5120, Carburized Case
Iteration #56

Fatigue Behavior, Monotonic Properties
and
Microstructural Data

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SUMMARY

This report presents the monotonic and fatigue test results obtained for 5120 carburized case (Iteration 56) 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 5120 carburized case steel samples (Iteration 56). 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 1.25” 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^{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 5120 Carburized case steel. 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.

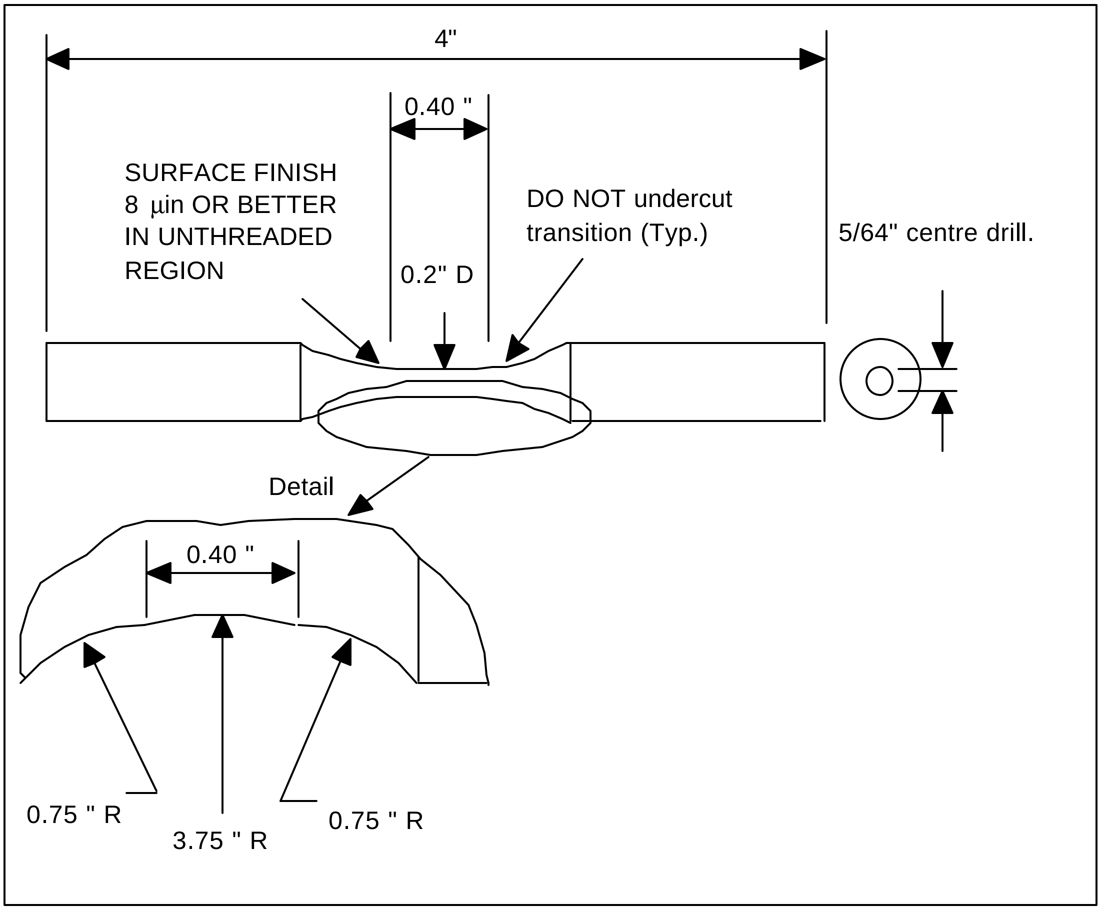

Figure 1 Smooth cylindrical fatigue specimen

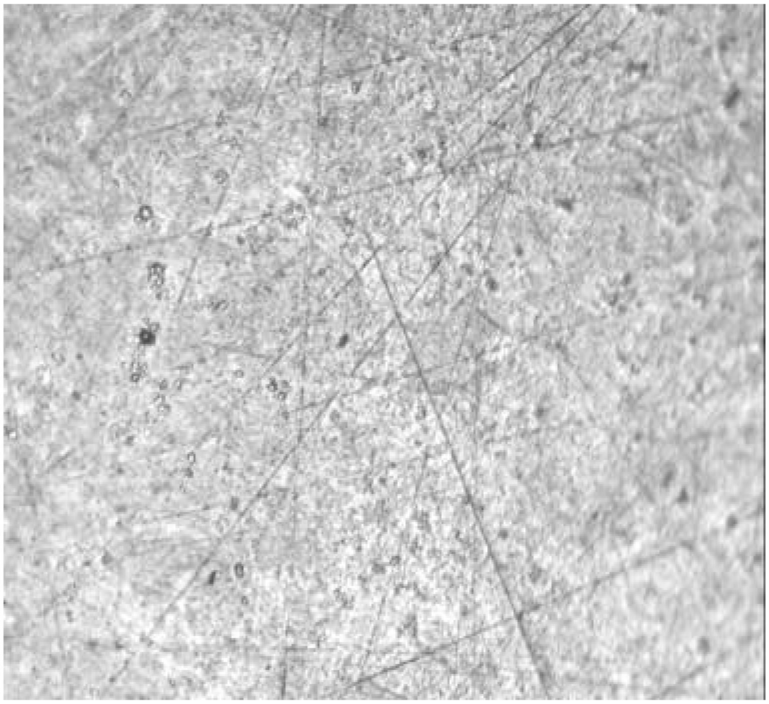

Figure 2 Photomicrographs of 5120 Carburized case steel (X20)

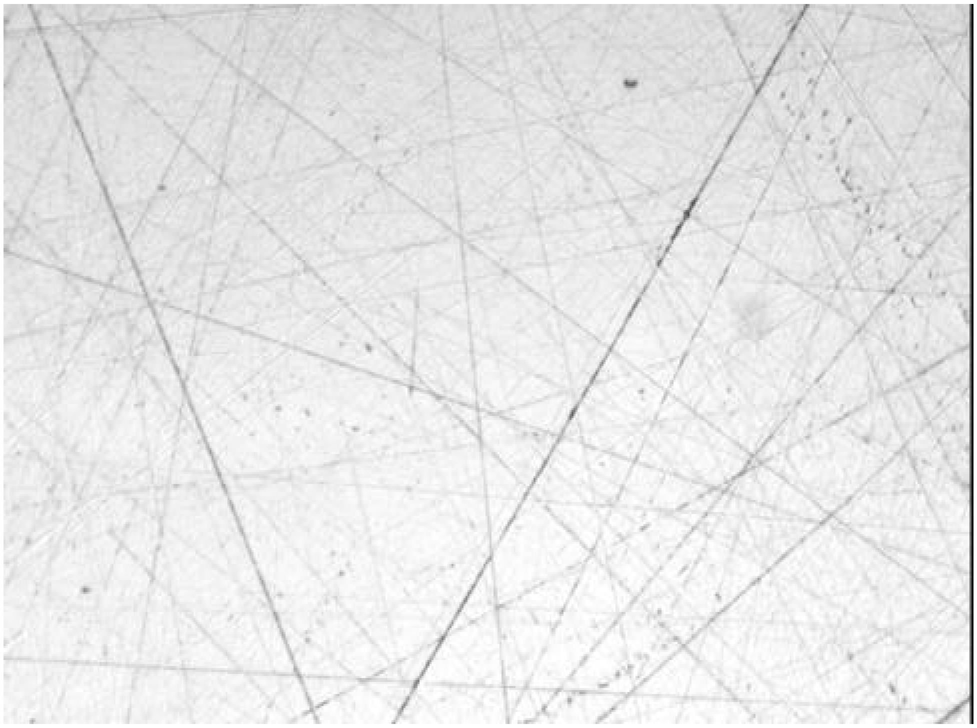

Figure 3 Inclusions photomicrograph of 5120 Carburized case steel (X20)

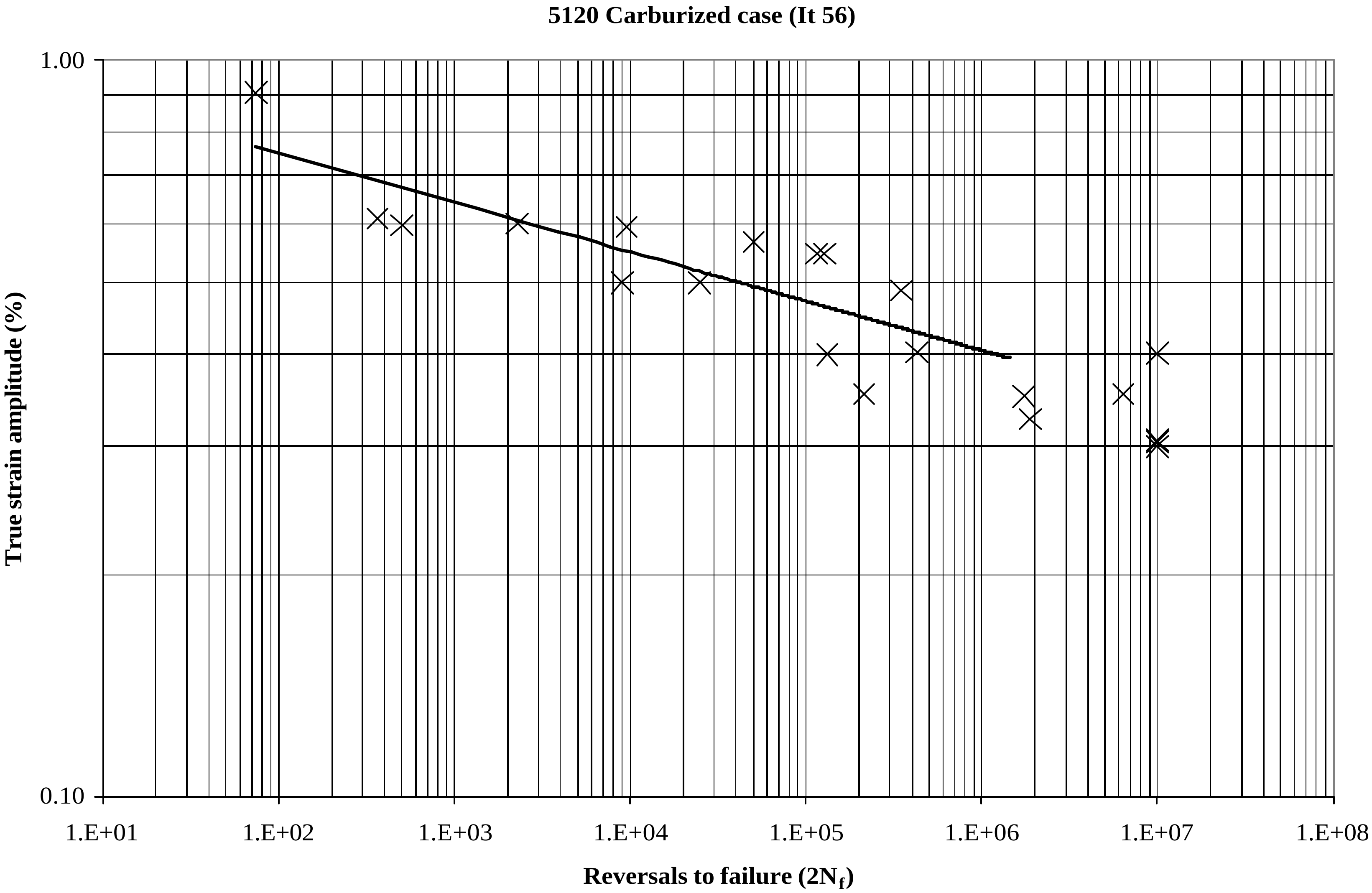

Figure 4. Constant amplitude fully reversed strain-life curve for Iteration 56

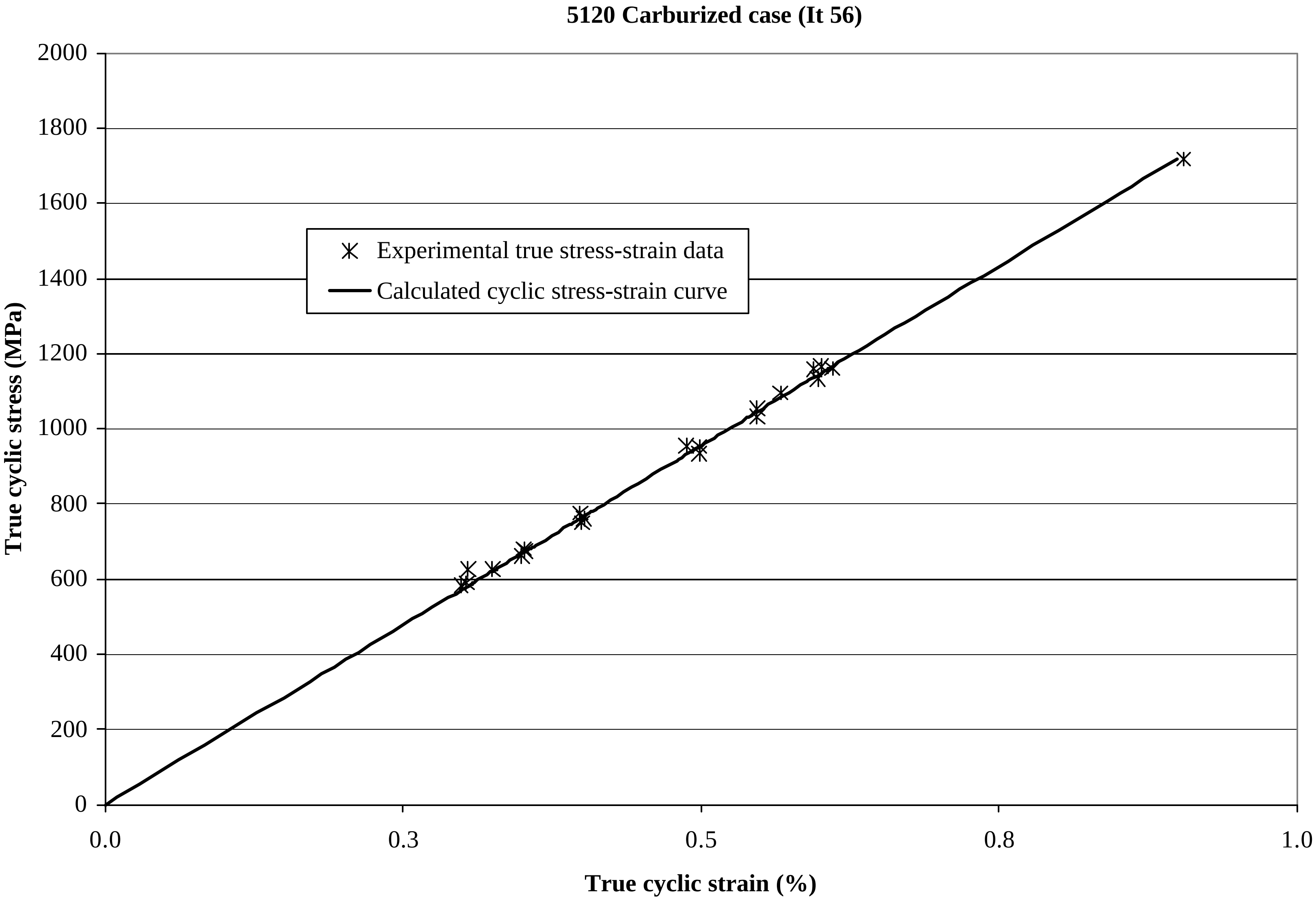

Figure 5. Cyclic true stress-strain curve for iteration 56

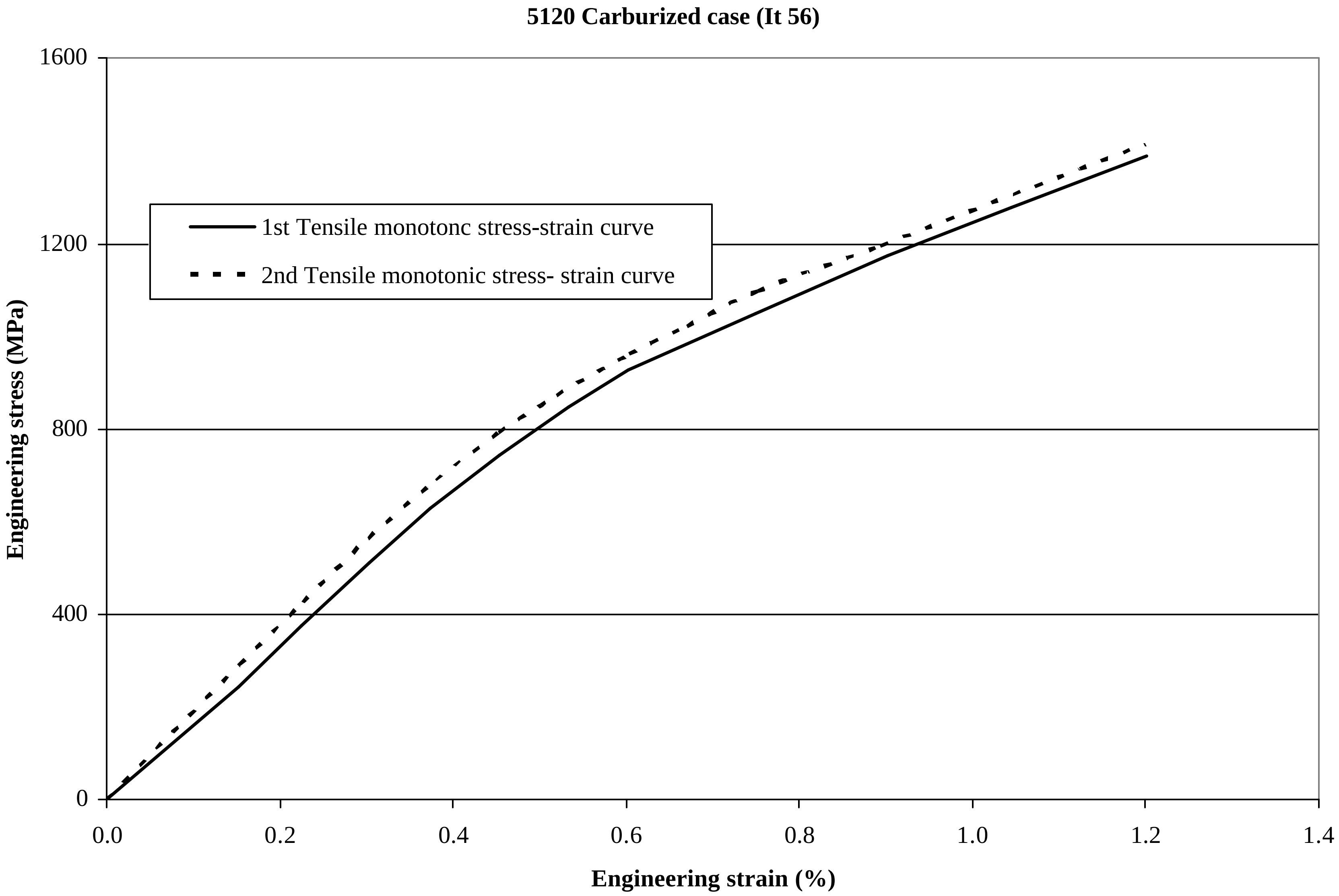

Figure 6. Tensile monotonic engineering stress-strain curves for iteration 56

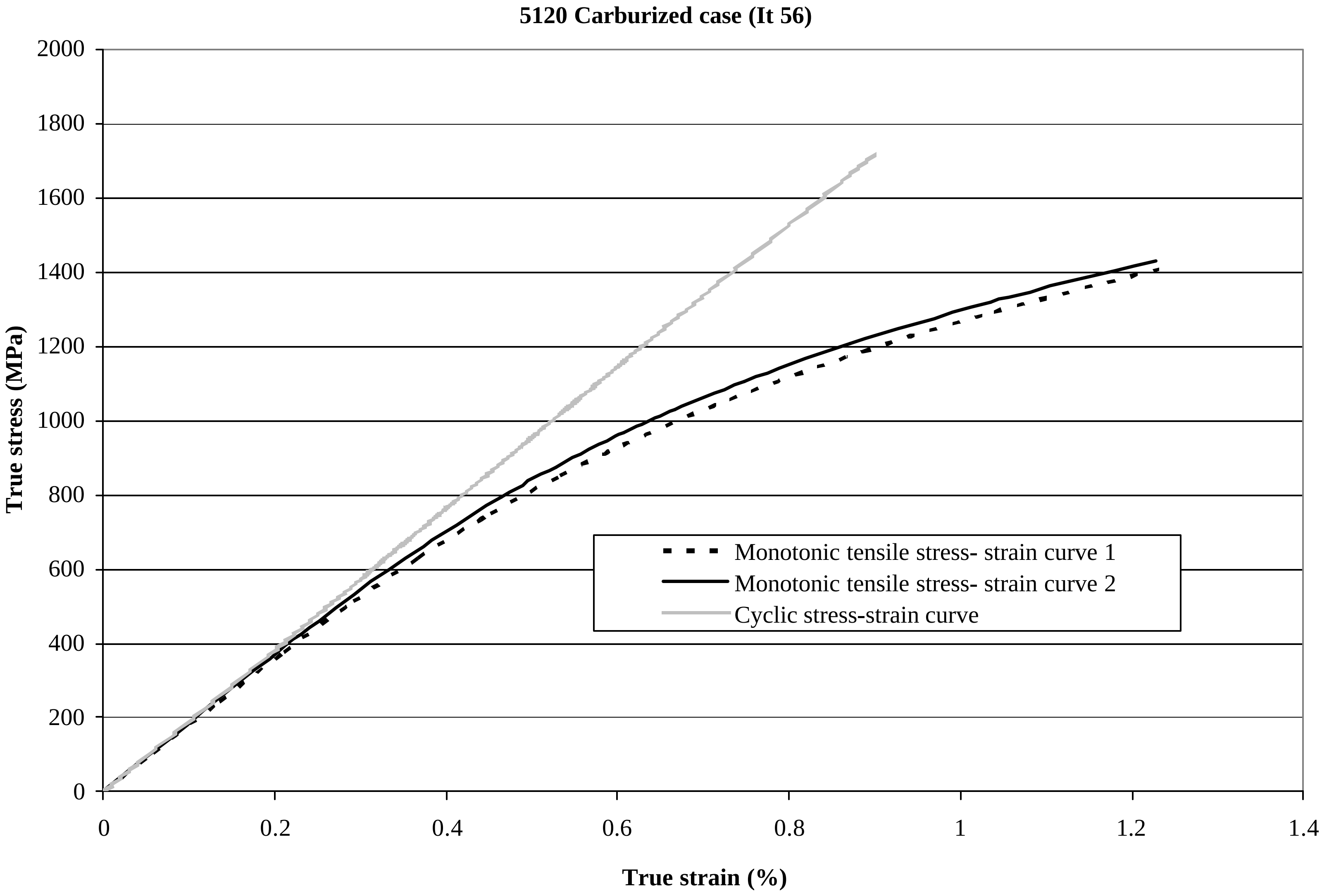

Figure 7. Monotonic and Cyclic true stress-strain curves for iteration 56

Table 1: Chemical composition for Iteration 56

Chemical element	Quantity (%)
C	0.2
Mn	0.79
P	0.013
S	0.026
Si	0.25
Cu	0.1
Ni	0.05
Cr	0.8
Mo	0.02
Sn	0.006
Al	0.025
V	0.004
Cb/Nb	0.001
Ti	0.003
B	0.0003
Ca	0.0008
Zr	0.001
Co	0.006
Zn	0.0014

Table 2: Fatigue Data for Iteration 56

Sp#	Total Strain Amplitude (%)	Stress Amplitude (MPa)	Plastic Strain Amplitude (%)	Elastic Strain Amplitude (%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	Hardness (Rockwell C)
1	0.905	1718.3	0.000	0.905	74	
2	0.598	1133.1	0.000	0.598	506	
10	0.595	1159.7	0.000	0.595	9520	
13	0.601	1166.5	0.000	0.601	2288	
21	0.610	1159.9	0.000	0.610	366	
8	0.567	1095.4	0.000	0.567	50520	
22	0.547	1032.6	0.000	0.547	127968	
23	0.547	1054.6	0.000	0.547	114668	
7	0.488	955.4	0.000	0.488	347638	
20	0.499	934.2	0.000	0.499	24892	
19	0.499	953.5	0.000	0.499	8964	61
3	0.399	776.3	0.000	0.399	132198	61
11	0.402	762.4	0.000	0.402	431022	
18	0.400	750.4	0.000	0.400	10000000*	
4	0.352	676.2	0.000	0.352	6401952	
16	0.350	662.9	0.000	0.350	1739934	62
17	0.352	681.5	0.000	0.352	214032	
5	0.325	625.5	0.000	0.325	1880000	
6	0.305	626.0	0.000	0.305	10000000*	
9	0.299	582.8	0.000	0.299	10000000*	
12	0.303	590.1	0.000	0.303	10000000*	

* Run out

Table 3: Monotonic and cyclic properties for iteration 56

Monotonic Properties	
Average Elastic Modulus, E (GPa)	183.65
Yield Strength (MPa)	1161.1
Ultimate tensile Strength (MPa)	1403
% Elongation (%)	1.2
% Reduction of Area (%)	2.7
True fracture strain, $Ln\ (A_i / A_f)$ (%)	2.7
True fracture stress, $s_f = \frac{P_f}{A_f}$ (MPa)	1441.9
Bridgman correction $= \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$ (MPa)	1187.9
Monotonic tensile strength coefficient, K (MPa)	5317.9
Monotonic tensile strain hardening exponent, n	0.245
Hardness, Rockwell C (HRC)	61.5
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)	191,000
Fatigue Strength Coefficient, σ'_f (MPa)	2528
Fatigue Strength Exponent, b	-0.092
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