Fatigue Behavior and Monotonic Properties For AISI 16MnCr5 Modified Steel Simulated Carburized Core 1700F Axial Test

Iteration 204

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Prepared for:
The AISI Bar Steel Applications Group

May 19, 2018

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Summary

The mechanical fatigue properties and hardness for AISI Iteration 204 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 16MnCr5 modified simulated core Steel specimens (Iteration 204). 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 3a. 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 3a. 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 10,000,000 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

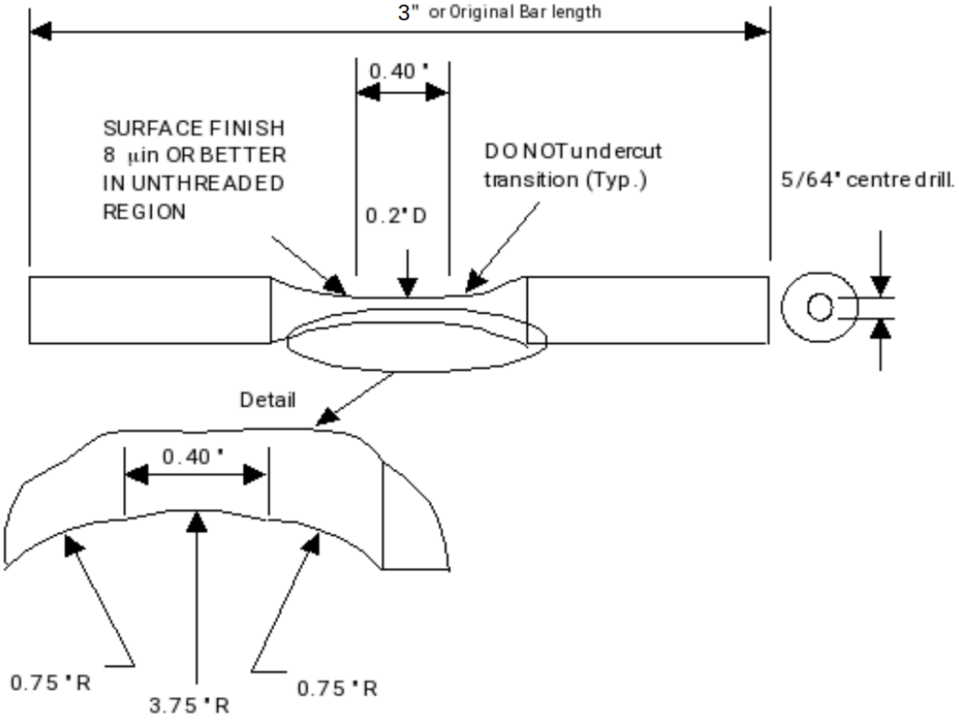

Figure 1: Tensile and fatigue specimen dimensions

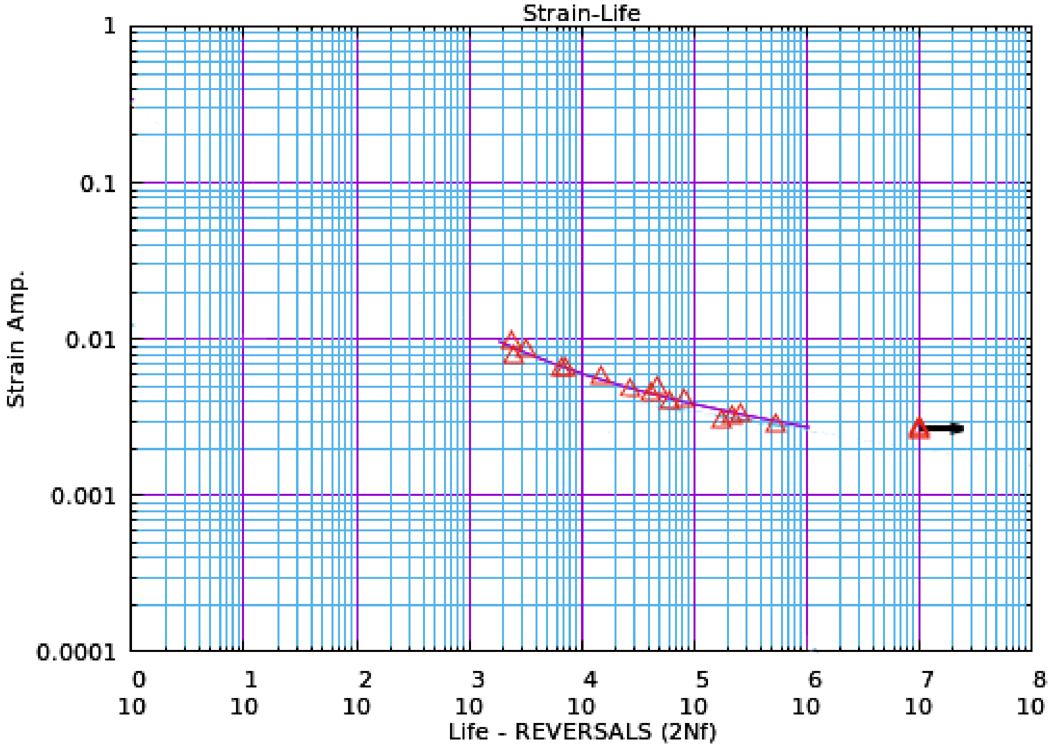

Figure 2: Strain amplitude vs. Fatigue Life data and curve for metal 16MnCr5 Modified Simulated Core

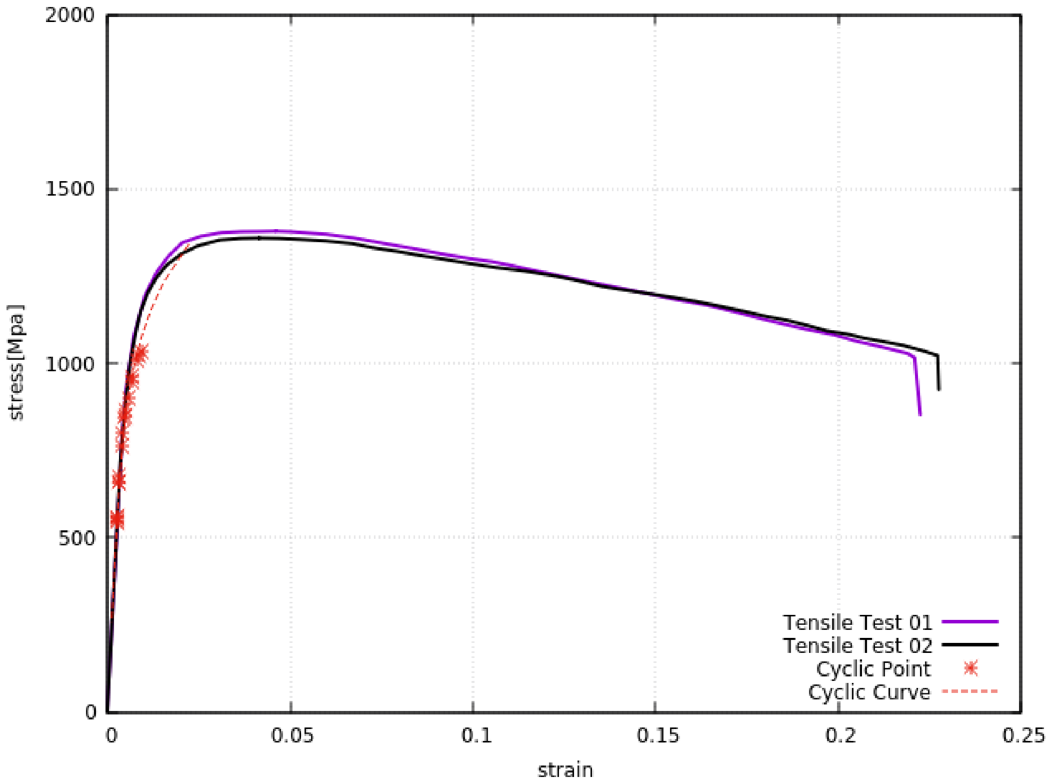

Figure 3a: Monotonic tension curves and cyclic stress-strain data points and curve for metal 16MnCr5 Modified Simulated Core (x-axis from 0 to 0.25)

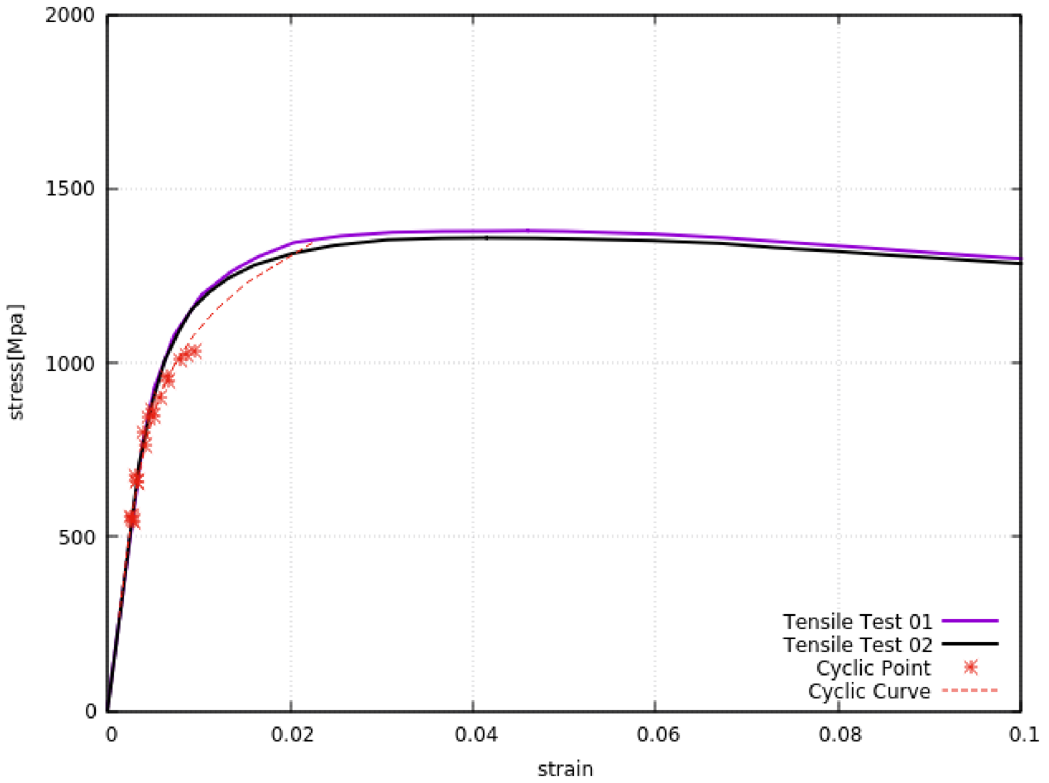

Figure 3b: Monotonic tension curves and cyclic stress-strain data points and curve for metal 16MnCr5 Modified Simulated Core (x-axis from 0 to 0.10)

Table 1: Tensile properties for metal 16MnCr5 Modified Simulated Core

Average elastic modulus, E	mpa	213822
0.2% offset Yield Strength, Sy	mpa	1050
Ultimate Tensile Strength, Su	mpa	1370
Strain at Su, eu		0.044
% Elongation		22.4%
% Reduction in Area		48.1%
Monotonic Strength Coefficient, K		2662
Monotonic Strain hardening Exponent, n		0.152
Rockwell C Hardness (avg. of 9 values), HRC		32.11

Table 2: Constant Strain Amplitude Fatigue Results for Metal 16MnCr5 Modified Simulated Core

StrainAmpl	2Nf	StresssAmpl	MeanStress	PlsStrAmp	1stLoadEmod	NeubStsAmpl	Specimen	
		mpa	mpa		mpa	mpa		
0.00966	2378	1035	-27	0.00467	207373	1440	12	
0.00796	2494	1011	-23	0.00301	204269	1282	6	
0.00860	3236	1026	-33	0.00376	212084	1368	11	
0.00666	6640	949	-21	0.00196	201786	1129	15	
0.00654	7368	963	-25	0.00198	210983	1153	16	
0.00580	14640	901	3	0.00154	211545	1051	8	
0.00490	27210	869	-43	0.00084	214010	955	1	
0.00459	41204	846	-45	0.00059	211367	906	17	
0.00500	46684	849	-85	0.00100	212014	949	7	
0.00402	62170	801	-29	0.00025	212325	827	13	
0.00415	81900	763	-60	0.00059	214440	824	14	
0.00304	178740	678	82	0.00000	212640	662	3	
0.00327	218940	657	-45	0.00017	211545	674	18	
0.00331	258928	658	31	0.00030	218382	690	2	
0.00284	531142	547	161	0.00027	212847	575	4	
0.00276	10000000	561	0	0.00000	204739	563	9	#runout
0.00268	10000000	550	-8	0.00000	216434	565	10	#runout
0.00260	10000000	561	-6	0.00000	219031	565	5	#runout

Table 3: Constant Strain Amplitude Fatigue Parameters for Metal 16MnCr5 Modified Simulated Core

Cyclic Yield Strength (0.2% offset)	mpa	945
Cyclic Strength Coefficient, K'	mpa	3271
Cyclic Strain Hardening exponent n'		0.1936
Elastic Modulus, E	mpa	211545
Fatigue Strength Coefficient, σ'_f	mpa	2641
Fatigue Strength Exponent, b		-0.1116
Fatigue Ductility Coefficient, ϵ'_f		0.3309
Fatigue Ductility Exponent, c		-0.5766

Table 4: Rockwell C Hardness Test Data for AISI 16MnCr5 Modified Simulated Core Steel

Specimen ID	Test 1	Test 2	Test 3	Average
14	32	31	32	31.67
16	32	32	32	32.00
12	33	33	32	32.67
Overall				32.11