Fatigue Behavior and Monotonic Properties

For

AISI 8822 High Side Steel

Iterations 108 &112

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Table of Contents

Summary

The required mechanical fatigue properties, cyclic stress-strain data, strain-controlled fatigue data and overload fatigue 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 nine measurements. Constant-amplitude tests as well as overload fatigue 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 (Iteration 108 and 112). 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

Two monotonic tension tests were 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^{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 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 80 Hz.

Results

Monotonic Tension Test

The engineering monotonic tensile stress-strain curve is given in Figure 2. The monotonic properties are given in Table 1. 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 1.

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:

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

(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 2, 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 2. 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:

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

(Eq. 2)

$$\frac{\Delta\varepsilon_P}{2} = \varepsilon_f^1\left(2N\right)^C$$

(Eq. 3)

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

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

(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 1.

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 112 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 112 are given in Table 3. The equivalent strain-life fatigue curve is shown together with constant amplitude fatigue life curve in Figure 6.

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

Note:

Some specimen IDs, a digital number with a letter "B", such as 9B, it means this specimen (9) was tested at low strain amplitude without failure, then it was tested at high strain amplitude (9B).

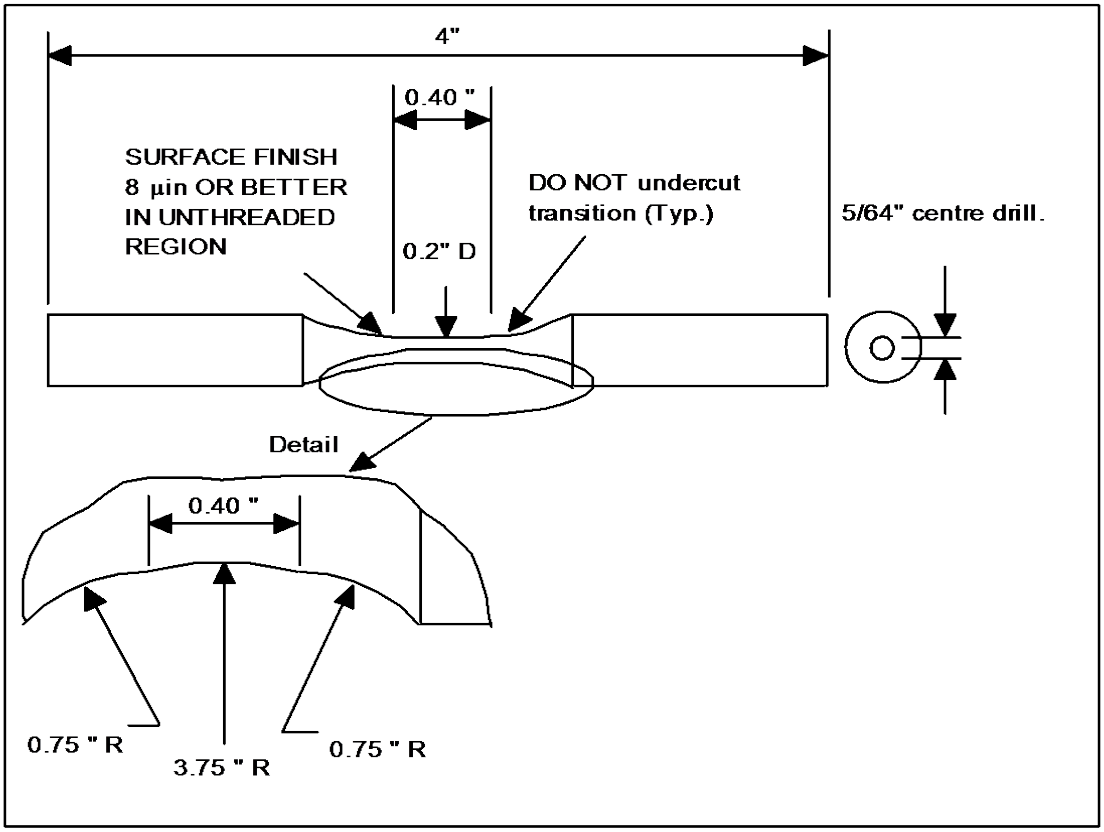

Figure 1: Uni-axial smooth cylindrical fatigue specimen

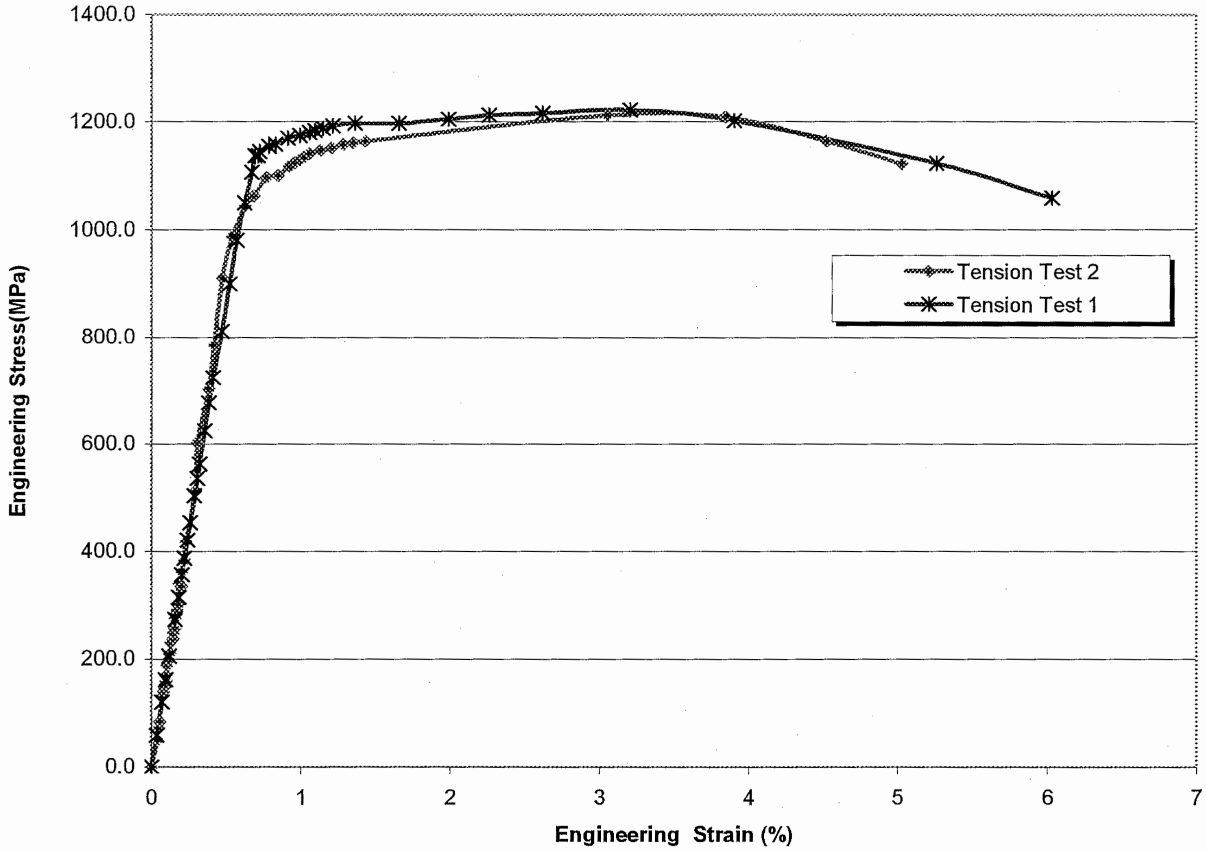

Figure 2: Monotonic tension engineering stress and strain curves

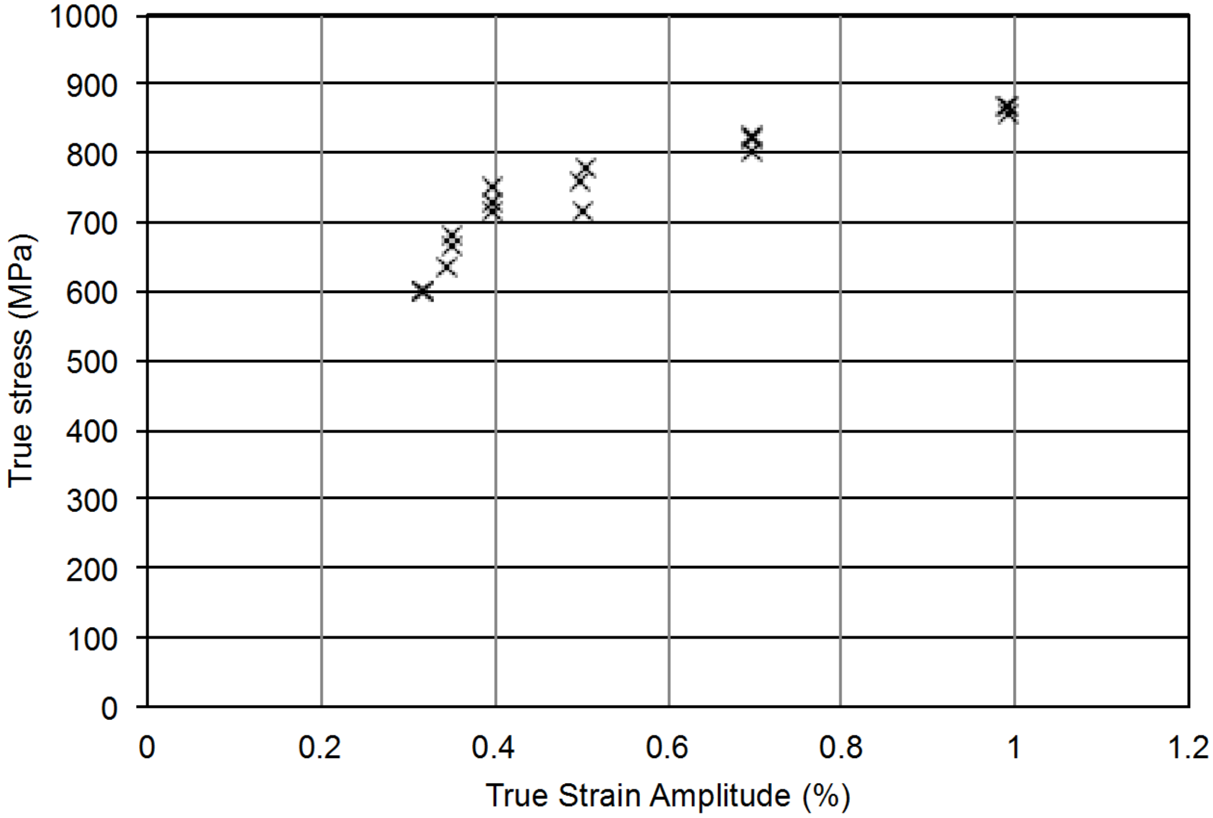

Figure 3: Cyclic true stress-strain curve for AISI 8822 High Side Steel (IT 108)

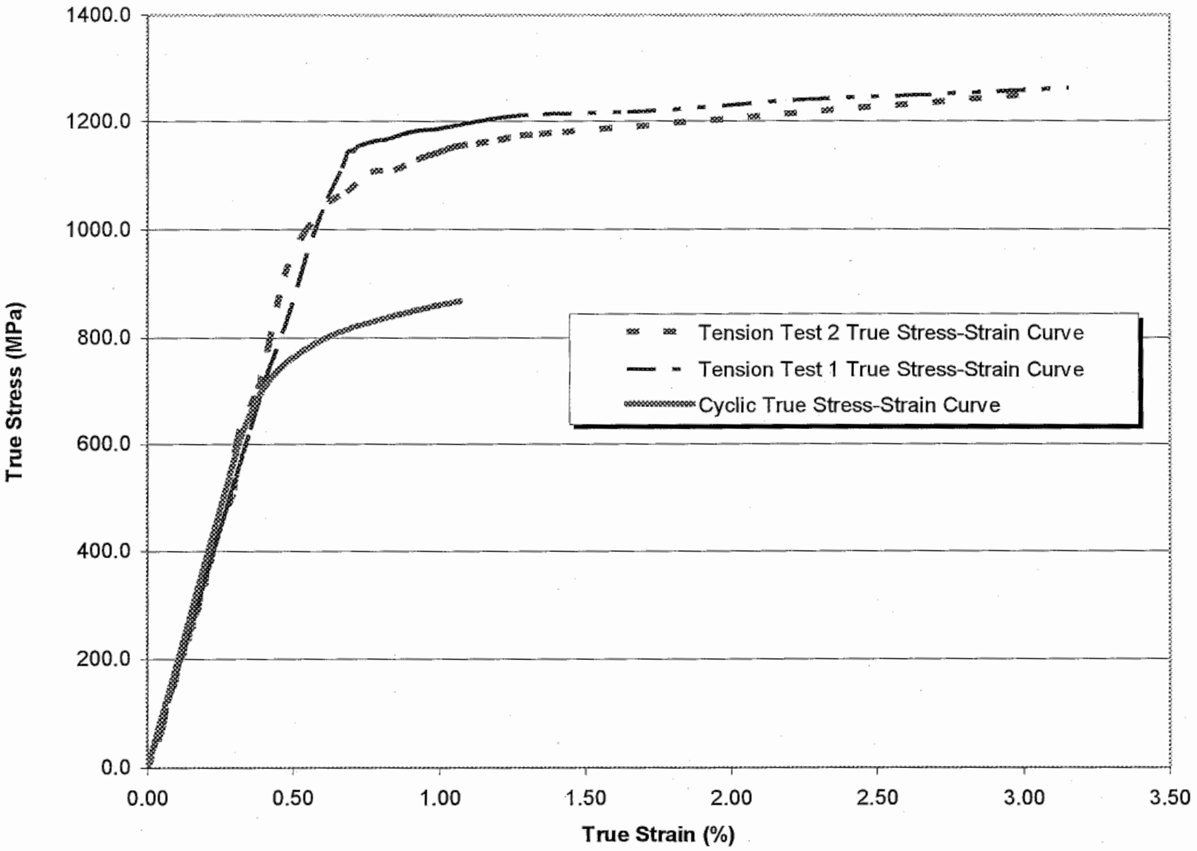

Figure 4: Monotonic & cyclic true stress-strain curves for AISI 4320 Steel (IT 122)

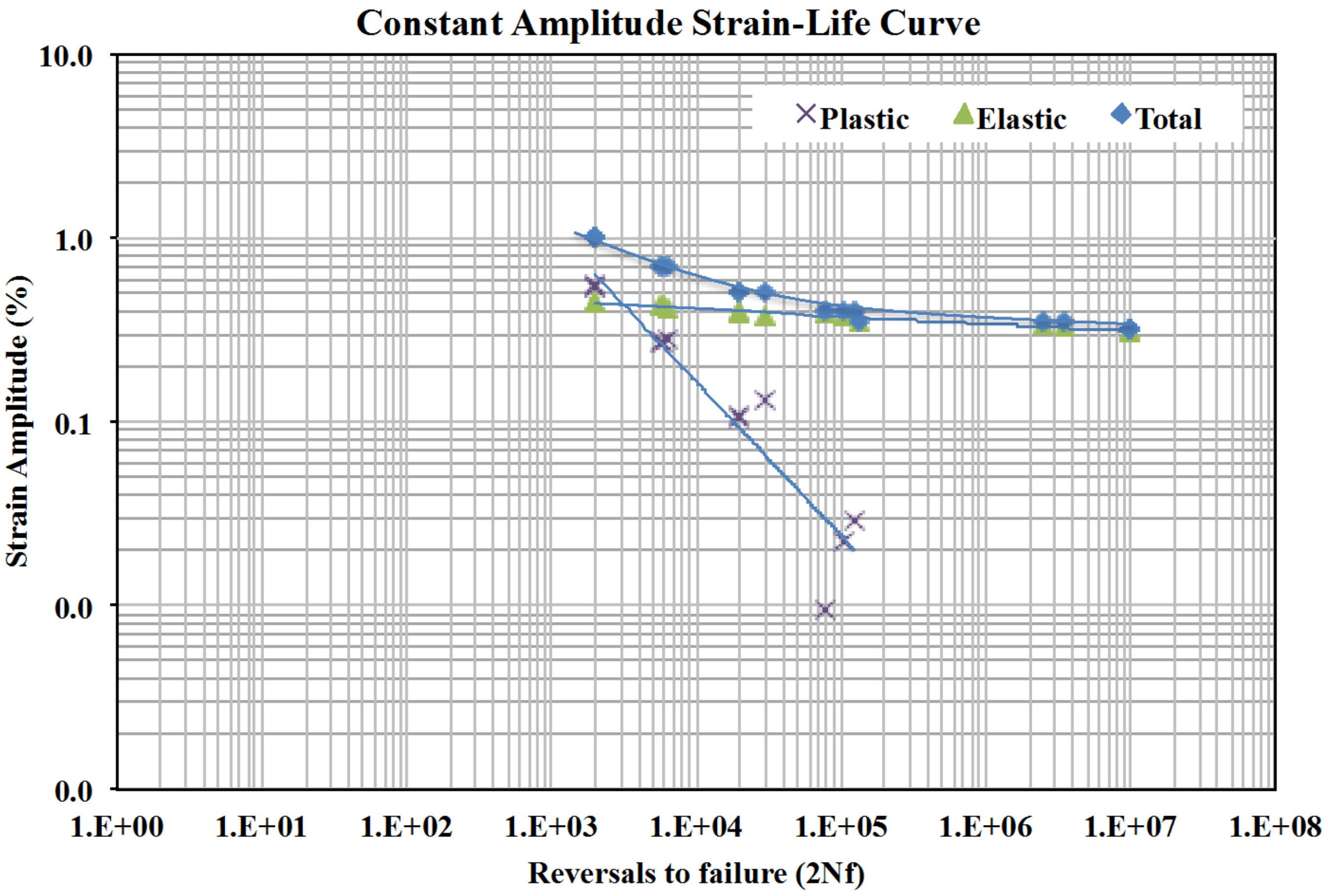

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Figure 5: Strain-life fatigue curves for AISI 8822 High Side Steel (IT 108)

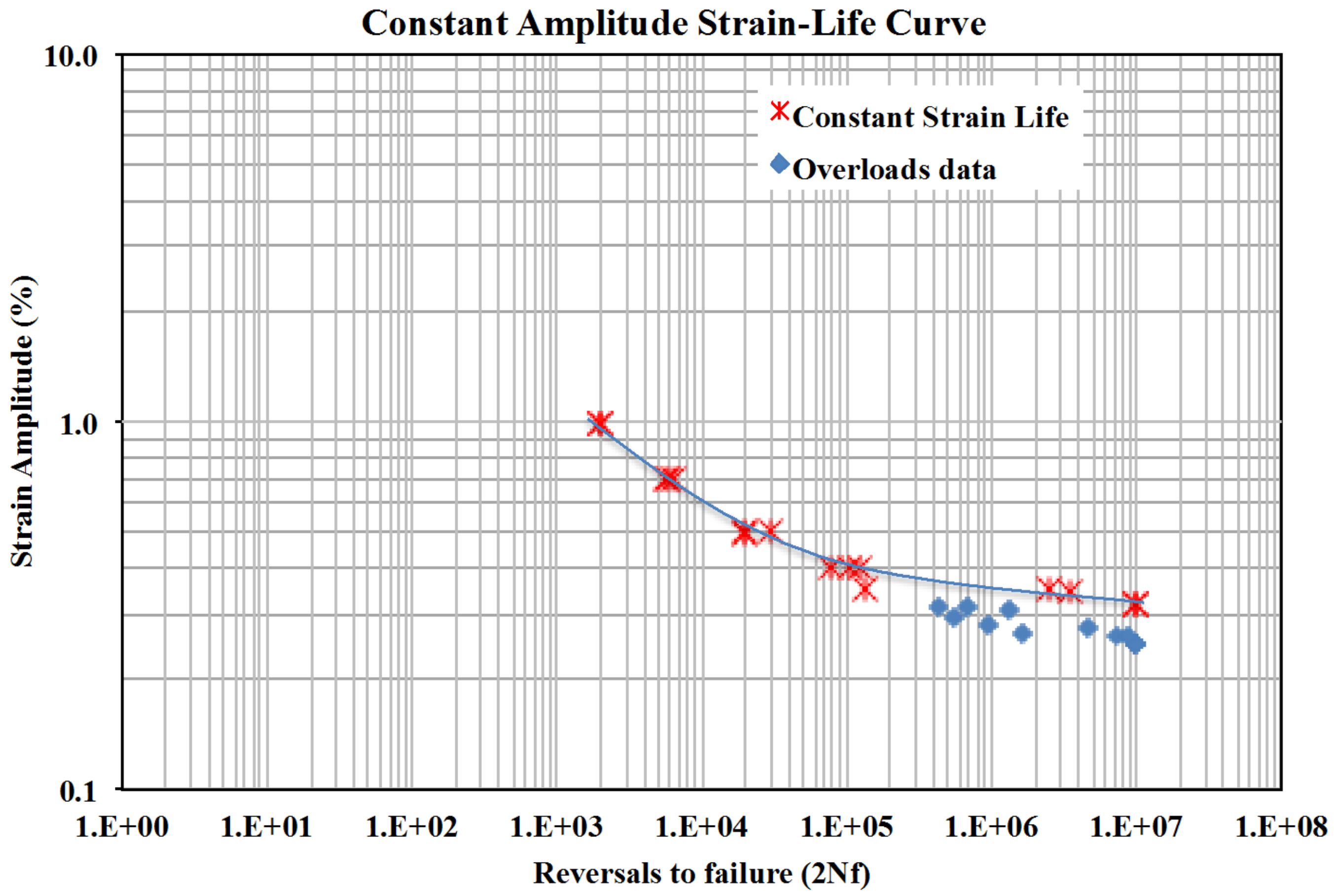

Figure 6: Overload and constant fatigue data for AISI 8822 High Side Steel (IT 108 & 112)

Table 1: Monotonic and Cyclic Properties for AISI 8822 High Side Steel (IT 108 and 112)

Monotonic Properties	
Average Elastic Modulus, E (GPa)	194
Yield Strength (MPa)	1135
Ultimate tensile Strength (MPa)	1215
% Elongation	5.5
% Reduction of Area	59.38
True Fracture Strain ln (Ai/Af) (%)	90.32
True fracture stress, σf= Pf/Af (MPa)	2690
Monotonic tensile strength coefficient, K (MPa)	1430
Monotonic tensile strain hardening exponent, n	0.0372
Hardness, Rockwell C (HRC)	39
Cyclic Properties	
Cyclic Yield Strength, (0.2% offset) = K'(0.002)^n' (MPa)	800
Cyclic strength coefficient, K' (MPa)	1054
Cyclic strain hardening exponent, n'	0.044
Cyclic elastic modulus, Ec (GPa)	194
Fatigue strength coefficient, σ'f (MPa)	1292
Fatigue strength exponent, b	-0.0519
Fatigue ductility coefficient, ε'f	0.818
Fatigue ductility exponent, c	-0.66

Table 2: Constant Strain Amplitude Data for AISI 8822 High Side Steel (IT 108)

Sp#	Total Strain Amplitude (%)	Stress Amplitude (MPa)	Plastic Strain Amplitude (%)	Elastic Strain Amplitude (%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	Hardness (Rockwell C)
1	0.994	855.7	0.553	0.441	1998	Hardness HRC Average of nine readings 39
11(10)	0.994	868.3	0.546	0.448	2000	
12(8)	0.99	866.8	0.543	0.447	2000	
14	0.698	823.4	0.274	0.424	5,600	
2	0.696	819.3	0.274	0.422	6,000	
13(9)	0.696	800.8	0.283	0.413	6,400	
15	0.505	776.4	0.105	0.400	20,000	
3	0.499	758.4	0.108	0.391	20,000	
16	0.502	717.8	0.132	0.370	30,000	
4	0.397	751.6	0.010	0.387	79,600	
17	0.397	727.6	0.022	0.375	104,904	
18	0.398	716.6	0.029	0.369	124,000	
7	0.351	680.7	0.000	0.351	137,706	
6	0.353	665	0.010	0.343	2,531,528	
5	0.347	635.2	0.020	0.327	3,560,450	
8	0.319	601.5	0.009	0.310	10,000,000	
9	0.319	601.2	0.009	0.310	10,000,000	
10	0.319	601.5	0.009	0.310	10,000,000	

Table 3: Periodic Overload Data for AISI 8822 High Side Steel (IT 112)

SP#	Stress Amplitude for small cycles (MPa)	Strain Amplitude for small cycles (%)	Number of cycles between overloads	Total number of cycles to failure	Equivalent fatigue life	
					(Cycles-Nf)	(Reversals-2Nf)
OL1	603.1	0.311	100	178,800	215,578	431,156
OL2	572.9	0.295	300	256,745	279,873	559,746
OL3	542.8	0.28	350	423,597	480,585	961,170
OL4	512.6	0.264	500	710,000	825,946	1,651,892
OL5	478.8	0.247	1500	3,751,502	5,000,000	10,000,000
OL6	478.8	0.247	1500	3,751,502	5,000,000	10,000,000
OL7	478.8	0.247	1500	3,751,502	5,000,000	10,000,000
OL8	503.6	0.26	1500	3,000,000	3,747,967	7,495,934
OL9	509.6	0.263	1500	3,406,000	4,404,410	8,808,820
OL10	603.1	0.311	250	305,387	346,547	693,094
OL11	597	0.308	500	600,700	681,403	1,362,806
OL12	530.7	0.274	1500	2,000,000	2,306,330	4,612,660