Fatigue Behavior and Monotonic Properties For AISI 4120 Modified Steel Simulated Carburized Core 1700F Axial Test

Iteration 206

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Summary

The mechanical fatigue properties and hardness for AISI Iteration 206 have been obtained. The American Iron and Steel Institute (AISI) provided the material in the form of metal bars that were machined into smooth axial fatigue specimens. The Rockwell C hardness (HRC) of the material was determined as the average of nine measurements; three tests were conducted on each of three specimens. Constant-amplitude fatigue tests were conducted in the laboratory at room temperature to establish cyclic strain-life and stress-life fatigue data.

Introduction

This report presents the results of fatigue tests performed on a group of 4120 Modified Simulated Core Steel specimens (Iteration 206). The American Iron and Steel Institute provided the material. The objective of this investigation was to obtain hardness, strain-life fatigue data and to derive the monotonic and cyclic stress-strain curves.

Experimental Procedure

Specimen Preparation

The material for this study was received in the form of round bars. Smooth cylindrical Fatigue specimens, shown in Figure 1, were machined from the bars. After machining the specimens were polished with 240 and 400 grit Emery paper followed by a final polish in the loading direction using 600 grit material.

Test Equipment and Procedure

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. Two monotonic tension tests were performed to determine the yield strength, the tensile strength, the percent elongation and the percent reduction of area. 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. Initial loading stress-strain modulii were recorded on the tensile samples and eighteen fatigue test samples.

A wave function generator and a process control computer, the latter controlled by FLEX [1] software, was used to create waveforms for constant strain amplitude tests.
Axial, constant strain amplitude, fully reversed (R=-1), strain controlled fatigue tests were performed on smooth specimens. The stress-strain limits for each specimen were recorded at intervals throughout

the test via peak reading voltmeters and digital oscilloscope peak detectors. Failure of a specimen was defined as a 50% drop in the tensile peak load from the peak load observed at one half the expected specimen life. The loading frequency varied from 0.5 Hz to 10 Hz. For fatigue lives greater than 10000 reversals (once the stress-strain loops had stabilized) the specimens were tested in load control. The test frequencies used in this case were between 1 and 80 Hz.

Results

Tensile Test Results

Tensile tests were performed on two specimens. Engineering stress-strain curves are given in Figure 3b. The tensile properties from the average of the two specimens are listed in Table 1.

Cyclic Stress-Strain Curves

Stabilized stress-strain data obtained from strain-life fatigue tests were used to construct the material's cyclic stress-strain curve shown in Figure 3b. The cyclic stress-strain curve is described by the following equation:

$$\varepsilon = \frac{\sigma}{E} + \frac{\sigma}{K'}^{\frac{1}{n'}} \tag{1}$$

Where ε is the true total strain amplitude, σ is the cyclically stable true stress amplitude, E is the average observed modulus of elasticity, K' is the cyclic strength coefficient, and n' is the cyclic strain hardening exponent. All of these values were obtained from a best fit of the above equation to the test data. The same equation with stress and strain, rather than stress and strain amplitudes was used to fit the monotonic engineering stress versus engineering strain results.

Constant Amplitude Fatigue Data

Constant amplitude fatigue test data obtained in this investigation are given in Table 2. The stress amplitude corresponding to the peak strain amplitude was calculated from the peak load amplitude at one half of the specimen's fatigue life. A constant strain amplitude fatigue life curve for material is given in Figure 2 and is described by the Following equations:

$$\frac{\triangle\varepsilon_e}{2} = \frac{\sigma'_f}{E}(2N_f)^b \tag{2a}$$

$$\frac{\triangle\varepsilon_p}{2} = \varepsilon'_f(2N_f)^c \tag{2b}$$

Since $\Delta\varepsilon = \Delta\varepsilon_e + \Delta\varepsilon_p$,

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c \tag{3}$$

Where

$\frac{\Delta\varepsilon}{2}$ is the total strain amplitude,
$\frac{\Delta\varepsilon_e}{2}$ is the elastic strain amplitude ($\frac{\Delta\varepsilon_e}{2} = \frac{\Delta\sigma_{measured}}{2E}$) ,
$\frac{\Delta\varepsilon_p}{2}$ is the plastic strain amplitude ($\frac{\Delta\varepsilon_p}{2} = \frac{\Delta\varepsilon_{measured}}{2} - \frac{\Delta\varepsilon_e}{2}$) ,
$2N_f$ is the number of reversals to failure,
σ'_f is the fatigue strength coefficient,
b is the fatigue strength exponent,
ε'_f is the fatigue ductility coefficient,
c is the fatigue ductility exponent.

The values of the strain-life parameters determined from a best fit of strain life data to Equations 2 are given in Table 3. Run-out tests (run 20,000,000 reversals without failure) were not included in the least squares fitting process.

References

[1] M. Pompetzki, R. Saper, T. Topper, Software for rig frequency control of variable amplitude fatigue tests, Canadian Metallurgical Quarterly 25 (2) (1987) 181-194

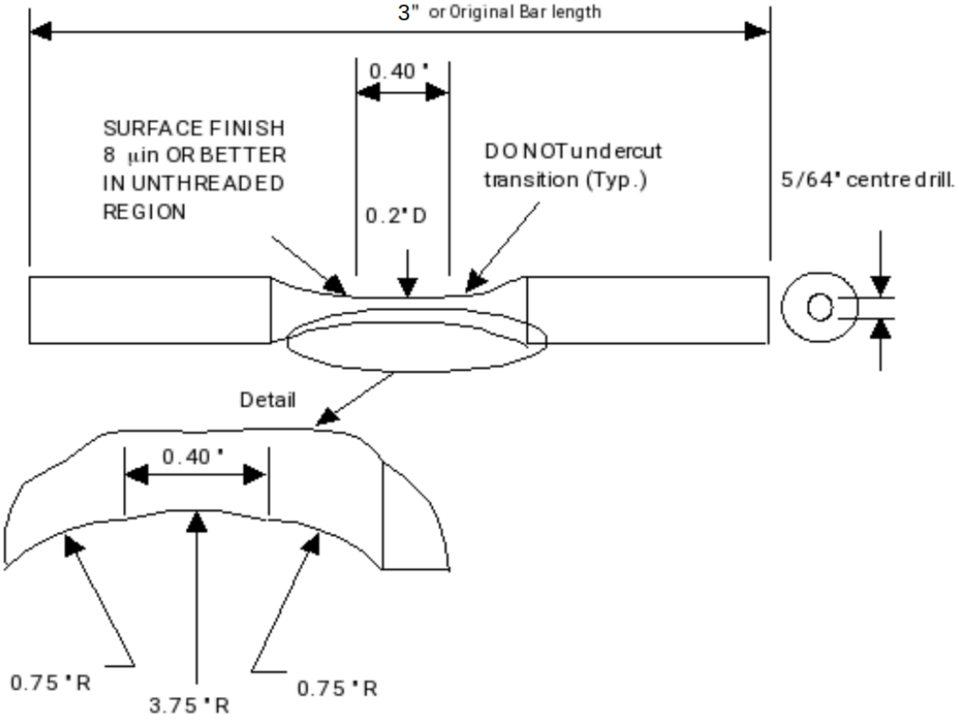

Figure 1: Tensile and fatigue specimen dimensions

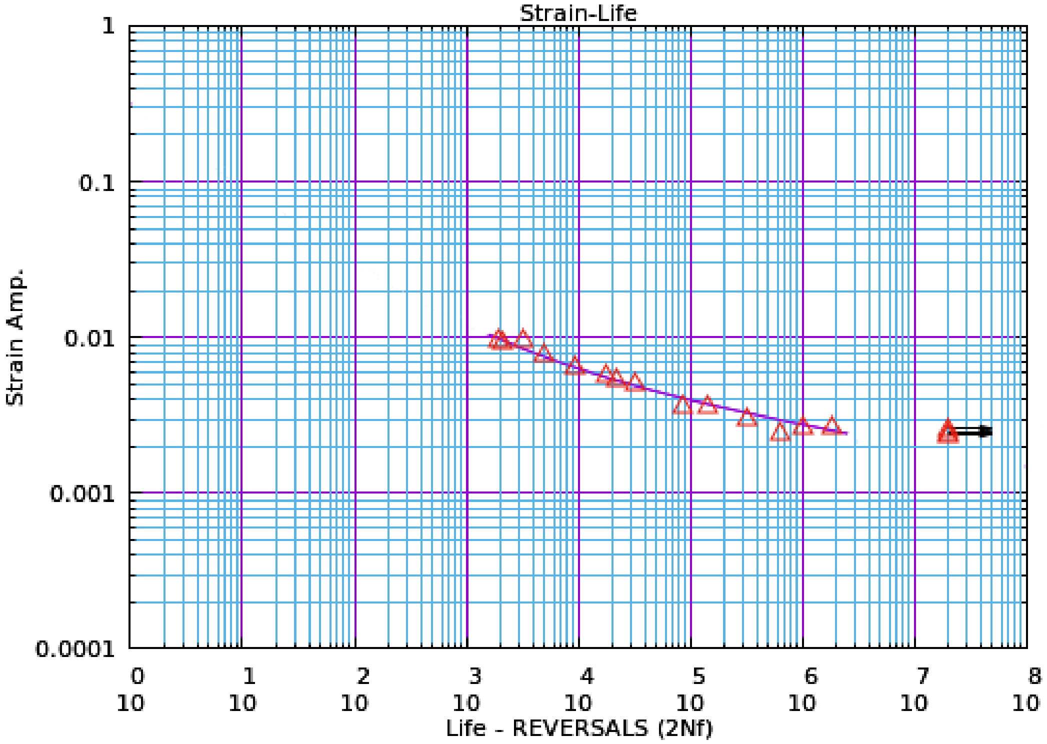

Figure 2: Strain amplitude vs. Fatigue Life data and curve for metal 4120 Modified Simulated Core

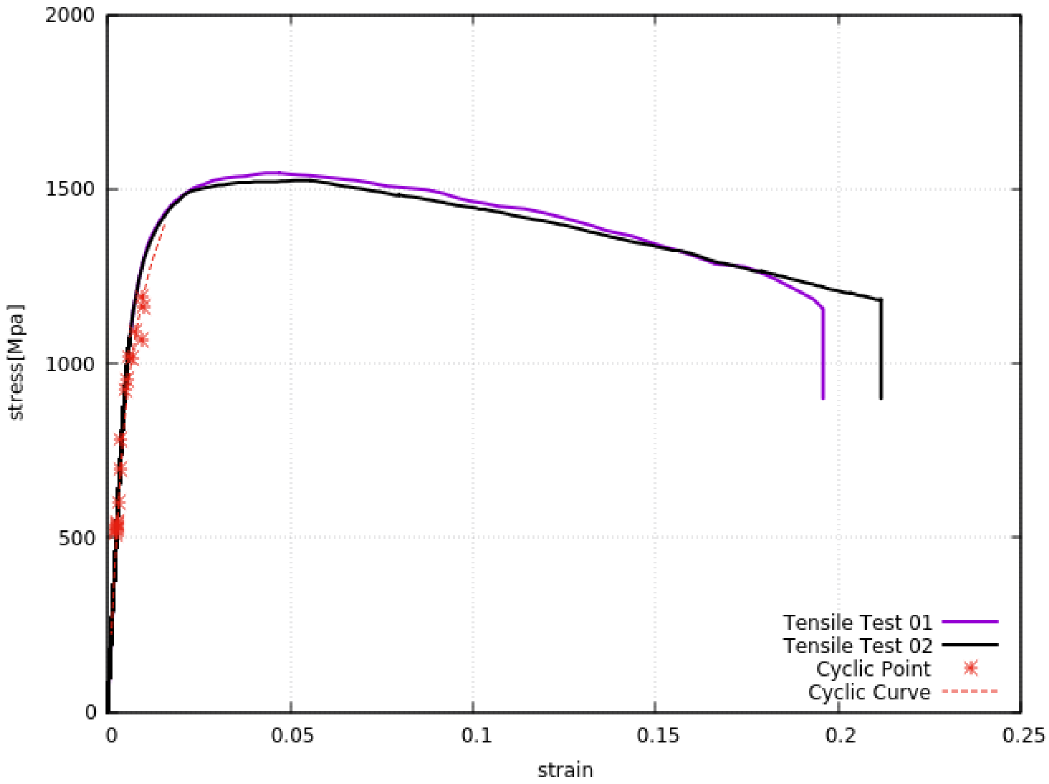

Figure 3a: Monotonic tension curves and cyclic stress-strain data points and curve for metal 4120 Modified Simulated Core (x-axis from 0 to 0.25)

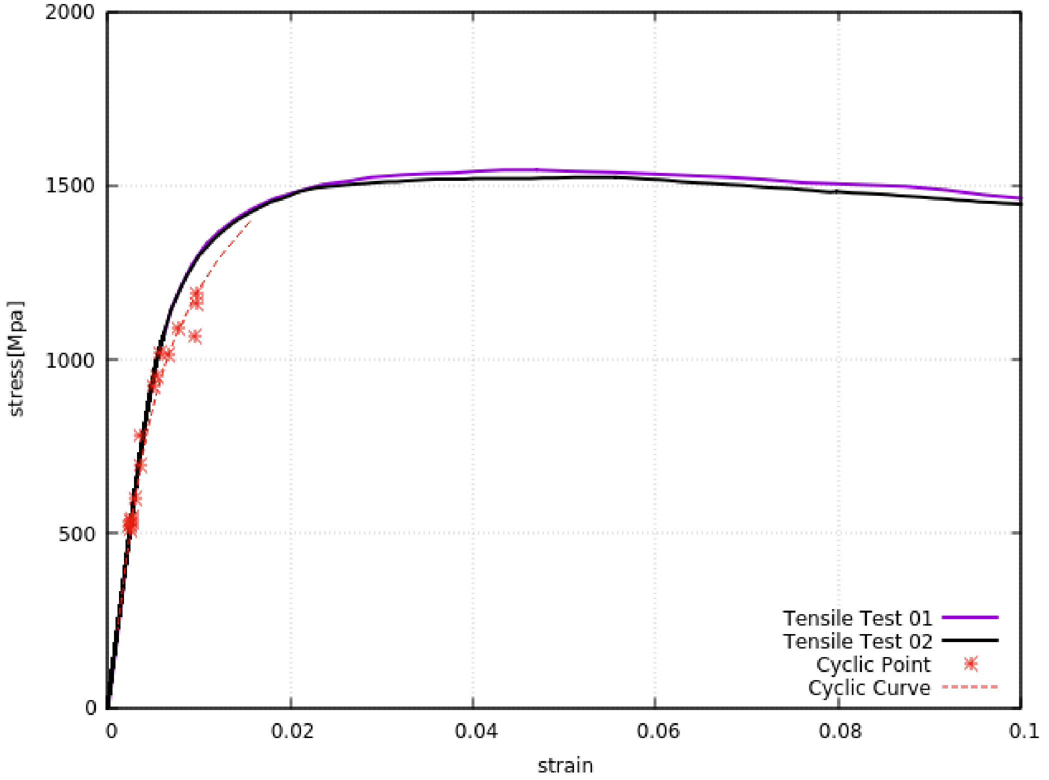

Figure 3b: Monotonic tension curves and cyclic stress-strain data points and curve for metal 4120 Modified Simulated Core (x-axis from 0 to 0.10)

Table 1: Tensile properties for metal 4120 Modified Simulated Core

Average elastic modulus, E	mpa	205644
0.2% offset Yield Strength, Sy	mpa	1194
Ultimate Tensile Strength, Su	mpa	1535
Strain at Su, eu		0.050
% Elongation		20.4%
% Reduction in Area		49.1%
Monotonic Strength Coefficient, K		1490
Monotonic Strain hardening Exponent, n		0.09
Rockwell C Hardness (avg. of 9 values), HRC		38.67

Table 2: Constant Strain Amplitude Fatigue Results for Metal 4120 Modified Simulated Core

StrainAmpl	2Nf	StresssAmpl mpa	MeanStress mpa	PlsStrAmp	1stLoadEmod mpa	NeubStsAmpl mpa	Specimen	
0.00977	1964	1161	-11	0.00380	194555	1486	13	
0.00951	2098	1069	194	0.00444	211032	1465	6B	
0.00968	3282	1193	-22	0.00414	215444	1577	17	
0.00783	5004	1093	-11	0.00254	206461	1329	4	
0.00662	9408	1015	5	0.00158	201503	1163	18	
0.00583	17384	1022	-118	0.00105	213818	1129	2	
0.00540	22268	954	-26	0.00083	208693	1037	19	
0.00506	31660	925	-18	0.00055	205181	980	3	
0.00365	86066	696	-16	0.00037	212193	734	8	
0.00370	144640	783	19	0.00000	210002	780	7	
0.00301	323680	604	212	0.00012	209355	617	9	
0.00249	625820	525	223	0.00000	215940	531	5	
0.00267	1023828	546	204	0.00000	196106	535	12	
0.00270	1835000	537	230	0.00015	210299	552	11	
0.00241	20000000	520	-2	0.00000	211014	514	14	#runout
0.00244	20000000	511	20	0.00000	211032	513	6	#runout
0.00258	20000000	542	-3	0.00000	207548	539	16	#runout

Table 3: Constant Strain Amplitude Fatigue Parameters for Metal 4120 Modified Simulated Core

Cyclic Yield Strength (0.2% offset)	mpa	1046
Cyclic Strength Coefficient, K’	mpa	4180
Cyclic Strain Hardening exponent n’		0.2229
Elastic Modulus, E	mpa	208246
Fatigue Strength Coefficient, σ'_f	mpa	3210
Fatigue Strength Exponent, b		-0.1282
Fatigue Ductility Coefficient, ϵ'_f		0.3057
Fatigue Ductility Exponent, c		-0.5753

Table 4: Rockwell C Hardness Test Data for AISI 4120 Modified Simulated Core Steel

Specimen ID	Test 1	Test 2	Test 3	Average
19	39	38.5	36	37.83
12	40.5	41	40	40.50
14	36	37	40	37.67
Overall				38.67