8822 High Side Steel
Iteration #109 & 113

Fatigue Behavior, Monotonic Properties
and
Microstructural Data

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Summary

The required mechanical fatigue properties, cyclic stress-strain data, strain-controlled fatigue data and overload data for AISI 8822 High Side Steel have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of metal bars. These bars were machined into smooth axial fatigue specimens. The Rockwell C hardness (RC) was determined as the average of three measurements. Constant-amplitude tests as well as overload tests were conducted in laboratory air at room temperature to establish the cyclic stress-strain curve, strain-life curve as well as the effective strain-life curve.

Introduction

This report presents the results of tensile and fatigue tests performed on a group of 8822 High Side Steel specimens (Iterations 109 and 113). The material was provided by the American Iron and Steel Institute. The objective of this investigation is to obtain the mechanical fatigue properties, cyclic stress-strain data, strain-life fatigue data, and overload data of this material.

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 cylindrical metal bars. Before testing, the specimens had a final polish in the loading direction in the gauge sections using 240, 400, 500, and 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

One monotonic tension test was performed to determine the yield strength, the tensile strength, the percent of 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 amplitudes for constant strain amplitude tests and stress amplitudes for the overload 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 logarithmic intervals throughout the test via a peak reading voltmeter. Failure of a specimen was defined as a 50 percent drop in the tensile peak load from the peak load observed at one half the expected specimen life. The loading frequency varied from 0.05 Hz to 3 Hz. For fatigue lives greater than 100,000 reversals (once the stress-strain loops had stabilized) in constant amplitude tests and in periodic overload tests, the specimens were tested in load control. For the load-controlled tests, failure was defined as the separation of the smooth specimen into two pieces. The test frequencies used in this case were between 50 and 100 Hz.

Results

Chemical Composition

The chemical composition as provided by MacSteel is shown in Table 1; their report is included in Appendix A.

Monotonic Test

The engineering monotonic tensile stress-strain curve is given in Figure 2. The monotonic properties are given in Table 2. The Hardness of the 8822 High Side Steel was taken as the average of the values obtained from three randomly chosen fatigue specimens and is given in Table 2. The individual hardness measurements are also given in Table 3.

Cyclic Stress-Strain Curves

Stabilized stress data obtained from strain-life fatigue tests were used to construct the companion specimen cyclic stress-strain curve shown in Figure 3. The true monotonic and true cyclic stress-strain curves are plotted together in Figure 4. The cyclic stress-strain curve is described by the following equation:

$$\varepsilon = \frac{\sigma}{E_c} + \left(\frac{\sigma}{K'}\right)^{\frac{1}{n'}} \qquad \textbf{(Eq. 1)}$$

Where ε is the true total strain amplitude, σ is the cyclically stable true stress amplitude, E_c is the cyclic modulus of elasticity obtained from a best fit of the above equation to the test data and is given in Table 1, K' is the cyclic strength coefficient , and n' is the strain hardening exponent

Constant Amplitude Fatigue Data

Constant amplitude fatigue test data obtained in this investigation are given in Table 3. The stress amplitude corresponding to the peak strain amplitude was calculated from the peak load amplitude at one half of the specimen's life. A constant amplitude fatigue life curve for 8822 High Side Steel is given in Figure 5 and is described by the following equations:

$$\frac{\Delta\varepsilon_e}{2} = \frac{\sigma_f^1}{E}\left(2N_f\right)^b \qquad \textbf{(Eq. 2)}$$

$$\frac{\Delta\varepsilon_P}{2} = \varepsilon_f^1\left(2N\right)^C \qquad \textbf{(Eq. 3)}$$

Since $\Delta\varepsilon = \Delta\varepsilon_e + \Delta\varepsilon_P$ **(Eq. 4)**

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{E}(2N_f)^b \quad + \varepsilon'_f(2N_f)^c \qquad \textbf{(Eq. 5)}$$

Where;

$\frac{\Delta\varepsilon}{2}$ is the total strain amplitude,

$\frac{\Delta\varepsilon_e}{2}$ is the elastic strain amplitude $\left(\frac{\Delta\varepsilon_e}{2} = \frac{\Delta\varepsilon_{measured}}{2} - \frac{\Delta\varepsilon_p}{2}\right)$,

$\frac{\Delta\varepsilon_P}{2}$ is the plastic strain amplitude $\left(\frac{\Delta\varepsilon_p}{2} = \frac{\Delta\varepsilon_{measured}}{2} - \frac{\Delta\sigma_{measured}}{2E}\right)$,

$2N_f$ 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 were determined from a best fit of Equations 2 and 3 and are given in Table 2.

Overload Fatigue Data

Previous work at the University of Waterloo introduced an effective strain-life curve for use in fatigue damage calculations due to overloads [2]. This effective stain-life curve is derived from periodic overload tests consisting of two blocks of load cycles repeated. The first block consists of a single R=-1 overload (tensile and compressive overload peaks) cycle, and this is followed by a block of smaller load cycles that have the same tensile peak stress as the overload cycle. The minimum of the small cycles varies from test to test, and similarly the number of small cycles between the overload cycles is varied depending upon the expected life. These two blocks are then repeated until the specimen fails. The aim is to have the large cycle (overload cycle) occur frequently enough that the crack opening stress remains below the minimum stress of the smaller cycles and crack growth during the application of the small cycles is free of crack closure. The overload cycle amplitude used in this testing for iteration 113 was set equal to the fully reversed constant-amplitude stress level that would give a fatigue life of 10,000 cycles. The reason for this choice was to achieve a large reduction in crack opening stress without allotting an undue fraction of the total damage to the large cycles. The number of small cycles in the second block was chosen so that they did 80 to 90% of the damage to the specimen and that they were free from closure. The damage due to the overloads was removed using Miner's rule [3] and the equivalent failure life of the small cycles in each test was calculated. The overload fatigue data for iteration 114 are given in Table 4 and are shown in Figure 6. The equivalent strain-life fatigue curve is shown together with constant amplitude fatigue life curve in Figure 7.

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

[2] T. Topper, T. Lam, Effective strain-fatigue life data for variable amplitude loading, International Journal of Fatigue 19 (1) (1997) 137-143

[3] I. Stephens, Metal Fatigue in Engineering, Second edition, John Wiley & Sons, 2001

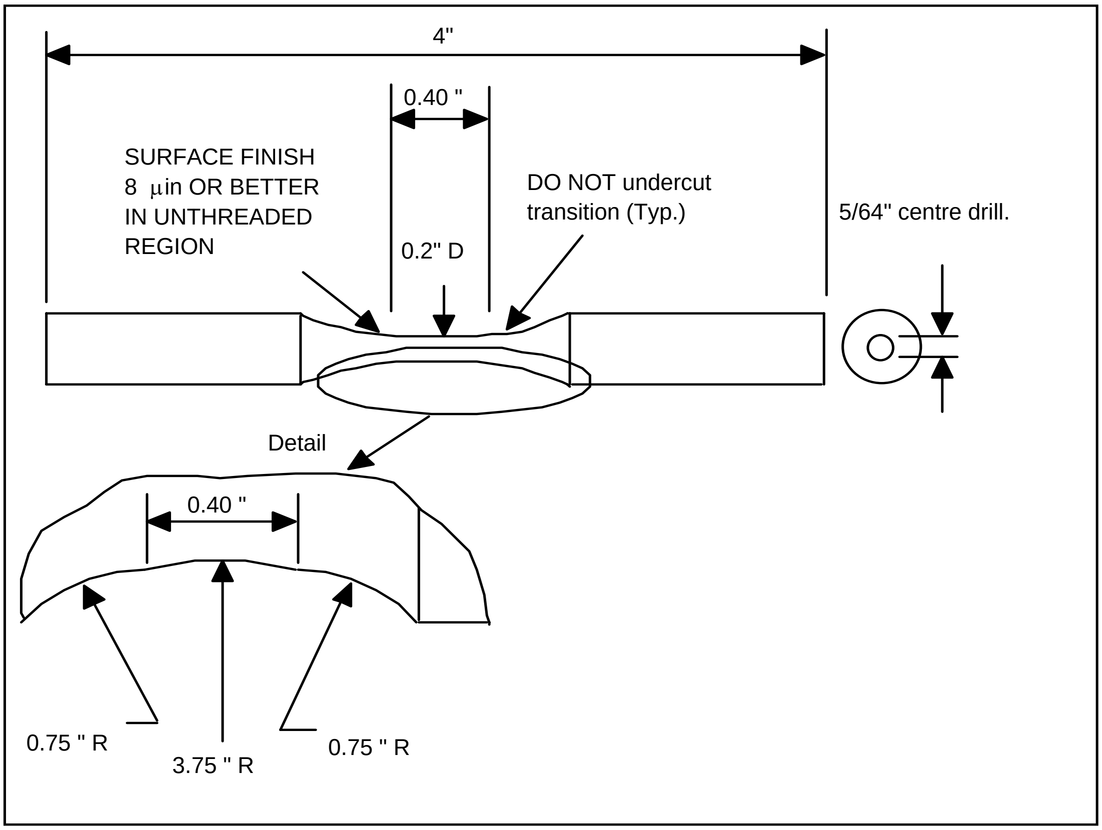

Figure 1: Uni-axial smooth cylindrical fatigue specimen

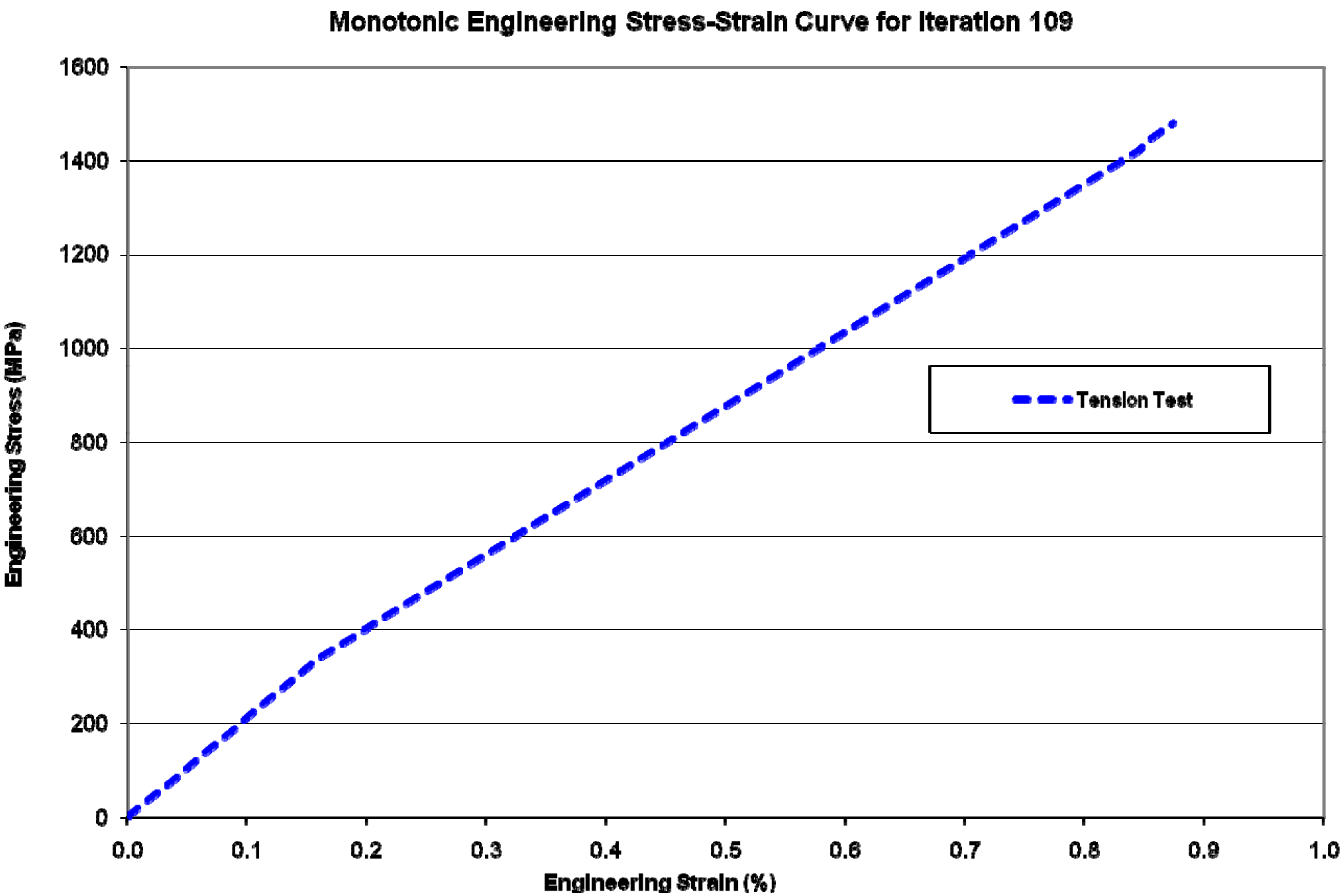

Figure 2 Monotonic engineering stress-strain curve for AISI 8822 High Side Steel (IT 109)

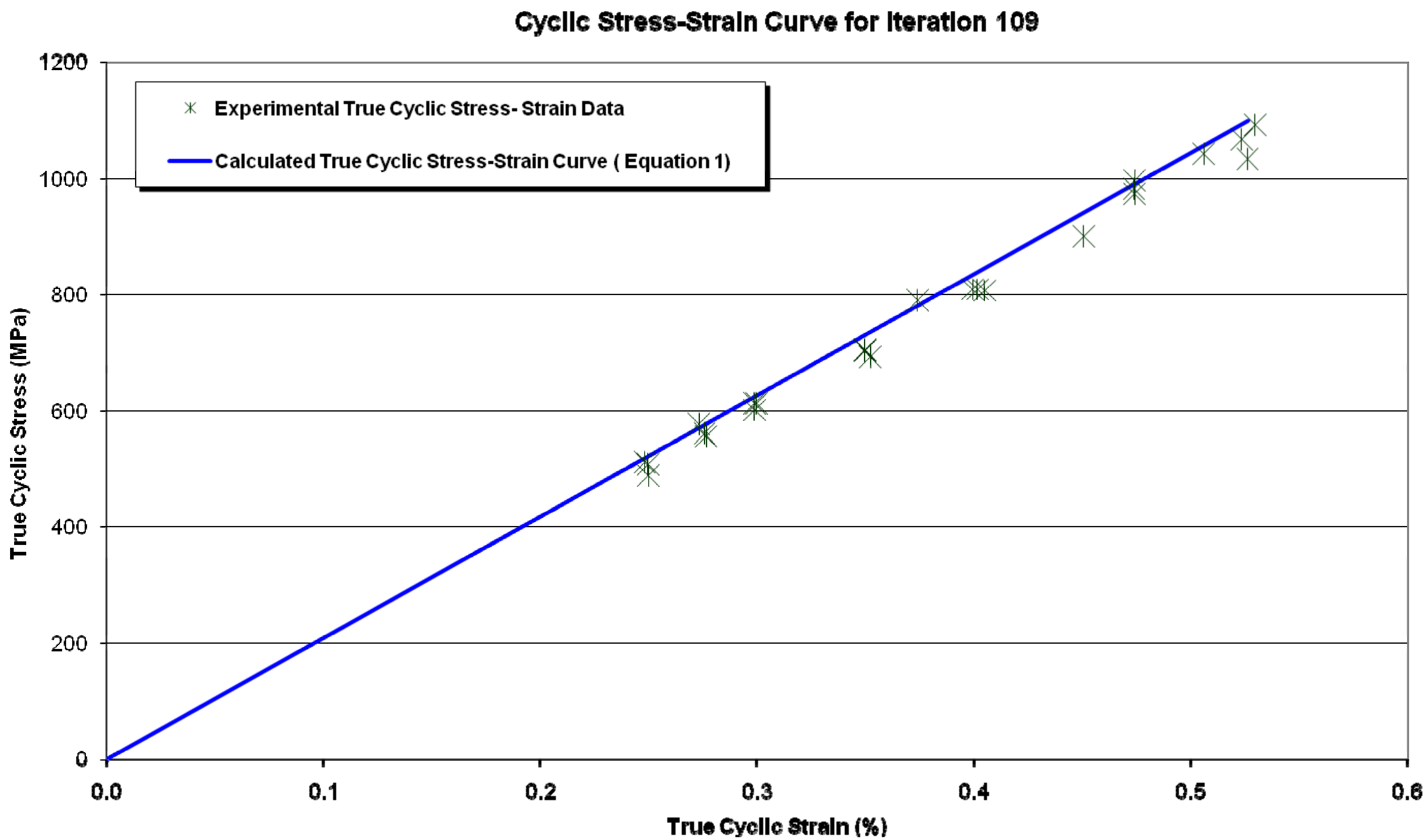
Cyclic Stress-Strain Curve for Iteration 109
Experimental True Cyclic Stress- Strain Data
Calculated True Cyclic Stress-Strain Curve (Equation 1)
True Cyclic Stress (MPa)
True Cyclic Strain (%)
0
200
400
600
800
1000
1200
0.0
0.1
0.2
0.3
0.4
0.5
0.6

Figure 3: Cyclic stress-strain curve for AISI 8822 High Side Steel (IT 109)

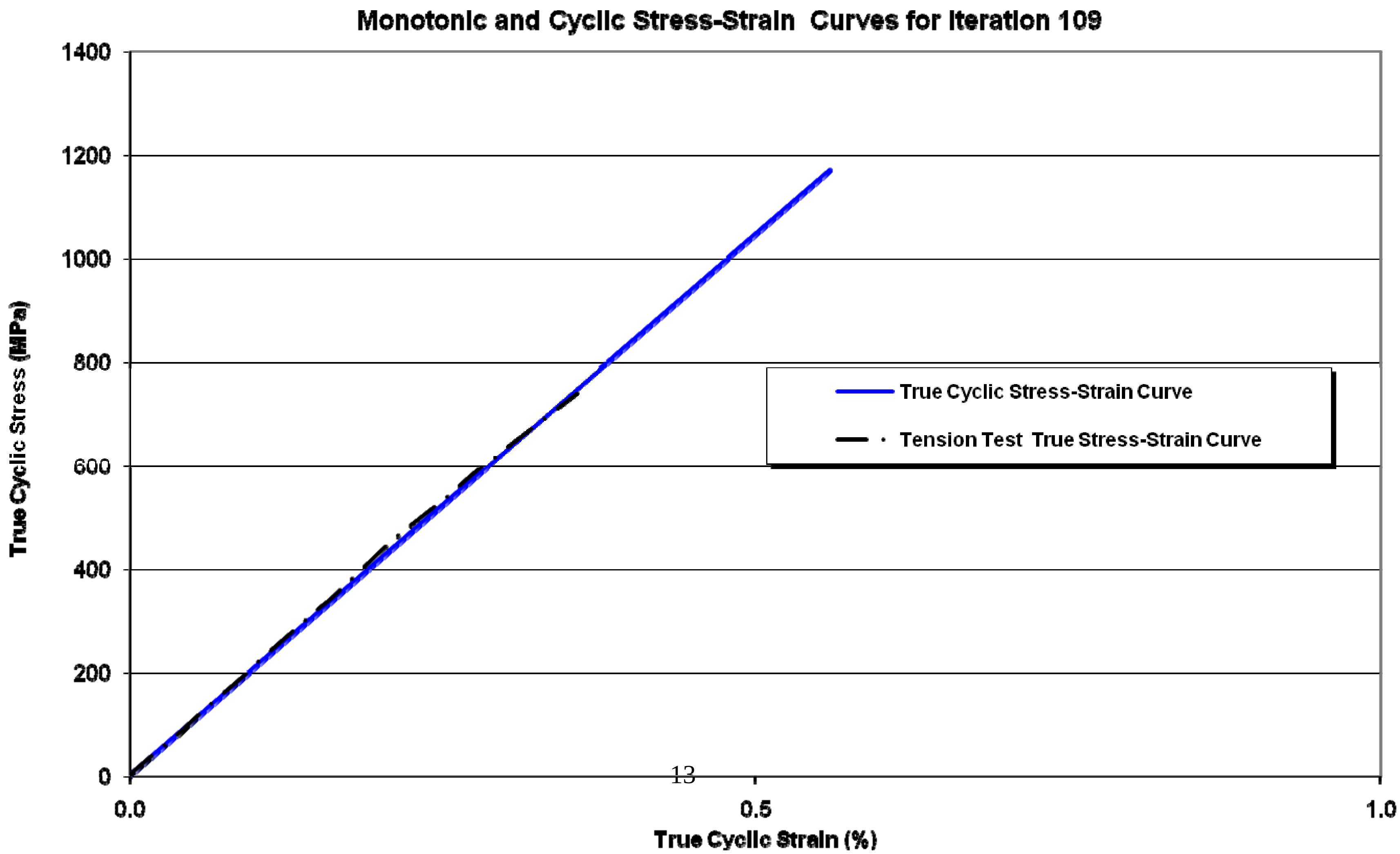

Figure 4: Monotonic and cyclic true stress-strain curves for AISI 8822 High Side Steel (IT 109)

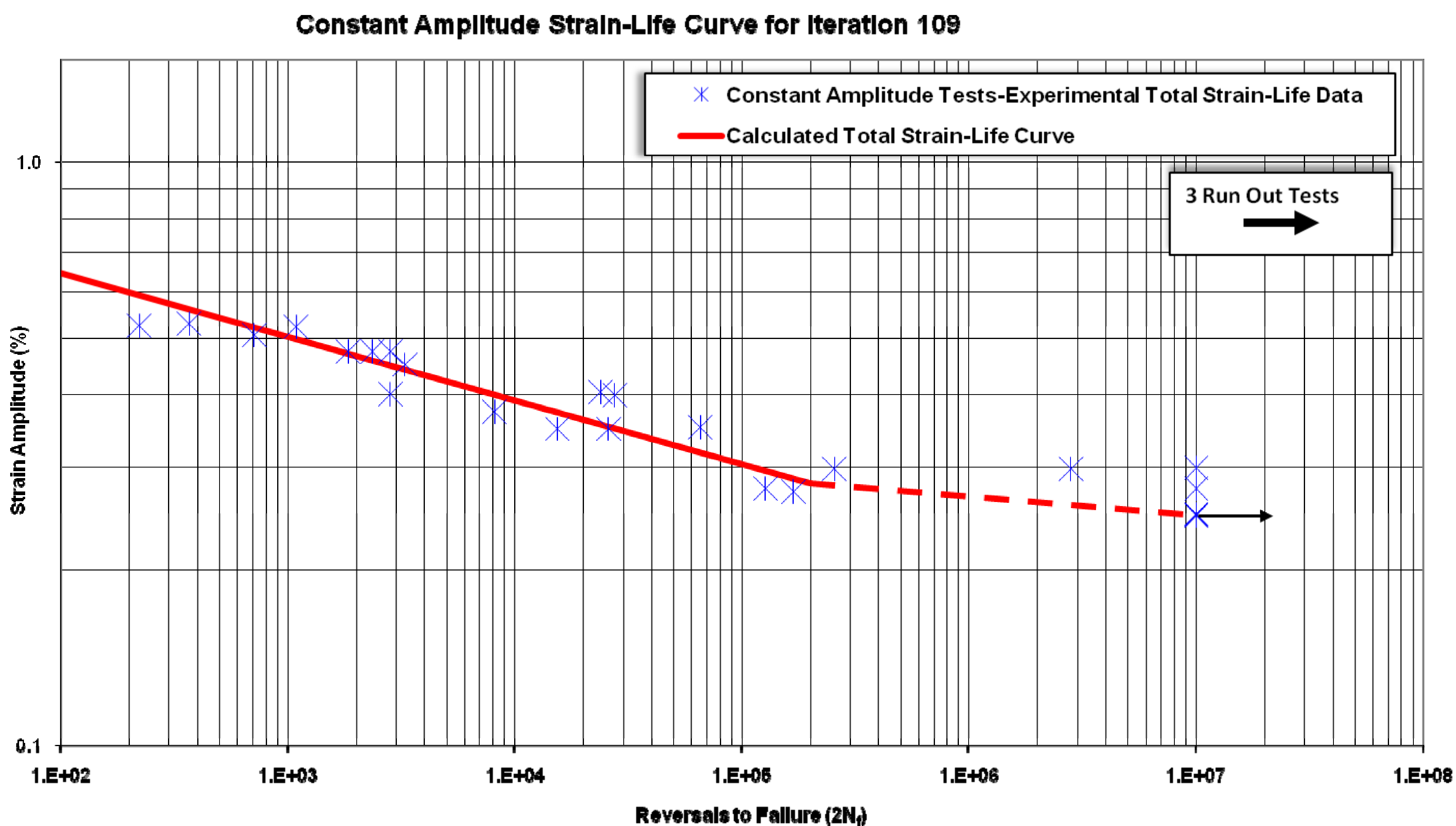

Figure 5: True strain-life curve for AISI 8822 High Side Steel (IT 109)

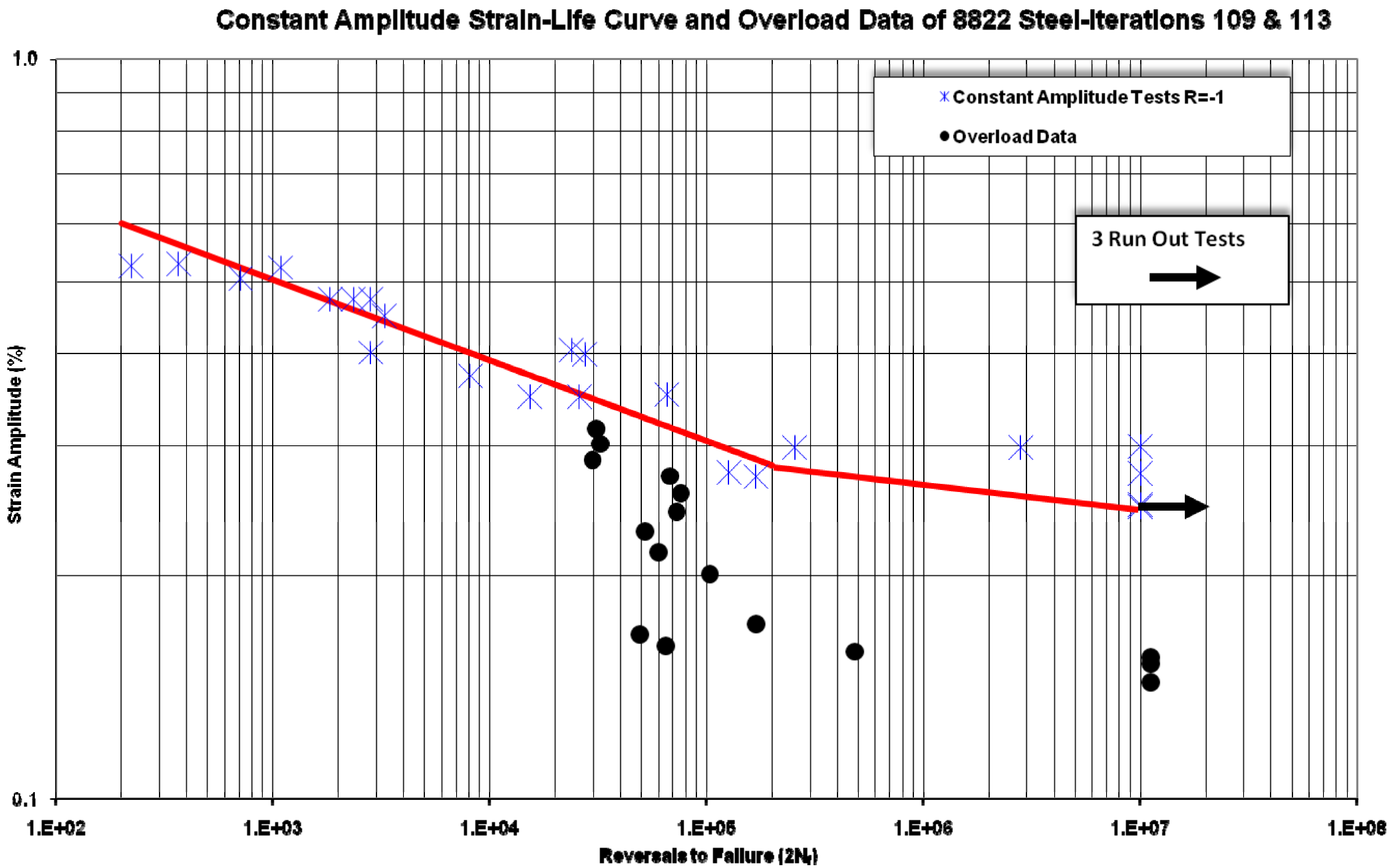
Constant Amplitude Strain-Life Curve and Overload Data of 8822 Steel-Iterations 109 & 113
Constant Amplitude Tests R=-1
Overload Data
3 Run Out Tests
1.0
0.1
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
Reversals to Failure (2Nf)
Strain Amplitude (%)

Figure 6: Strain-life curve and overload data for AISI 8822 High Side Steel (IT 109 and 113)

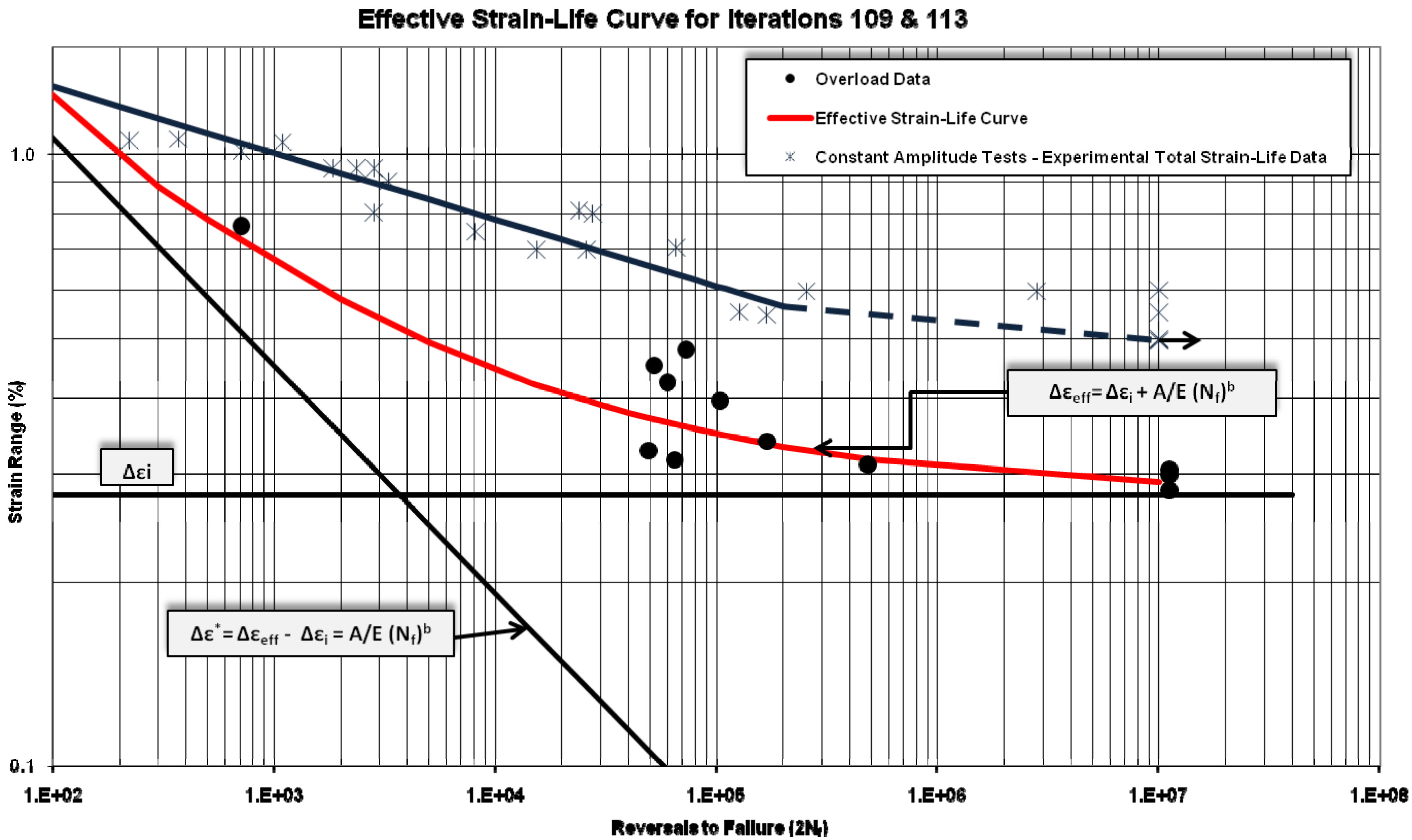
Effective Strain-Life Curve for Iterations 109 & 113
Overload Data
Effective Strain-Life Curve
Constant Amplitude Tests - Experimental Total Strain-Life Data
1.0
0.1
Strain Range (%)
Δεi
$\Delta\varepsilon_{eff} = \Delta\varepsilon_i + A/E\,(N_f)^b$
$\Delta\varepsilon^* = \Delta\varepsilon_{eff} - \Delta\varepsilon_i = A/E\,(N_f)^b$
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
Reversals to Failure (2Nf)

Figure 7: Effective strain-life curve for AISI 8822 High Side Steel (IT 109 and 113)

Table 1: Chemical Analysis (Bar Average) for AISI 8822 High Side Steel (Iterations 109 and 113)

C	0.22
Mn	0.86
P	0.013
S	0.025
Si	0.17
Ni	0.43
Cr	0.54
Mo	0.39
Cu	0.24
Sn	0.01
Al	0.028
V	0.004

Table 2: Monotonic and Cyclic Properties for AISI 8822 High Side Steel (Iterations 109 and 113)

Monotonic Properties	
Average elastic modulus, E (GPa)	209
Yield strength (MPa)	-
Ultimate tensile strength (MPa)	1480
% Elongation (%)	0.87%
% Reduction of area (%)	-
True fracture strain, $Ln\ (A_i / A_f)$ (%)	-
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$ (MPa)	1480
Monotonic tensile strength coefficient, K (MPa)	-
Monotonic tensile strain hardening exponent, n	-
Hardness, Rockwell C (HRC)	55
Cyclic Properties	
Cyclic Yield Strength, (0.2% offset) $= K'(0.002)^{n'}$ (MPa)	-
Cyclic strength coefficient, K' (MPa)	-
Cyclic strain hardening exponent, n'	-
Cyclic elastic modulus, E_c (GPa)	209
Fatigue strength coefficient, σ'_f (MPa)	2234
Fatigue strength exponent, b	-0.109
Fatigue ductility coefficient, ε'_f	-
Fatigue ductility exponent, c	-

Table 3: Constant Strain Amplitude Data for AISI 8822 High Side Steel (Iteration 109)

Specimen #	True Total Strain Amplitude (%)	True Stress Amplitude (Mpa)	True Plastic Strain Amplitude (%)	True Elastic Strain Amplitude (%)	Hardness (RC)	Fatigue Life (Reversals, $2N_f$)
1	0.527	1035	0.0	0.526		222
2	0.531	1093	0.0	0.529		368
3	0.525	1068	0.0	0.523	53	1,090
4	0.507	1044	0.0	0.506		710
5	0.475	997	0.0	0.474		2,354
6	0.475	982	0.0	0.473		2,828
7	0.475	974	0.0	0.474		1,840
8	0.451	900	0.0	0.450		3,276
9	0.402	809	0.0	0.401	58	2,820
10	0.400	809	0.0	0.399		27,538
11	0.405	808	0.0	0.405		23,874
12	0.374	790	0.0	0.374		8,120
13	0.350	706	0.0	0.349		15,348
14	0.350	704	0.0	0.349	55	25,846
15	0.353	693	0.0	0.352		65,610
16	0.299	602	0.0	0.298		255,128
17	0.299	613	0.0	0.299		2,805,890
18	0.300	613	0.0	0.300		10,000,000
19	0.273	577	0.0	0.273		168,306
20	0.276	562	0.0	0.276		10,000,000
21	0.277	556	0.0	0.276		126,558
22	0.250	489	0.0	0.250		10,000,000
23	0.248	511	0.0	0.248		10,000,000
24	0.250	508	0.0	0.250		10,000,000

* run out specimens

Table 4: Periodic Overload Fatigue Data for AISI 8822 High Side OL Steel (Iteration 113)

Test	Stress Amplitude for Small Cycles (MPa)	Strain Amplitude for Small Cycles (%)	Number of Small Cycles between Overloads	Total Number of Cycles to Failure (N_f)	Equivalent Small Cycles Fatigue Life ($2N_f$)
OL1	601	0.287	100	14,880	29,759
OL2	571	0.273	100	33,836	67,673
OL3	541	0.259	100	38,057	76,113
OL4	511	0.244	100	36,357	72,714
OL5	481	0.230	80	26,080	52,160
OL6	361	0.172	250	84,375	168,749
OL7	301	0.144	5,000	5,554,444	11,108,889
OL8	331	0.158	5,000	241,637	483,274
OL9	319	0.152	5,000	5,554,444	11,108,889
OL10	325	0.155	5,000	5,554,444	11,108,889
OL11	631	0.302	50	16,209	32,418
OL12	661	0.316	50	15,539	31,077
OL13	451	0.216	3,000	30,050	60,100
OL14	421	0.201	3,000	51,814	103,628
OL15	349	0.167	50	24,640	49,280
OL16	337	0.161	1,000	32,329	64,659

Appendix A

MACSTEEL

Quanex

MacSteel

ONE JACKSON SQUARE
SUITE 500
JACKSON, MICHIGAN 49201

CERTIFIED MATERIAL TEST REPORT

CUSTOMER ORDER NUMBER	CUSTOMER PART NUMBER	HEAT NUMBER	WORK ORDER NUMBER	DATE
105152	40022410-CUT	2M45025	50155 202	2/14/07

REPORT TO
QUALITY ASSURANCE
AMERICAN AXLE and MFG
ACCOUNTS PAYABLE DEPT.

P.O. BOX 12159
DETROIT , MI 48212

SHIP TO
AMERICAN AXLE & MFG INC
TONAWANDA FORGE PLANT
NET SHAPE WAREHOUSE
2390 KENMORE AVE
TONAWANDA , NY 14150

ORDERED

GRADE	SIZE	LENGTH
8822	1.339"	1.88"

CUSTOMER SPECIFICATIONS
P/N 40022410 MS2527 DTD 6-14-01 MS1001

CHEMICAL ANALYSIS - (BAR AVERAGE)

C	Mn	P	S	Si	Ni	Cr	Mo	Cu	Sn	Al
0.22	0.86	0.013	0.025	0.17	0.43	0.54	0.39	0.24	0.010	0.028

V
0.004

GRAIN SIZE SPECIFICATION ASTM E112

HARDENABILITY SPECIFICATION ASTM A255

J1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 20 22 24 26 28 30 32 34

MICROCLEANLINESS SPECIFICATION ASTM E45 METH C

S O

*** INCOMPLETE TEST RESULTS ***
REVISED REPORT TO BE FORWARDED WHEN TESTING COMPLETE

PAGE 1

We certify that these data are correct and in compliance with specified requirements.

MacSteel Jackson
3100 Brooklyn Road
Jackson, MI 49204

Patrick J. Doyle
Quality Assurance Representative

CONTINUED ON PAGE 2

MACSTEEL

Quanex

MacSteel

ONE JACKSON SQUARE
SUITE 500
JACKSON, MICHIGAN 49201

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CUSTOMER SPECIFICATIONS
P/N 40022410 MS2527 DTD 6-14-01 MS1001

MACROCLEANLINESS SPECIFICATION ASTM E381

PLATE I PLATE II

S R C

DI CALCULATION SPECIFICATION 1E38 FOR INFO

03.065

CUSTOMER PRESAMPLE

** MATERIAL 100% MELTED AND MANUFACTURED IN THE U.S.A. BY THE ELECTRIC ARC FURNACE AND CONTINUOUS CASTING METHOD. THE PRODUCT HAS NOT BEEN REPAIRED BY WELDING AND THIS MATERIAL HAS NOT BEEN EXPOSED TO MERCURY OR TO ANY OTHER METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURES DURING PROCESSING OR WHILE IN OUR POSSESSION. **

*** INCOMPLETE TEST RESULTS ***
REVISED REPORT TO BE FORWARDED WHEN TESTING COMPLETE

PAGE 2 OF 2

We certify that these data are correct and in compliance with specified requirements.

MacSteel Jackson
3100 Brooklyn Road
Jackson, MI 49204

Patrick J. Doyle
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