Fatigue Behavior and Monotonic Properties For AISI 4120 Modified Steel Simulated Carburized Core 1900F Axial Test Iteration 198

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Summary

The mechanical fatigue properties and hardness for AISI Iteration 198 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 198). 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. The samples were then quenched and tempered to simulate the core mateiral at 1900°F. Before testing, the specimens had a final polish in the loading direction in the gauge sections using 600 emery paper.

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 Fgen10 [1] software, was used to create waveforms for constant strain amplitude tests.

[1]Fgen10: Test control and monitoring program developed at University of Waterloo, 2018

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 3a and 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 $\Delta\varepsilon = \Delta\varepsilon_e + \Delta\varepsilon_p$,

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

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 10,000,000 reversals without failure) were not included in the least squares fitting process.

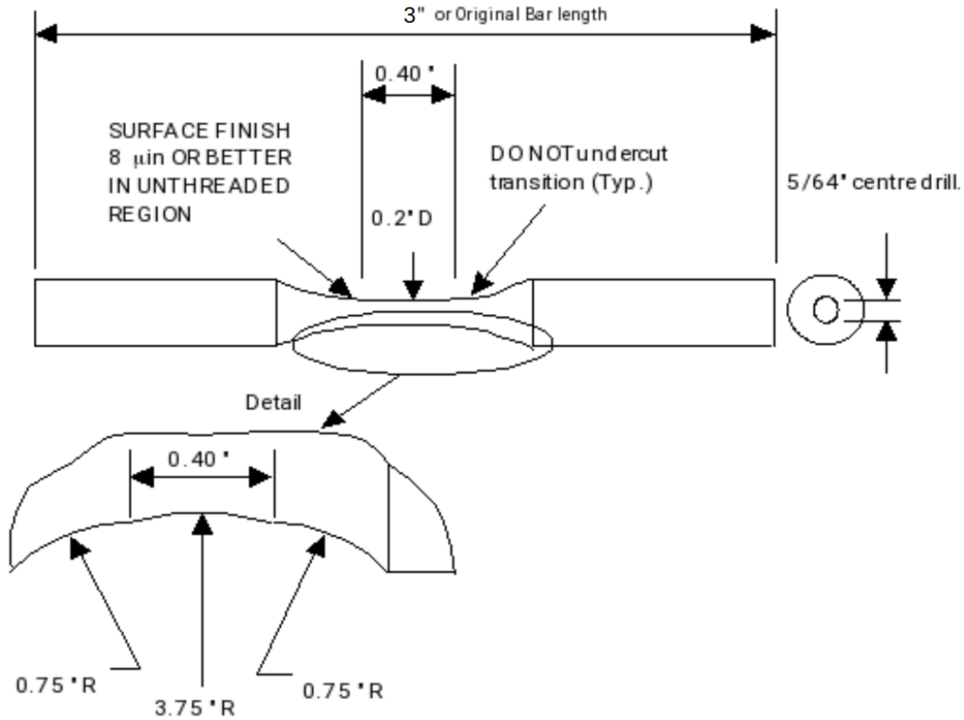

Figure 1: Tensile and fatigue specimen dimensions

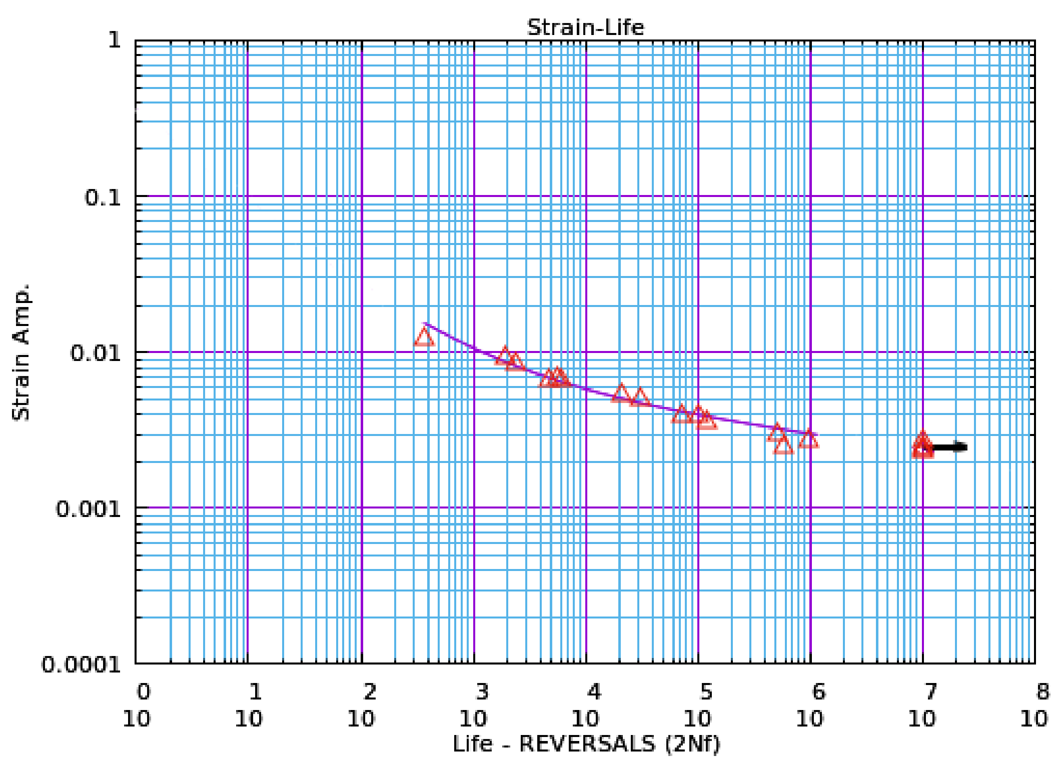

Figure 2: Strain amplitude vs. Fatigue Life data and curve for metal 4120 Modified Simulated Core

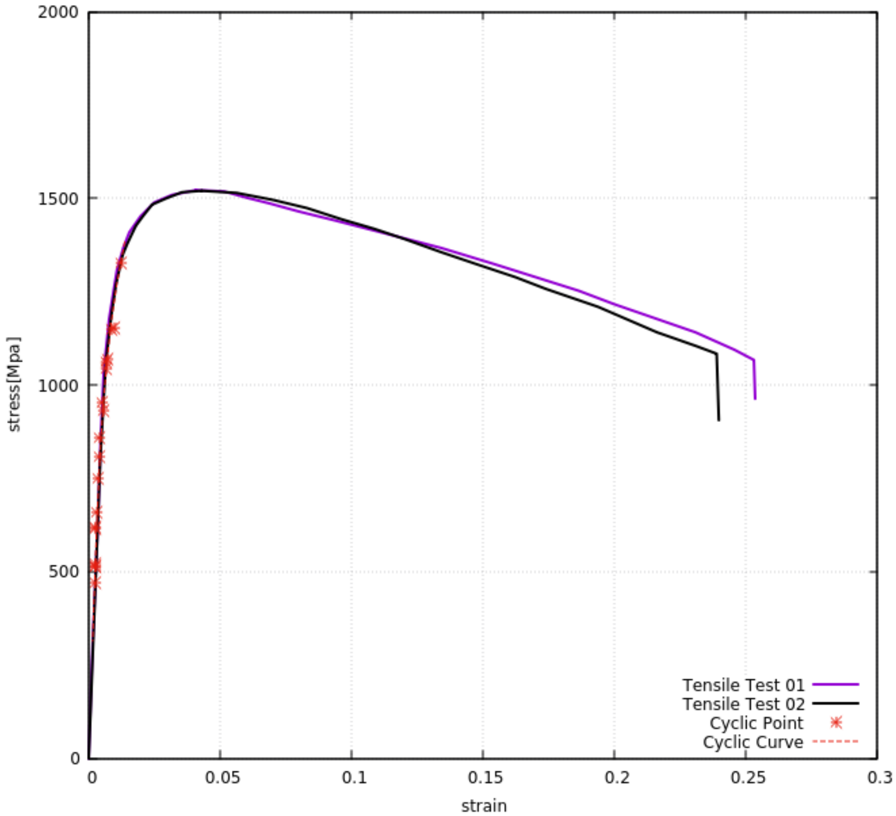

Figure 3a: Monotonic tension curves and cyclic stress-strain data points and curve for metal 4120 Modified Simulated Core (x-axis from 0 to 0.3)

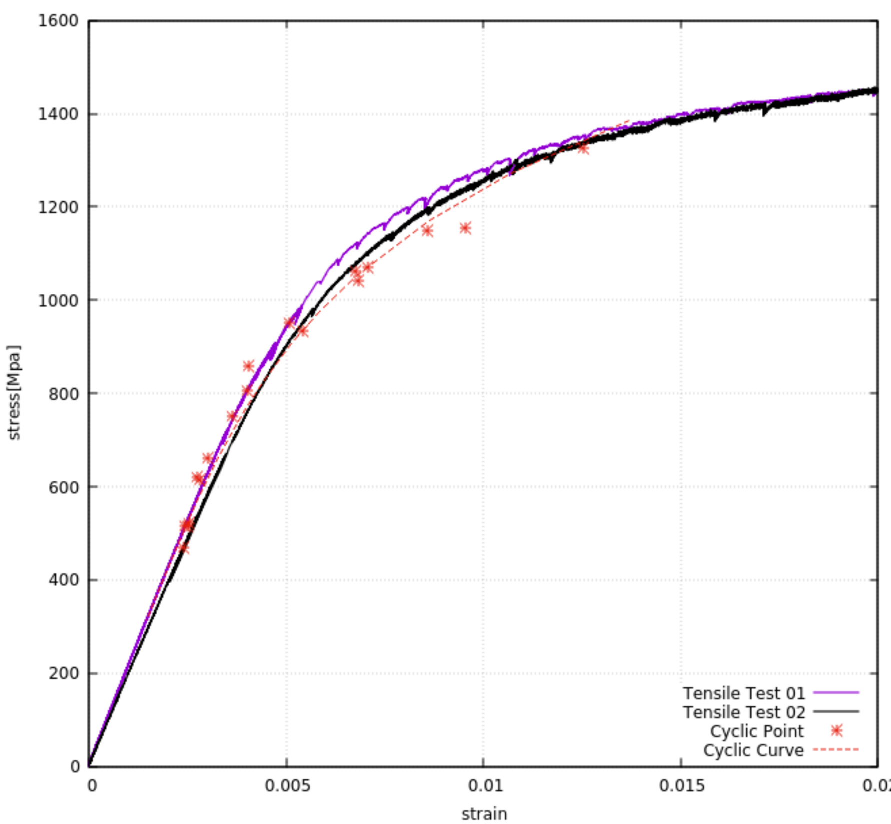

Figure 3b: Monotonic tension curves and cyclic stress-strain data points and curve for metal 4120 Modified Simulated Core (x-axis from 0 to 0.02)

Table 1: Tensile properties for metal 4120 Modified Simulated Core

Average elastic modulus, E	mpa	214474
0.2% offset Yield Strength, Sy	mpa	1131
Ultimate Tensile Strength, Su	mpa	1528
Strain at Su, eu		0.050
% Reduction in Area		52.6%
% Elongation (8mm gauge length)		24.4%
True Fracture Strain, ϵ_f		0.746
True Fracture Stress, σ_f	mpa	2274
Monotonic Strength Coefficient, K		2684
Monotonic Strain hardening Exponent, n		0.143
Rockwell C Hardness (avg. of 9 values), HRC		35

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

StrainAmpl	2Nf	StresssAmpl	MeanStress	PlsStrAmp	1stLoadEmod	NeubStsAmpl	Specimen	
		mpa	mpa		mpa	mpa		
0.01254	368	1326	-51	0.005914	200039	1823	10	
0.00954	1910	1154	-30	0.003997	208172	1514	14	
0.00858	2372	1148	-32	0.003179	212571	1447	12	
0.00684	4744	1043	-22	0.001993	215078	1238	16	
0.00708	5582	1070	-42	0.002083	214078	1273	15	
0.00678	6114	1062	-42	0.001864	216124	1248	20	
0.00543	21130	933	-21	0.000585	192642	988	18	
0.00509	30670	952	-63	0.000694	216516	1024	17	
0.00400	73228	807	1	0.000171	210860	825	19	
0.00404	100198	860	-82	0.000055	215808	866	8	
0.00363	120900	750	7	0.000092	212015	760	2	
0.00303	518944	660	45	0.000118	226637	673	1	
0.00250	585148	516	-79	0.000018	207798	518	4	
0.00275	971072	621	-16	-0.000161	213363	604	3	
0.00280	10000000	616	-67	0.000051	223956	621	11	
0.00254	10000000	521	38	0.000110	214291	532	9	#runout
0.00244	10000000	515	-31	-0.000021	209387	513	7	#runout
0.00239	10000000	471	40	0.000178	213051	490	5	#runout

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

Cyclic Yield Strength (0.2% offset)	mpa	1065
Cyclic Strength Coefficient, K'	mpa	3009
Cyclic Strain Hardening exponent n'		0.1617
Elastic Modulus, E	mpa	212553
Fatigue Strength Coefficient, σ'_f	mpa	2541
Fatigue Strength Exponent, b		-0.1006
Fatigue Ductility Coefficient, ϵ'_f		0.3514
Fatigue Ductility Exponent, c		-0.6223

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

Specimen ID	Test 1	Test 2	Test 3	Average
8	37	32	35	34.67
15	35	34	35	34.67
1	35	35	34	34.67
Overall				34.67