9310, Carburized Case
Iteration #58

Fatigue Behavior, Monotonic Properties
and
Microstructural Data

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SUMMARY

This report presents the monotonic and fatigue test results obtained for 9310 carburized case (Iteration 58) 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 conducted 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 9310 carburized case steel samples (Iteration 58). 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 1.156” round bars. Smooth cylindrical fatigue specimens, shown in Figure 1, were machined from the metal bars and then case-carburized. 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°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 9310 carburized case. 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.

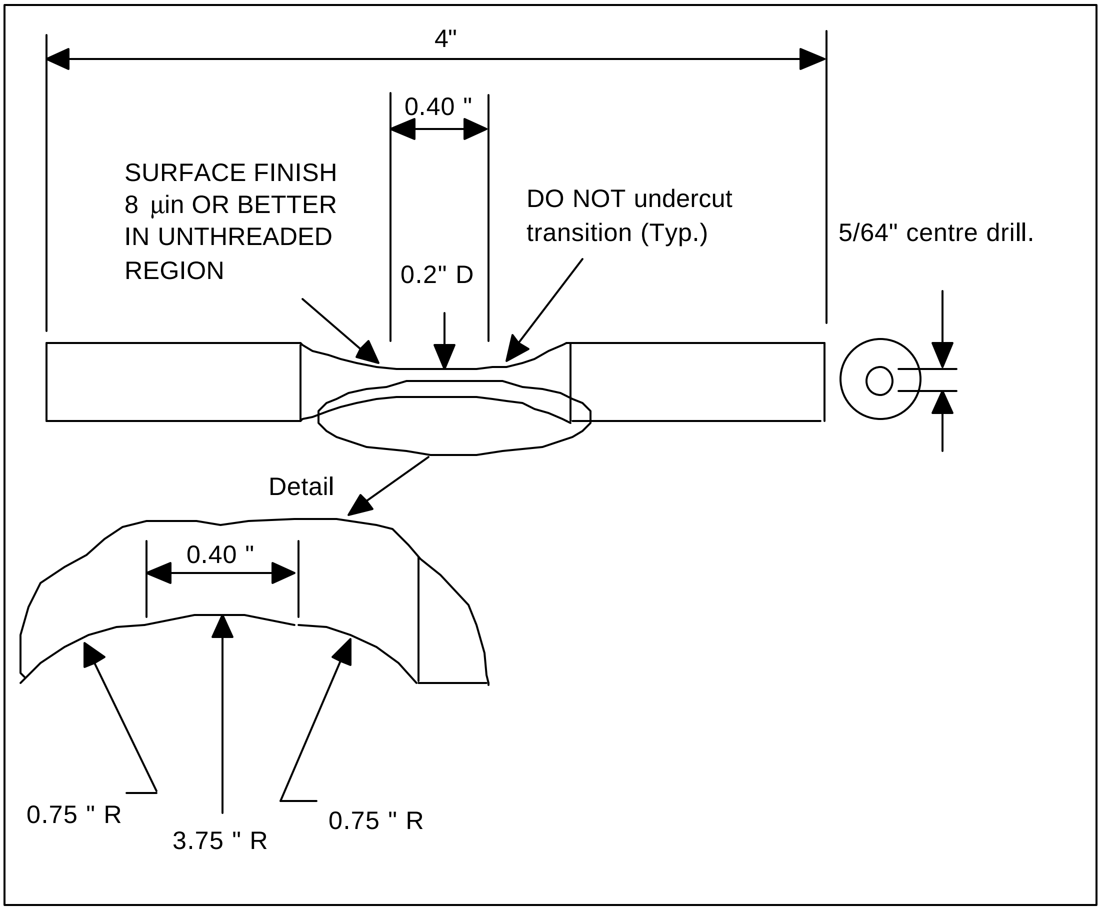

Figure 1 Smooth cylindrical fatigue specimen

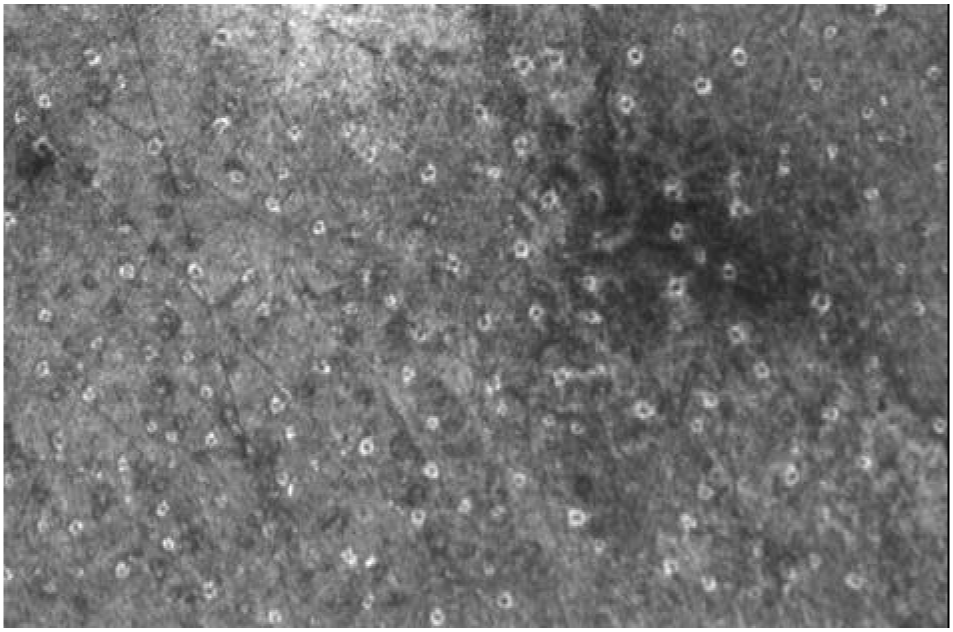

Figure 2 Photomicrographs of 9310 carburized case steel (X20)

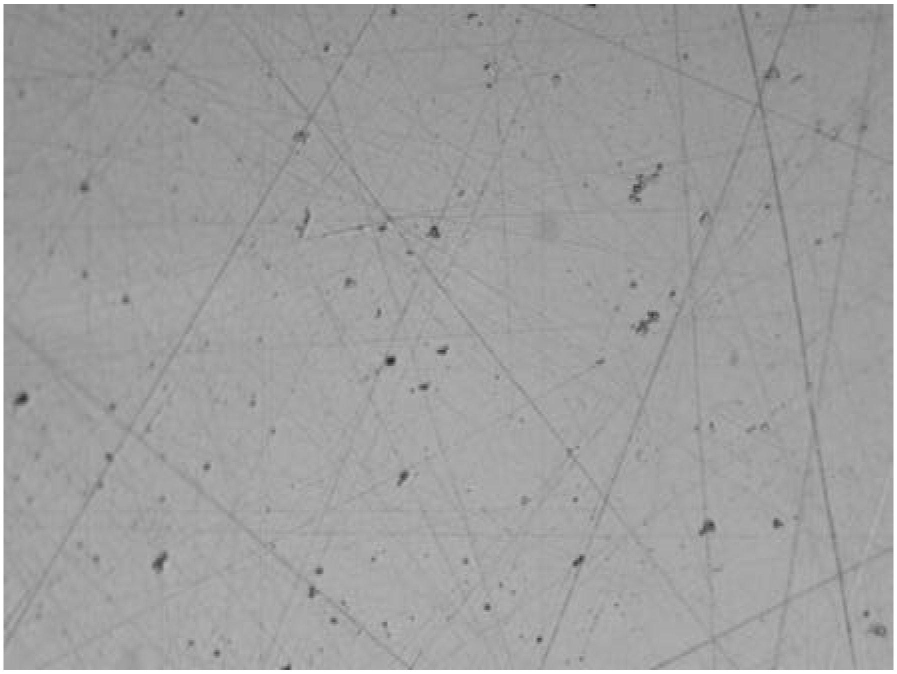

Figure 3 Inclusions photomicrograph of 9310 carburized case steel (X20)

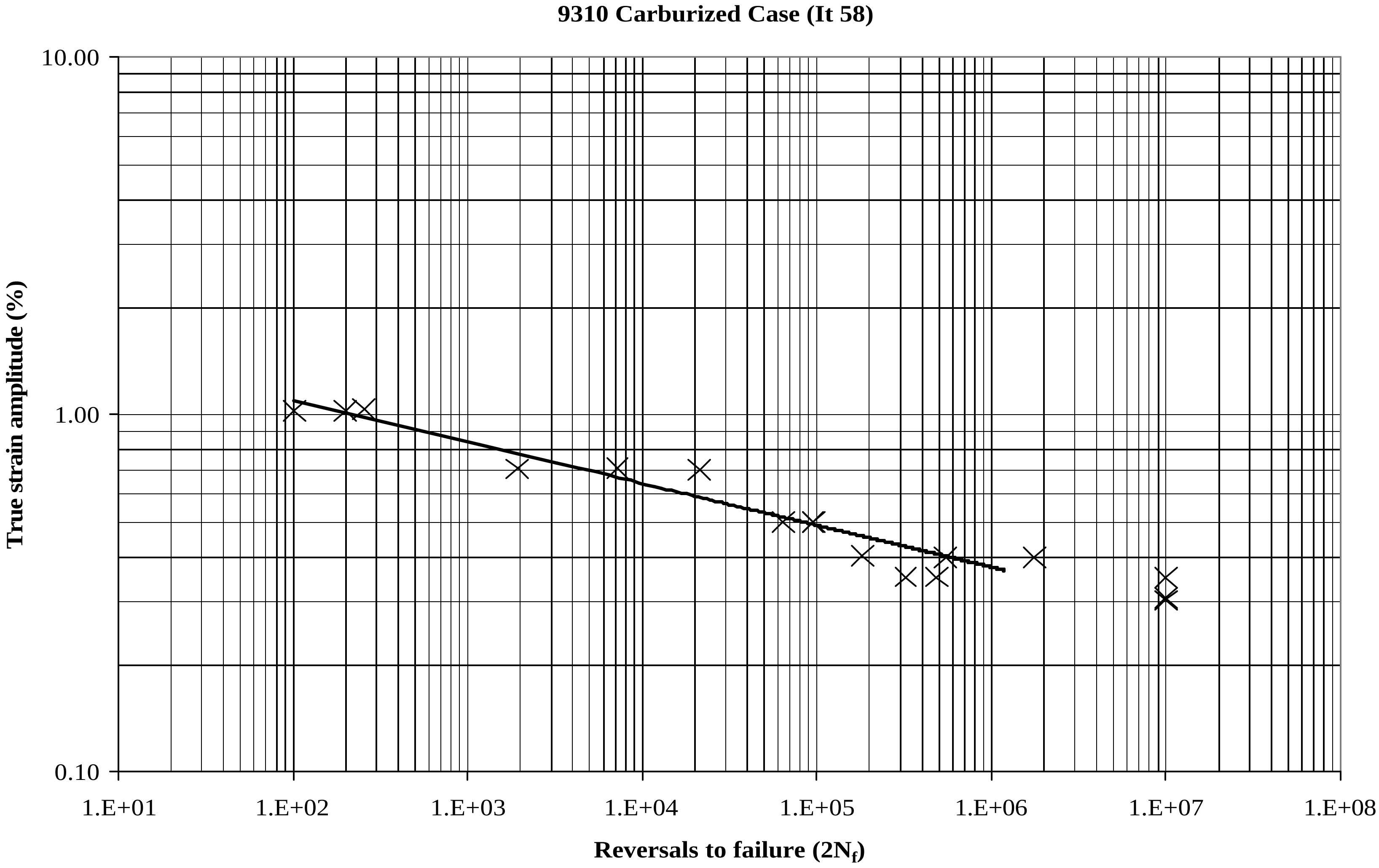

Figure 4. Constant amplitude fully reversed strain-life curve for Iteration 58

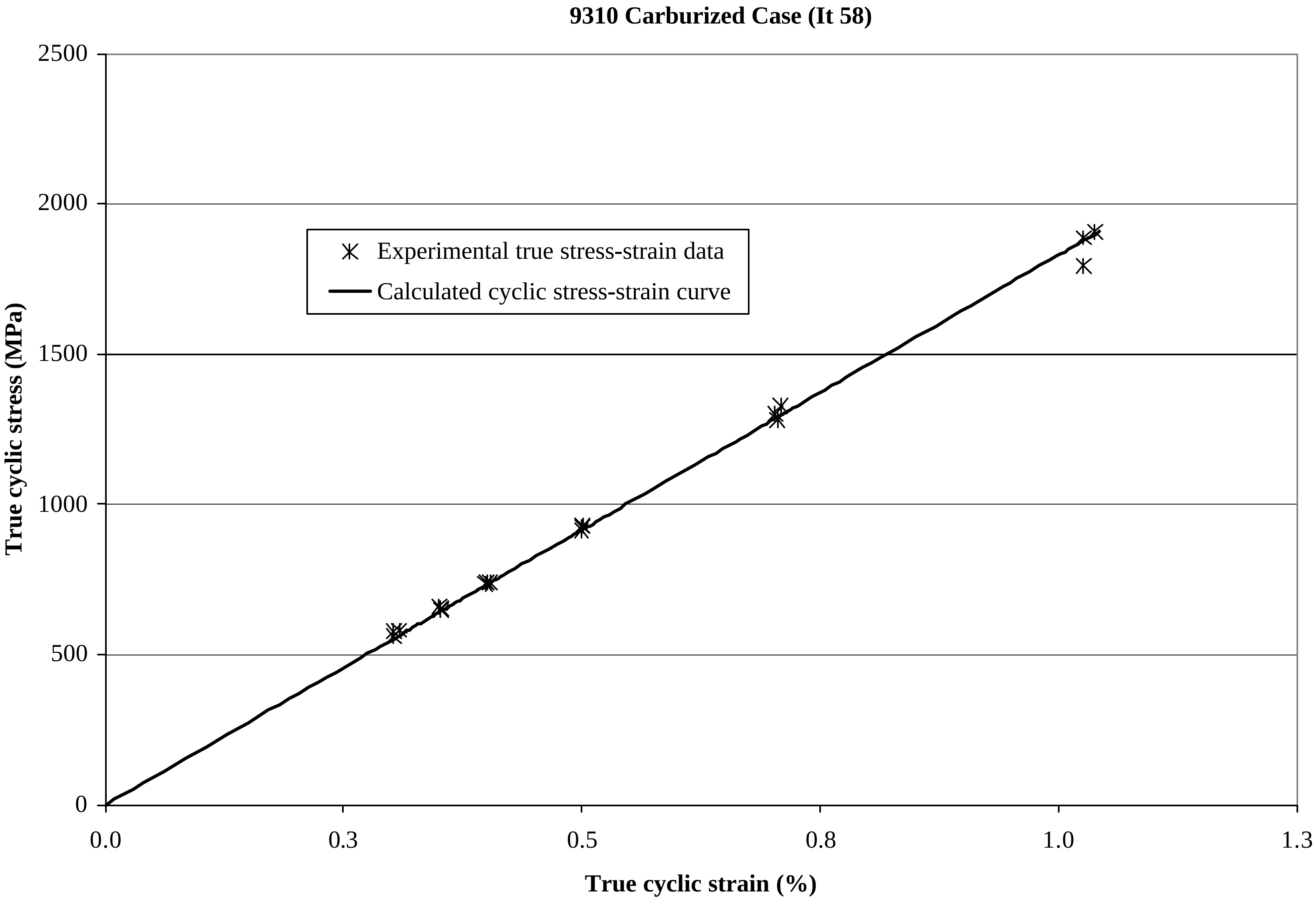

Figure 5. Cyclic true stress-strain curve for iteration 58

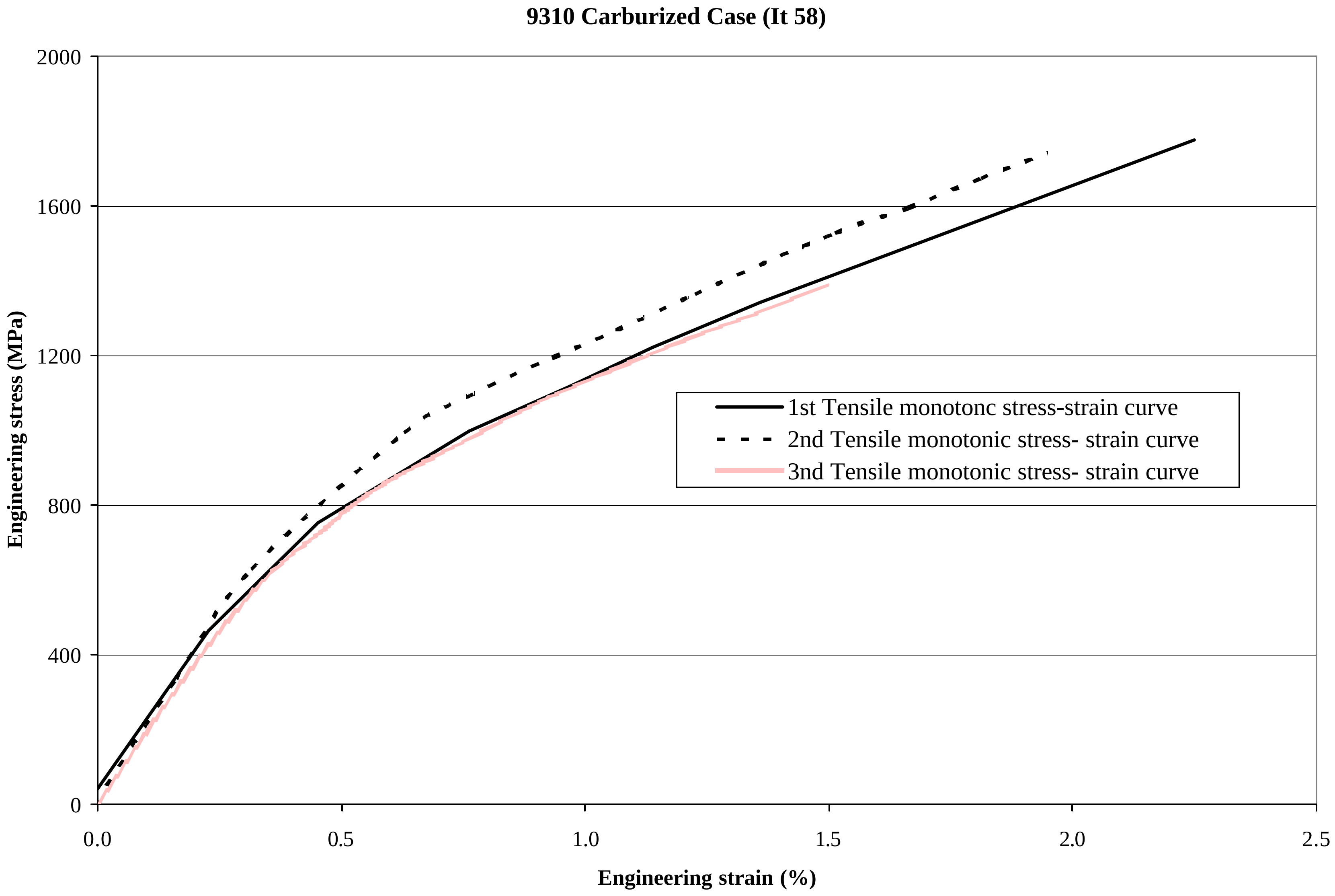

Figure 6. Tensile monotonic engineering stress-strain curves for iteration 58

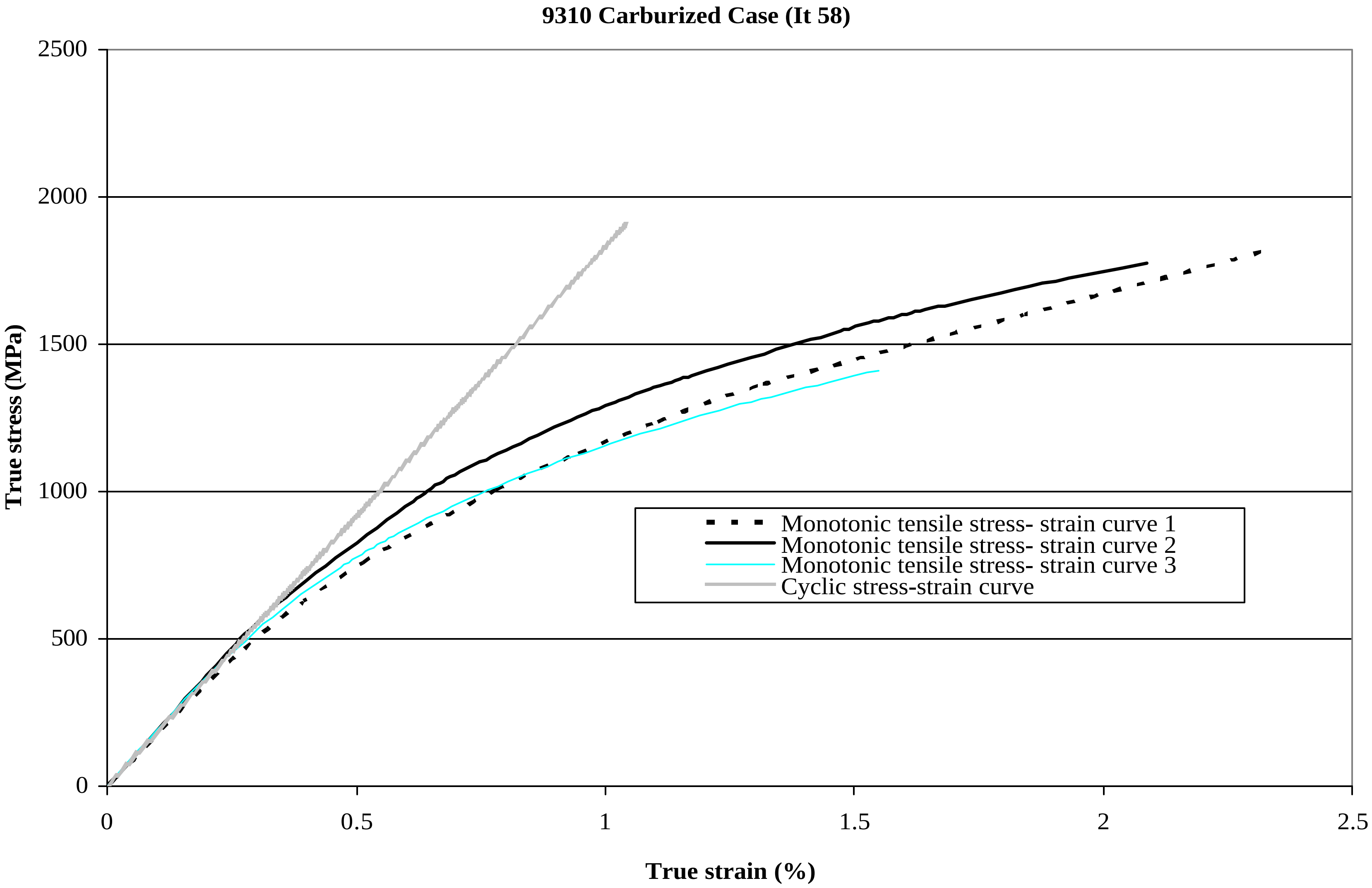

Figure 7. Monotonic and Cyclic true stress-strain curves for iteration 58

Table 1: Chemical composition for Iteration 58

Chemical element	**Quantity (%)**
Carbon-- C	0.11000
Manganese (Mn)	0.62000
Phosphorus (P)	0.01300
Sulfur (S)	0.01800
Silicon (Si)	0.24000
Copper (Cu)	0.20000
Nickel (Ni)	3.00000
Chromium (Cr)	1.18000
Molybdenum (Mo)	0.08000
Tin (Sn)	0.01000
Aluminum (Al)	0.03400
Vanadium (V)	0.00500
Columbium/Niobium (Nb)	0.00200
Titanium (Ti)	0.00300
Boron (B)	0.00030
Calcium (Ca)	0.00020
Zirconium (Zr)	0.00200
Nitrogen (N)	0.01040
Oxygen (O)	0.00000

Table 2: Fatigue Data for Iteration 58

Sp#	Total Strain Amplitude (%)	Stress Amplitude (MPa)	Plastic Strain Amplitude (%)	Elastic Strain Amplitude (%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	Hardness (Rockwell C)
1	1.027	1793.6	0.000	1.027	102	
17	1.027	1888.3	0.000	1.027	200	
18	1.039	1908.8	0.000	1.039	256	58
5	0.706	1281.8	0.000	0.706	1930	
16	0.708	1329.1	0.000	0.708	7224	
19	0.703	1302.0	0.000	0.703	21346	
2	0.500	927.1	0.000	0.500	64402	
10	0.501	928.4	0.000	0.501	95018	
12	0.500	915.0	0.000	0.500	95774	57
6	0.404	739.9	0.000	0.404	182984	57
14	0.400	739.2	0.000	0.400	1764892	
15	0.399	736.5	0.000	0.399	548508	
7	0.350	660.2	0.000	0.350	10000000*	
8	0.352	649.4	0.000	0.352	485270	
13	0.352	653.4	0.000	0.352	322812	
4	0.303	561.1	0.000	0.303	10000000*	
9	0.308	581.3	0.000	0.308	10000000*	
11	0.303	577.9	0.000	0.303	10000000*	

* Run out

Table 3: Monotonic and cyclic properties for iteration 58

Monotonic Properties	
Average Elastic Modulus, E (GPa)	190.17
Yield Strength (MPa)	1024.2
Ultimate tensile Strength (MPa)	1635.7
% Elongation (%)	1.9%
% Reduction of Area (%)	2.9%
True fracture strain, $Ln\ (A_i / A_f)$ (%)	3.0%
True fracture stress, $s_f = \frac{P_f}{A_f}$ (MPa)	1684.7
Bridgman correction $= \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$(MPa)	1388.2
Monotonic tensile strength coefficient, K (MPa)	6292.9
Monotonic tensile strain hardening exponent, n	0.2921
Hardness, Rockwell C (HRC)	57
Cyclic Properties	
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
Cyclic Elastic Modulus, E_c (MPa)	183000
Fatigue Strength Coefficient, σ'_f(MPa)	3448
Fatigue Strength Exponent, b	-0.115
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