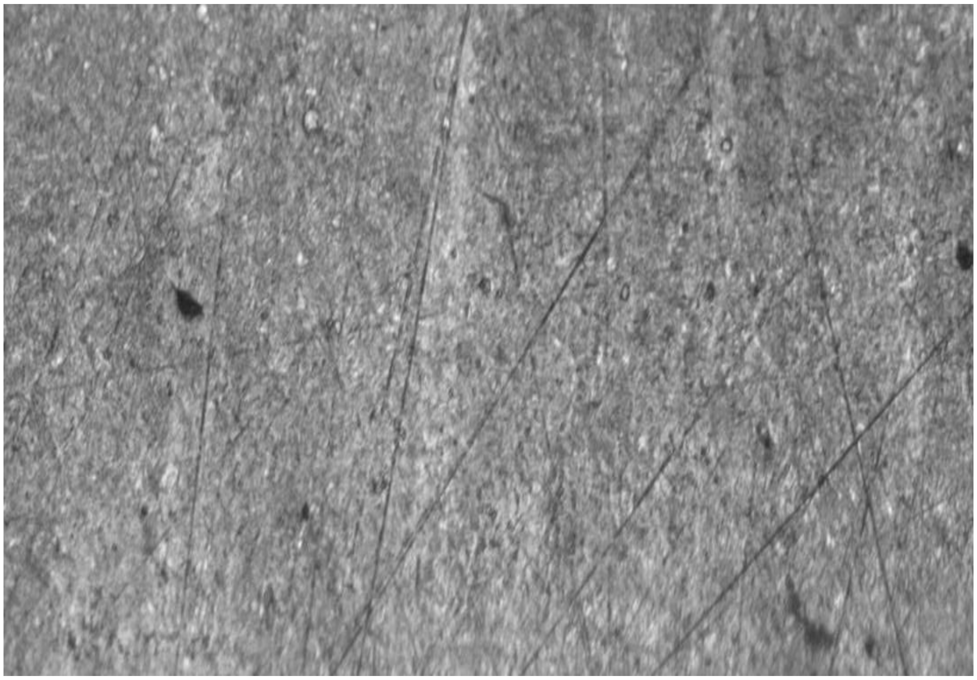

Figure 2 Photomicrographs of 5160H quenched and tempered steel (X20)

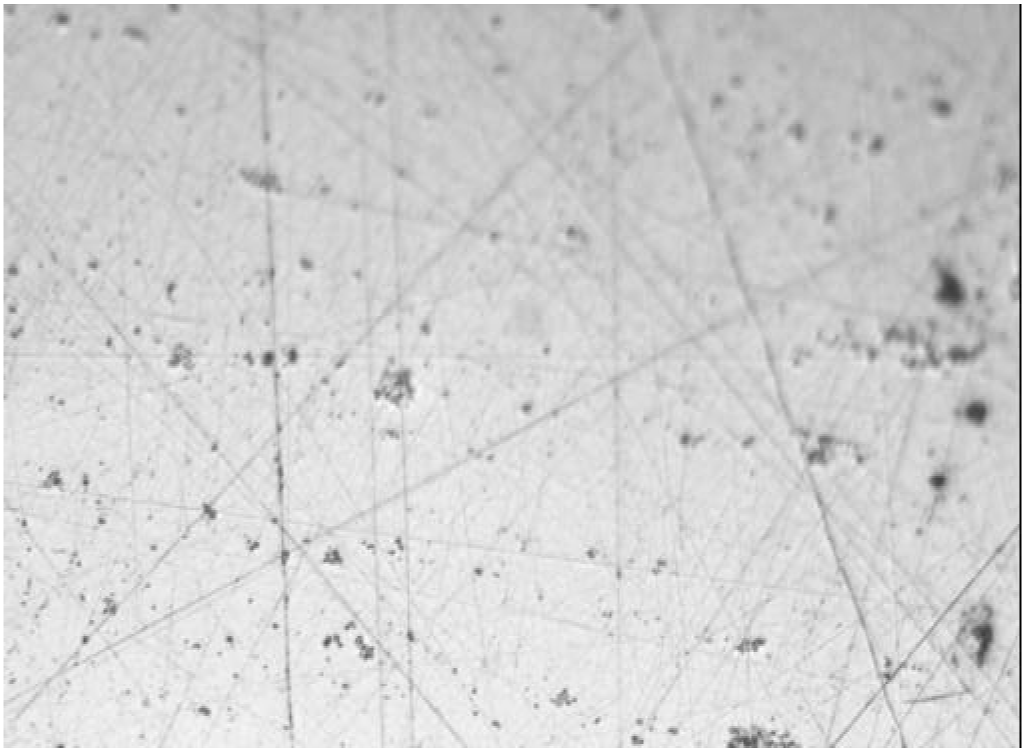

Figure 3 Inclusions photomicrograph of 5160H quenched and tempered steel (X20)

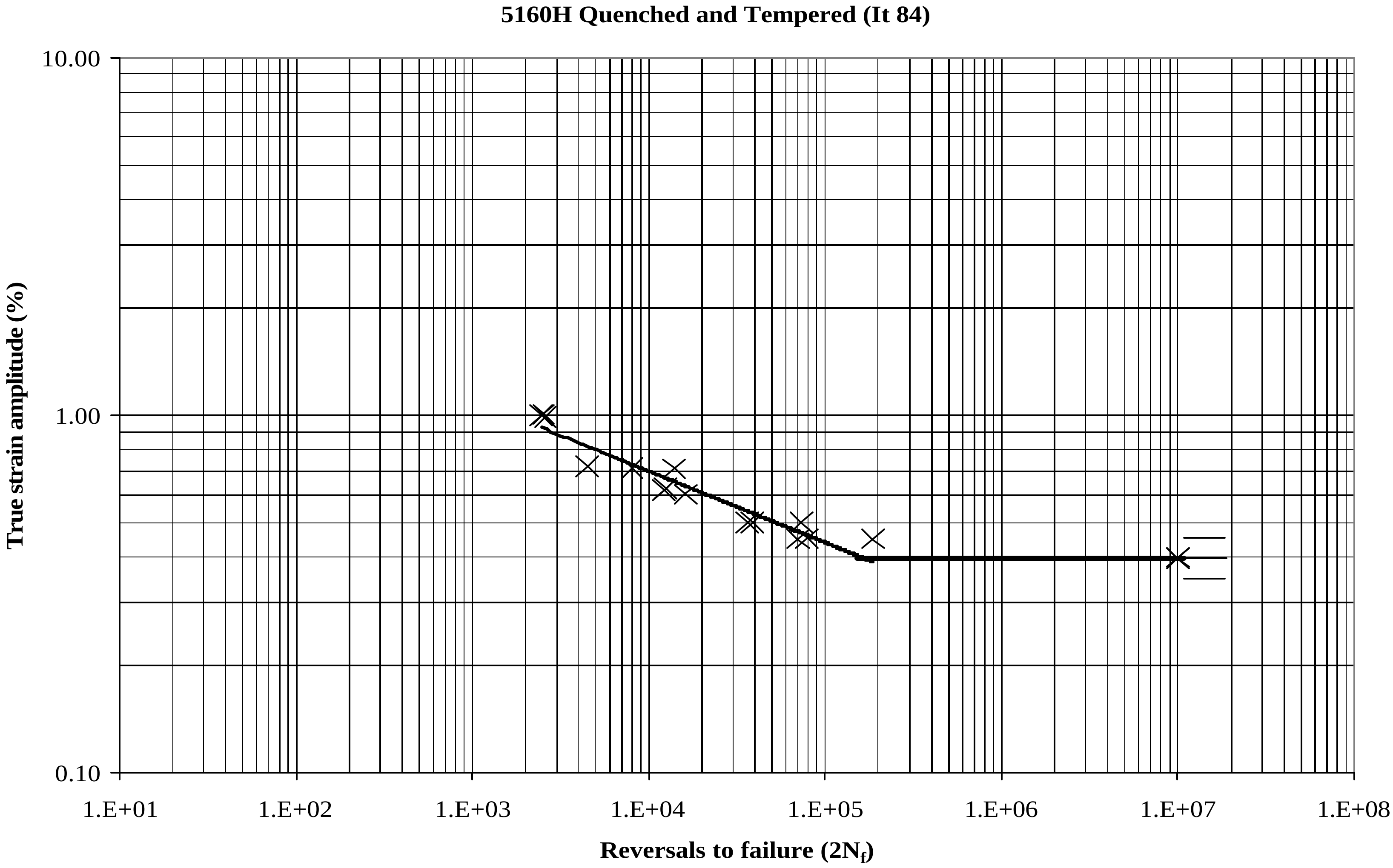

Figure 4. Constant amplitude fully reversed strain-life curve for Iteration 84

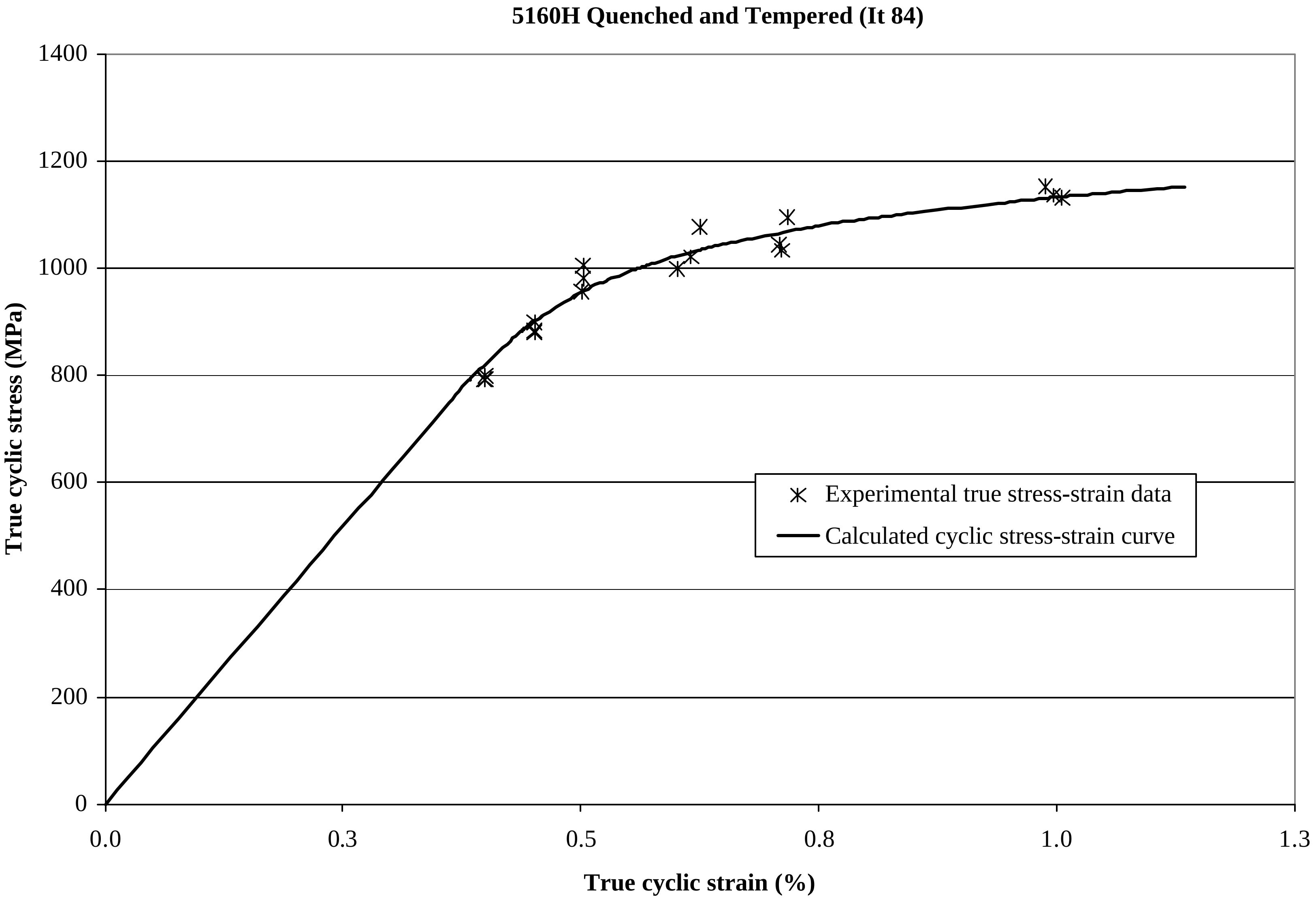

Figure 5. Cyclic true stress-strain curve for iteration 84

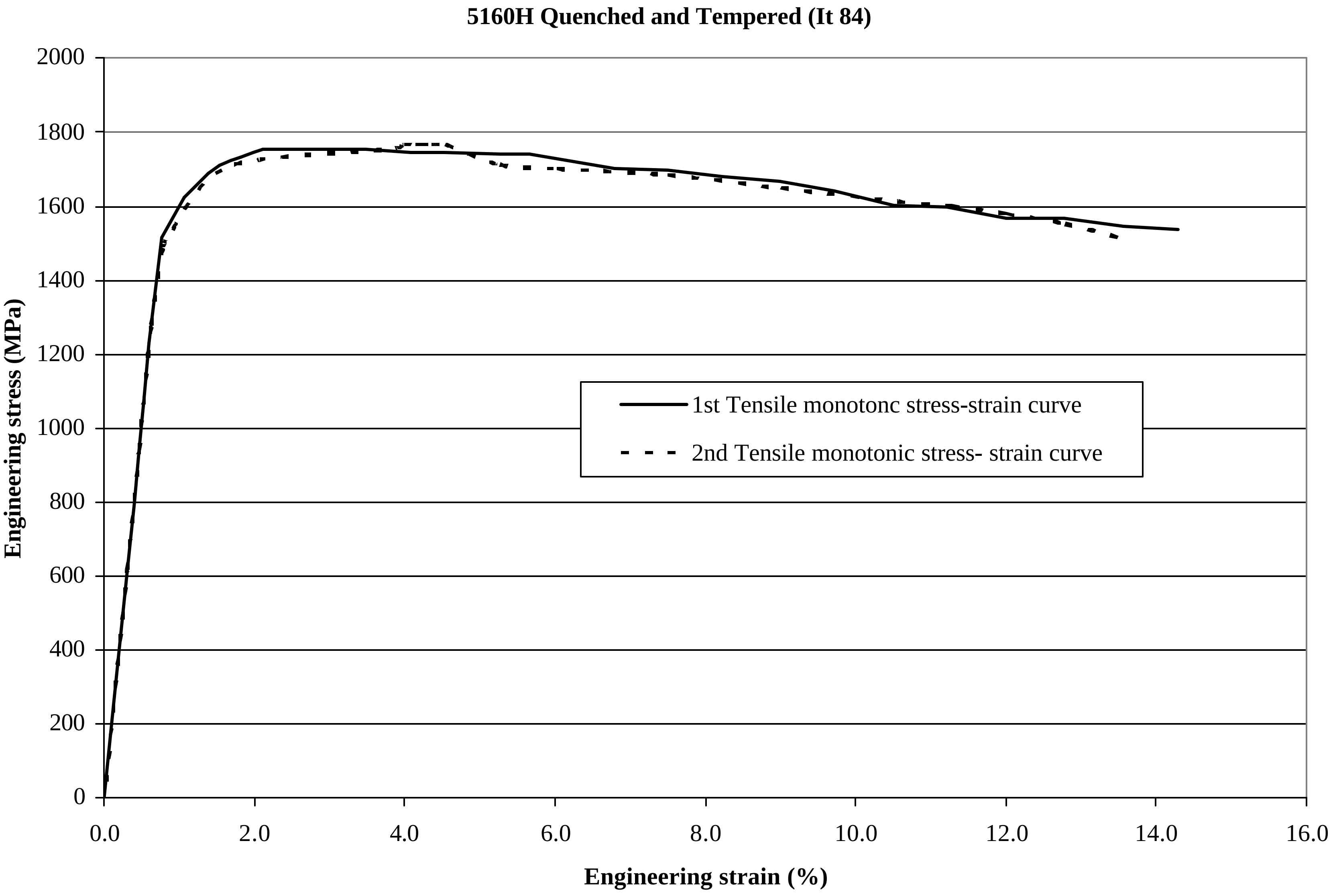

Figure 6. Tensile monotonic engineering stress-strain curves for iteration 84

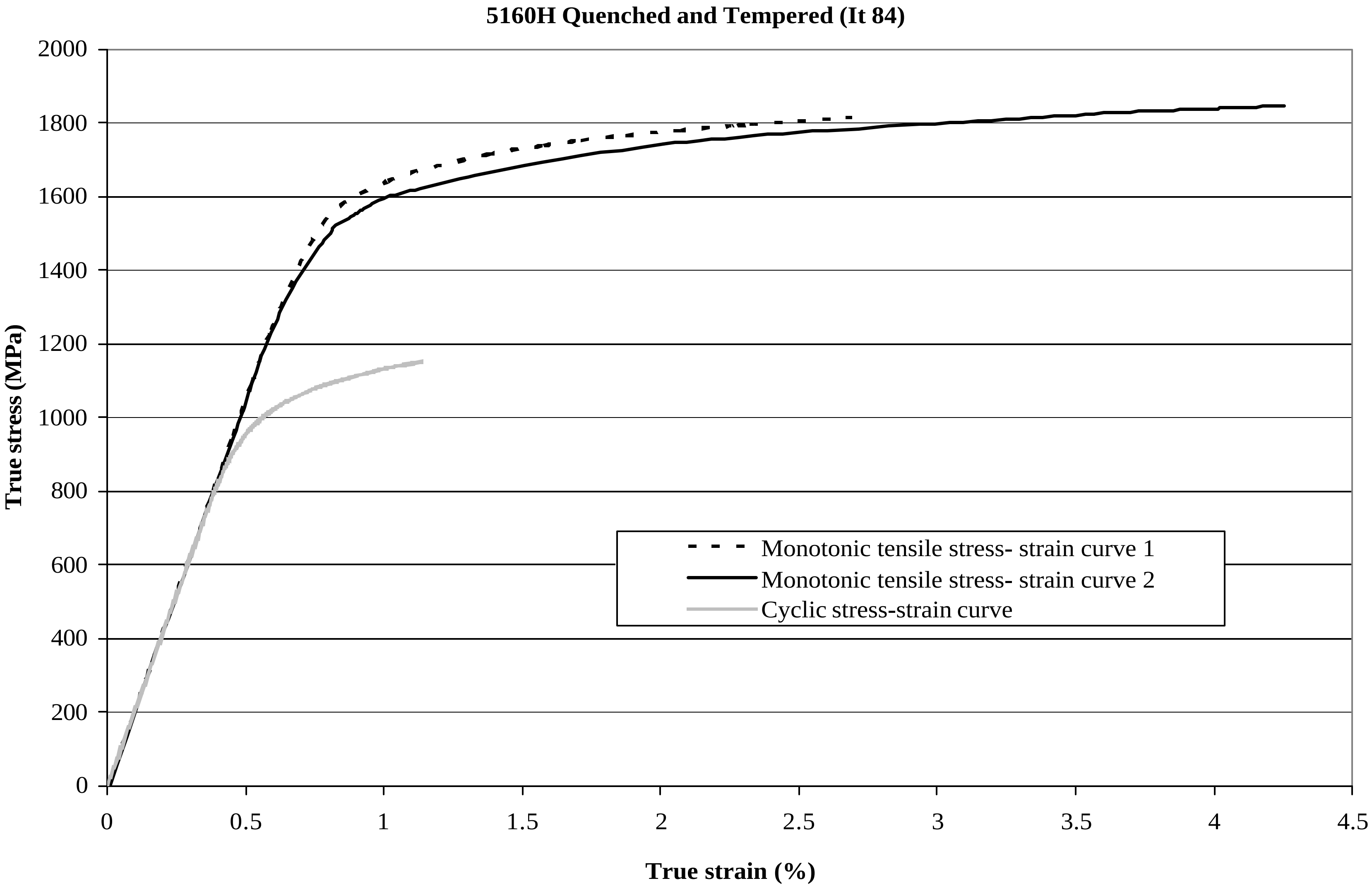

Figure 7. Monotonic and Cyclic true stress-strain curves for iteration 84

Table 1: Chemical composition for Iteration 84

Chemical element	Quantity (%)
Carbon-- C	0.59000
Manganese (Mn)	0.83000
Phosphorus (P)	0.01500
Sulfur (S)	0.01300
Silicon (Si)	0.28000
Copper (Cu)	0.10000
Nickel (Ni)	0.05000
Chromium (Cr)	0.79000
Molybdenum (Mo)	0.02000
Tin (Sn)	0.00600
Aluminum (Al)	0.00000
Vanadium (V)	0.03600
Columbium/Niobium (Nb)	0.00100
Titanium (Ti)	0.00200
Boron (B)	0.00020
Calcium (Ca)	0.00000
Zirconium (Zr)	0.00000
Nitrogen (ppm) (N)	0.00000
Oxygen (ppm) (O)	0.00000

Table 2: Fatigue Data for Iteration 84

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	1130.6	0.464	0.542	2536	
8	0.997	1136.0	0.453	0.544	2464	
15 R	0.988	1152.6	0.436	0.552	2596	
16	0.711	1033.3	0.216	0.495	8056	
17	0.708	1044.4	0.208	0.500	14000	
18	0.717	1094.2	0.193	0.524	4504	
2	0.601	999.1	0.123	0.479	16256	48
4	0.625	1076.6	0.109	0.516	12540	
11	0.616	1021.3	0.127	0.489	12246	
5	0.502	981.0	0.032	0.470	38960	
13	0.501	956.7	0.042	0.458	73226	
14	0.503	1004.7	0.021	0.481	36284	
6	0.451	883.5	0.028	0.423	187306	
10	0.452	879.6	0.030	0.421	78956	46
12	0.451	898.9	0.021	0.431	70162	47
3	0.400	792.7	0.020	0.380	10000000*	
7	0.399	791.6	0.020	0.379	10000000*	
9	0.399	799.9	0.016	0.383	10000000*	

* Run out

Table 3: Monotonic and cyclic properties for iteration 84

Monotonic Properties	
Average Elastic Modulus, E (GPa)	208.71
Yield Strength (MPa)	1604.2
Ultimate tensile Strength (MPa)	1761.2
% Elongation (%)	13.9%
% Reduction of Area (%)	30.2%
True fracture strain, $Ln\ (A_i / A_f)$ (%)	35.9%
True fracture stress, $s_f = \frac{P_f}{A_f}$ (MPa)	2184.4
Bridgman correction $= \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$(MPa)	1843.8
Monotonic tensile strength coefficient, K (MPa)	2216.2
Monotonic tensile strain hardening exponent, n	0.052
Hardness, Rockwell C (HRC)	47
Cyclic Properties	
Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ (MPa)	1066.9
Cyclic strength coefficient, K' (MPa)	1671
Cyclic strain hardening exponent, n'	0.0722
Fatigue Strength Coefficient, σ'_f(MPa)	1947.9
Fatigue Strength Exponent, b	-0.067
Fatigue Ductility Coefficient, ε'_f	2.51
Fatigue Ductility Exponent, c	-0.801

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