Fatigue Behavior and Monotonic Properties

For

AISI 8620 Steel

Iterations 165 & 166

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Summary

The required mechanical fatigue properties, cyclic stress-strain data, strain-controlled fatigue data and overload fatigue data for AISI 8620 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 by micro-hardness measurements performed at Dana Holding Corporation. Constant-amplitude tests as well as overload fatigue tests were conducted in laboratory air at room temperature to establish the cyclic stress-strain curve and strain-life curve.

Introduction

This report presents the results of tensile and fatigue tests performed on a group of 8620 Steel specimens (Iterations 165 and 166). 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 being heat treated, the specimens had a final polish in the loading direction in the gauge sections using 240, 400, 500, and 600 emery papers. A thin band of M-coat D acrylic coating was applied along the central gauge section before testing. 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 elongation and the percent reduction of area. 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 peak reading voltmeters. 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 all 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 30 and 120 Hz.

Results

Chemical Composition

The chemical composition as provided by Gerdau corporation is shown in Table 1.

Monotonic Tension 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 8620 Steel was taken from DANA Lab Report 2015-0134 on 8620 specimens [2] and is given in Table 2

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 2, K’ is the cyclic strength coefficient, and n’ is the strain hardening exponent.

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 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 the 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)**

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

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 Test Data

Previous work at the University of Waterloo introduced an effective strain-life curve for use in fatigue damage calculations due to overloads [3]. 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 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 [4] and the equivalent failure life of the small cycles in each test was calculated. The overload fatigue data are given in Table 4. The equivalent strain-life fatigue curve is shown together with constant amplitude fatigue life curve in Figure 6.

Microstructure:

Microstructure was analyzed by Chrysler lab, and is shown in Figures 7 and 8.

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] DANA Lab Report 2015-0134 on 8620 specimens

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

[4] 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 19B, it means this specimen (19) was tested at low strain amplitude without failure, then it was tested at high strain amplitude (19B).

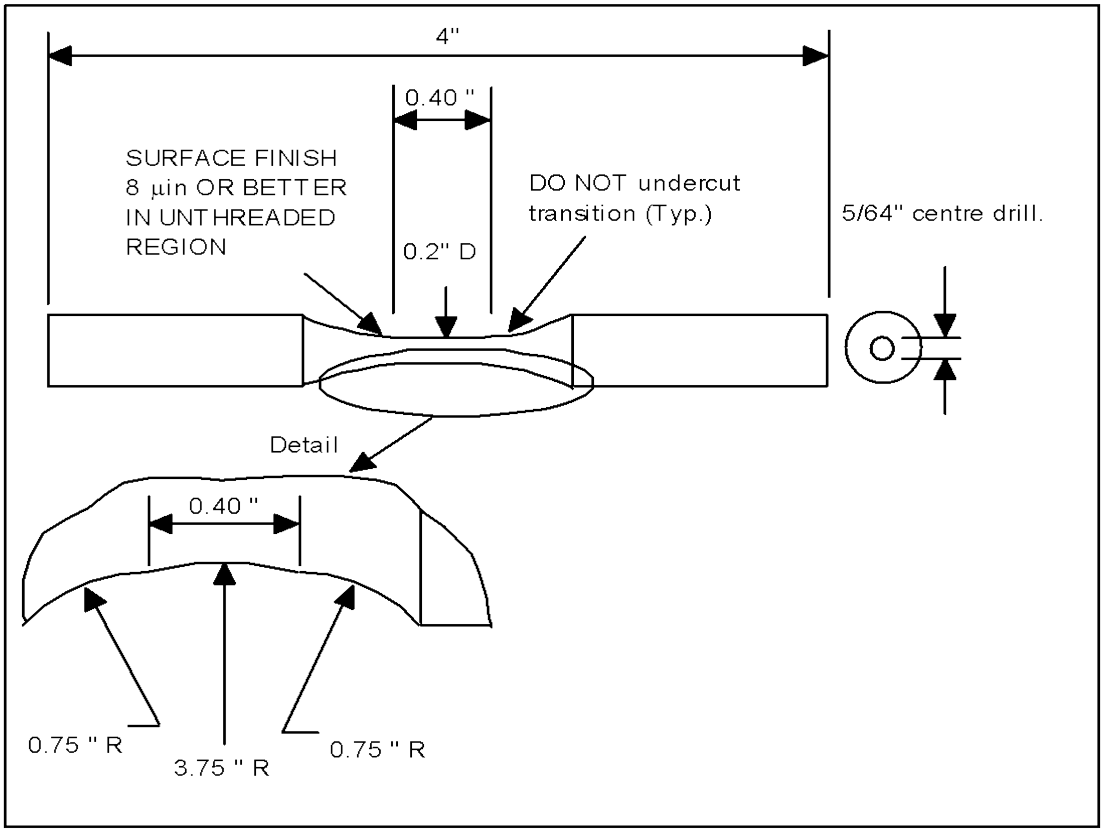

Figure 1: Uni-axial smooth cylindrical fatigue specimen

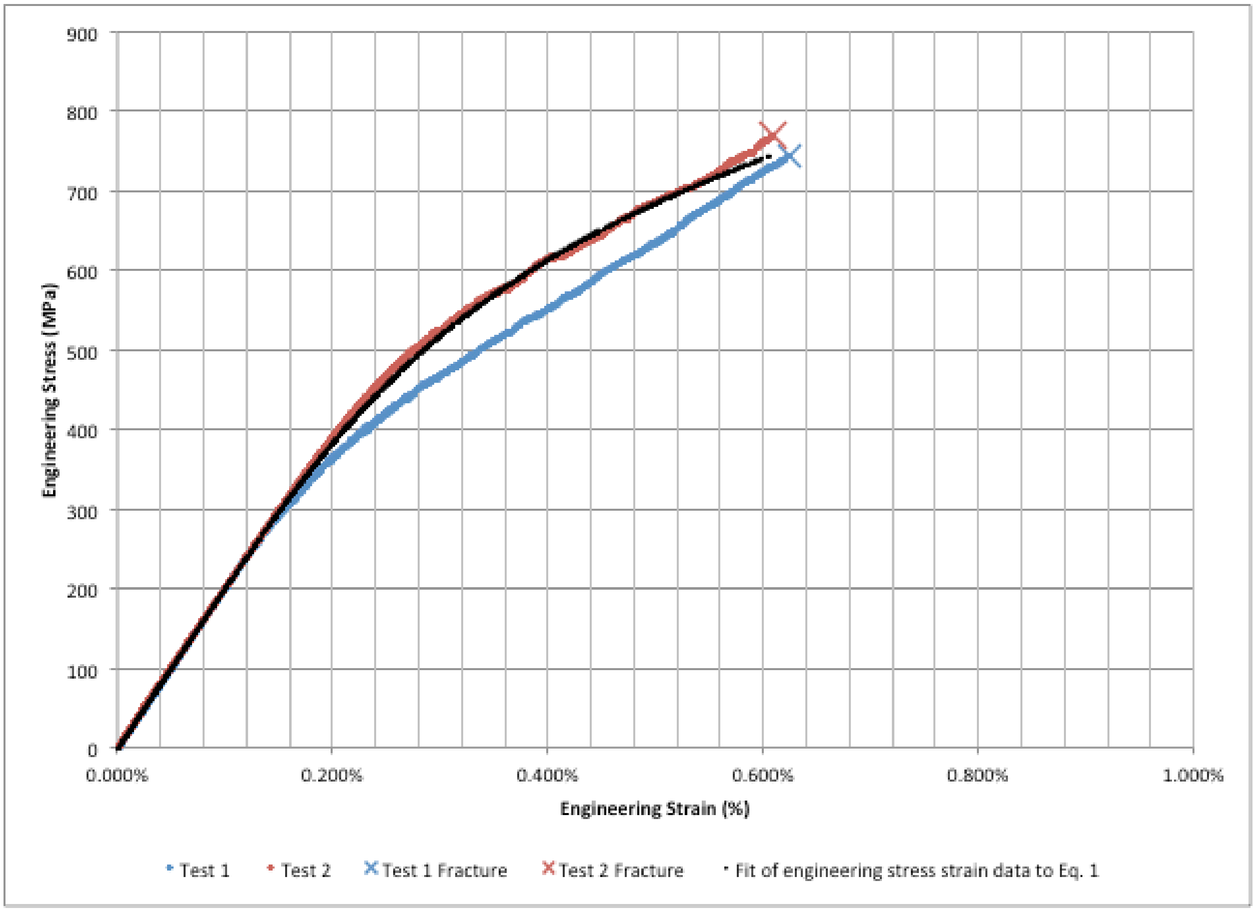

Figure 2: Monotonic engineering stress-strain curves for AISI 8620 (IT 165)

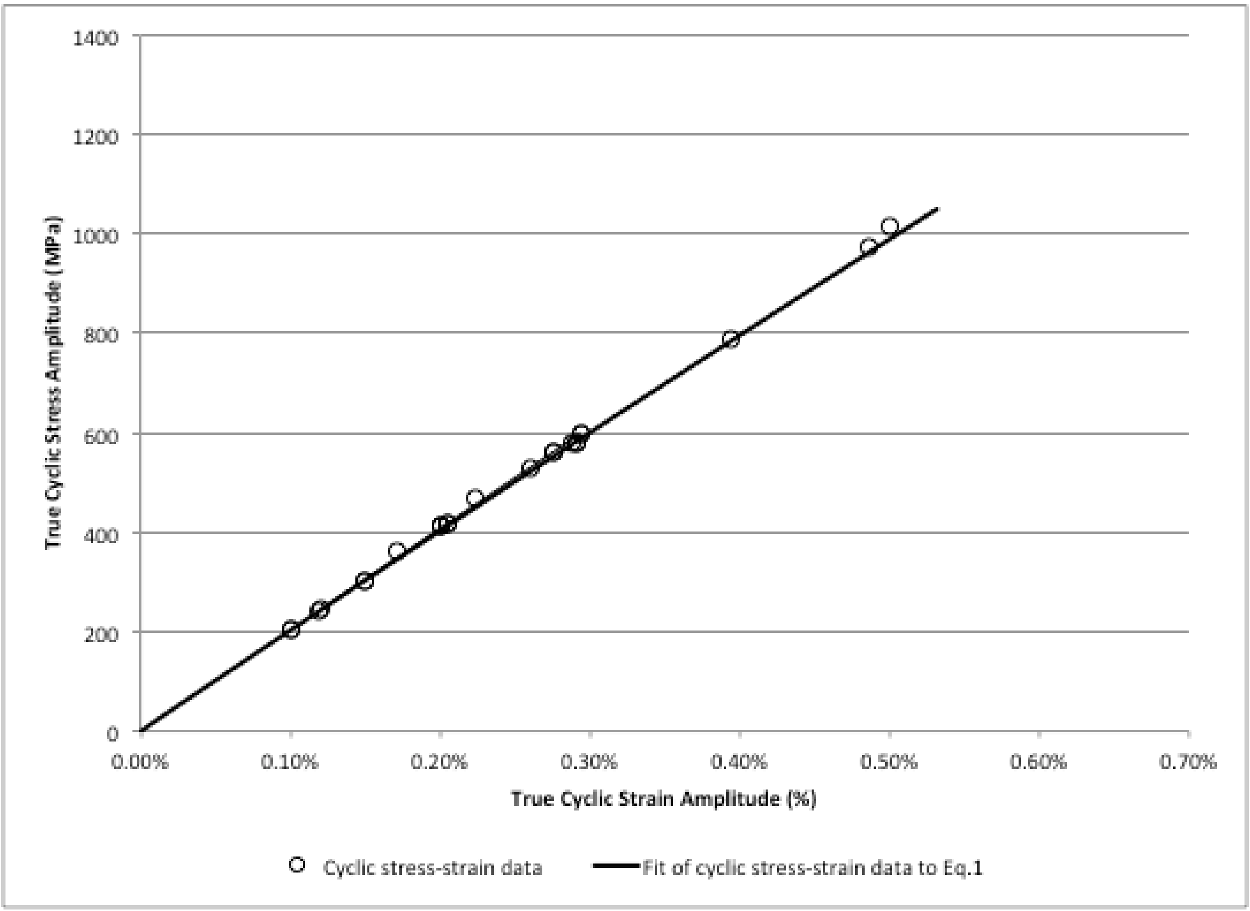

Figure 3: Cyclic stress-strain curve for AISI 8620 Steel (IT 165)

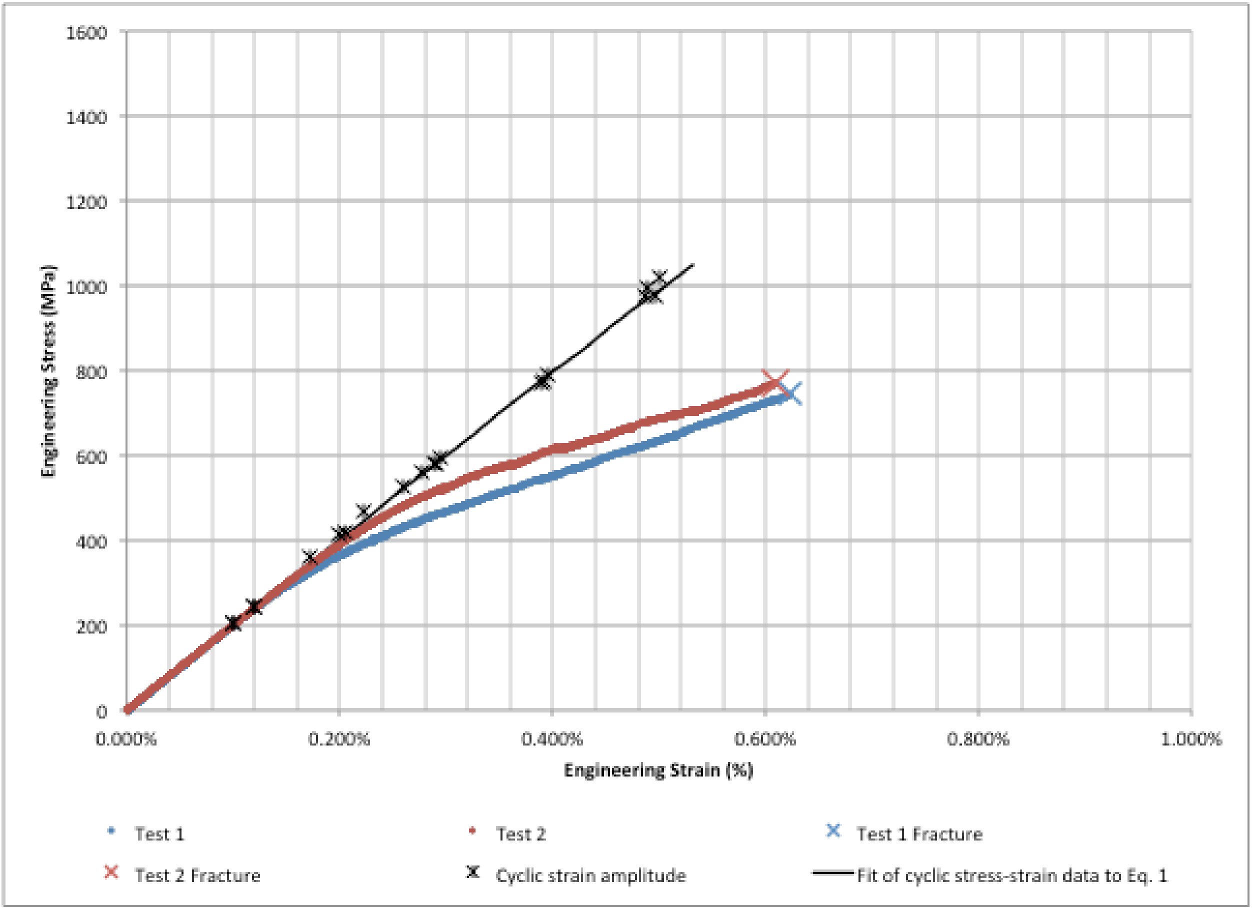

Figure 4: Monotonic & cyclic true stress-strain curves for AISI 8620 Steel (IT 165)

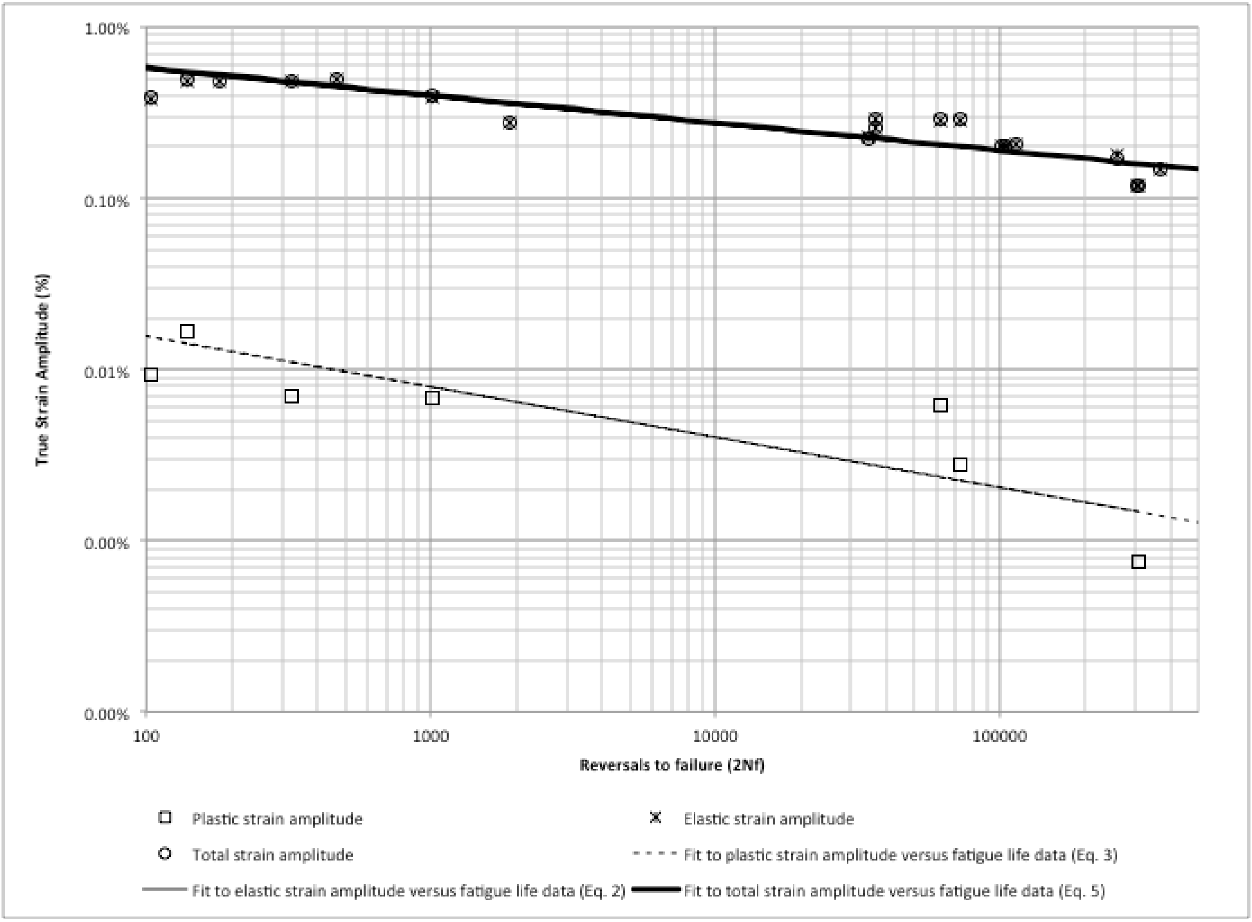

Figure 5: Strain-life fatigue curves for AISI 8620 (IT 165)

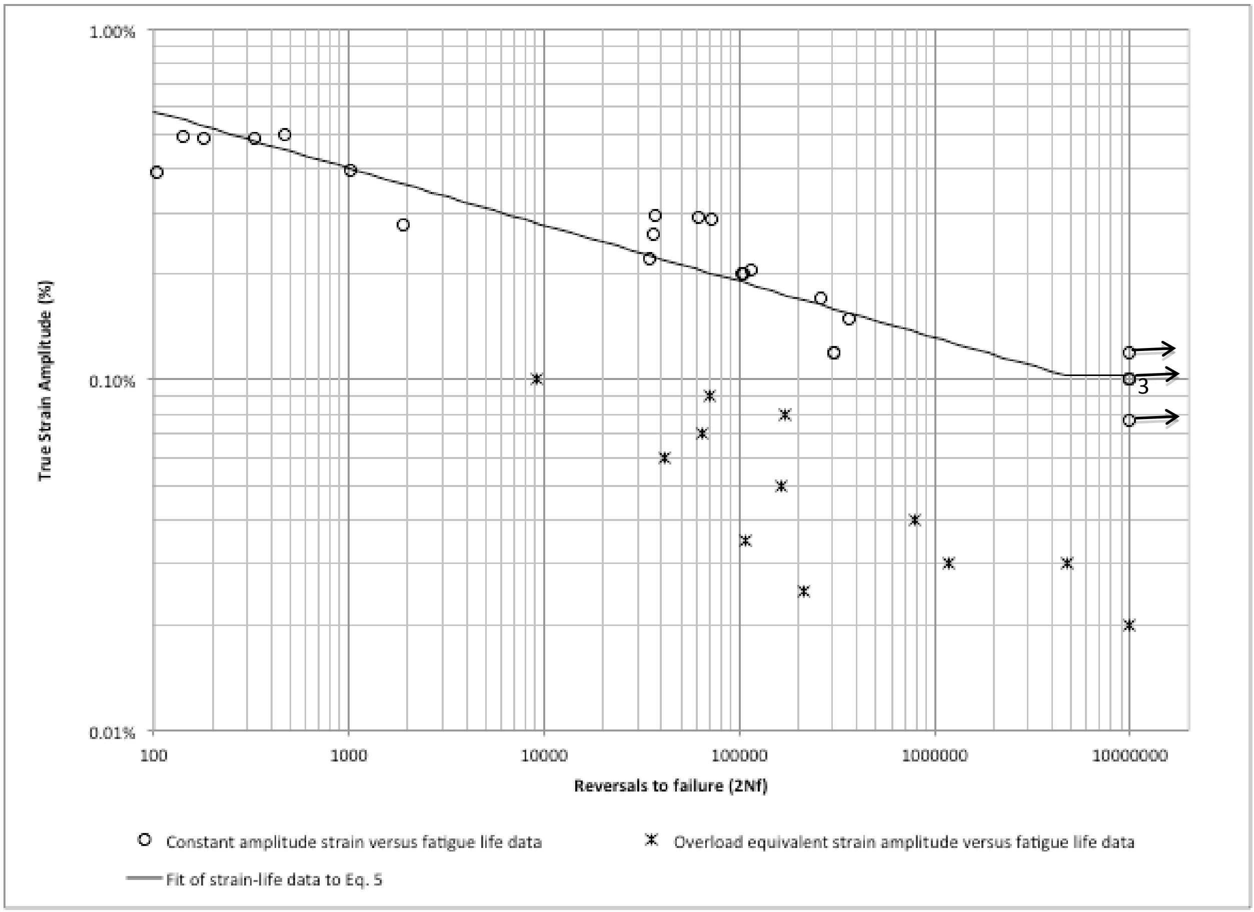

Figure 6: Overload and constant amplitude fatigue curve for AISI 8620 (IT 165 & 166)

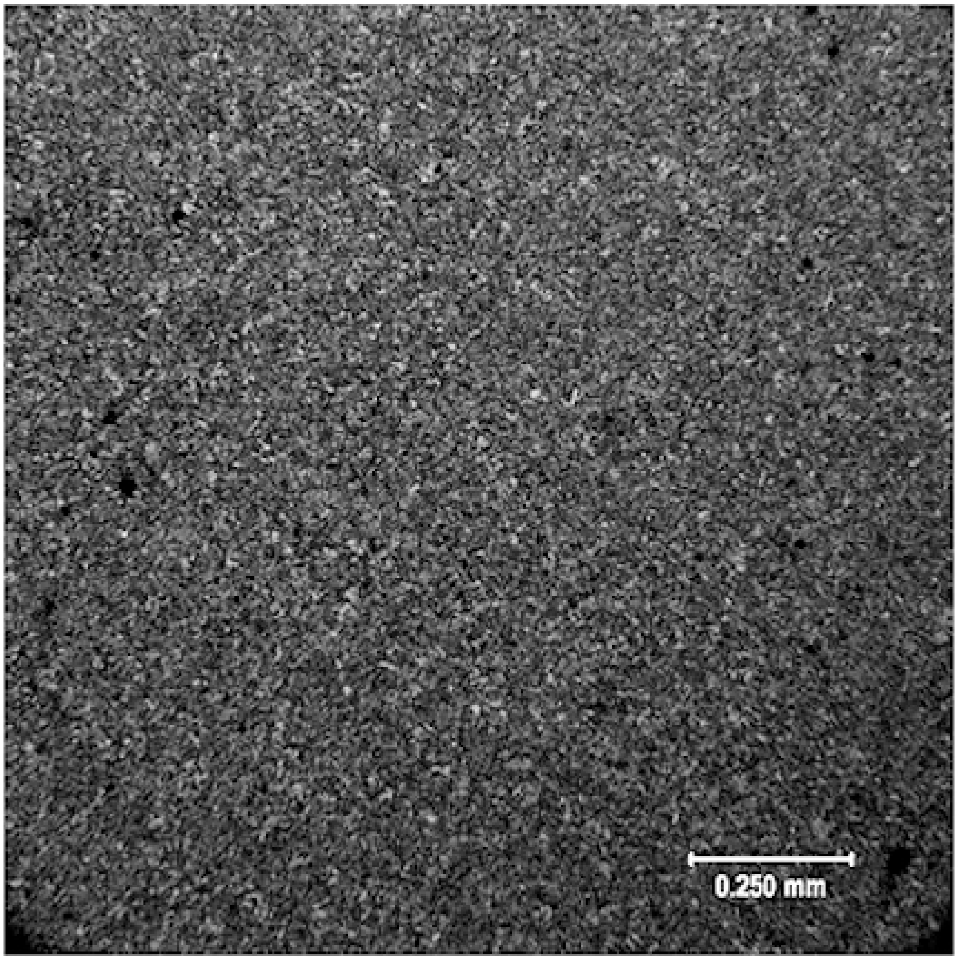

Figure 7: Microstructure of Iteration 165/166, low magnification.

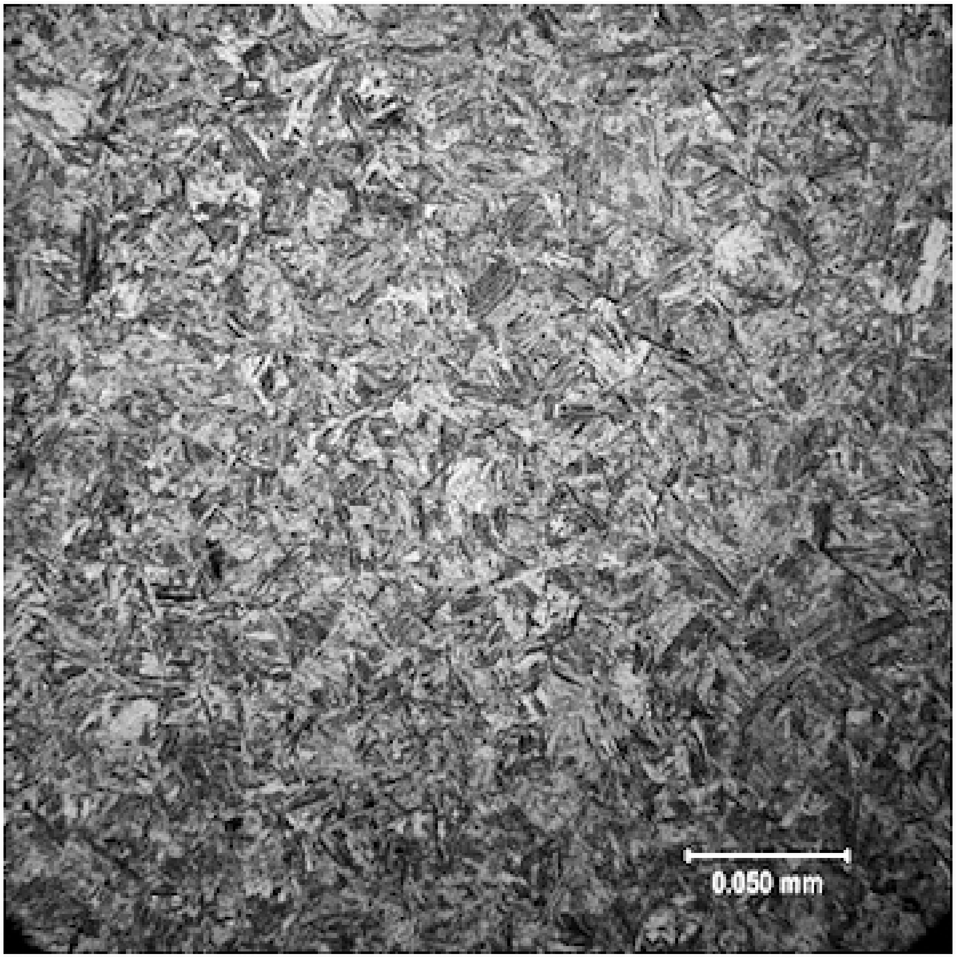

Figure 8: Microstructure of Iteration 165/166, high magnification.

Table 1: Chemical Analysis (Bar Average) for AISI 8620 Steel (Iterations 165 and 166)

C	**0.22**
Mn	**0.85**
P	**0.013**
S	**0.009**
Si	**0.25**
Ni	**0.50**
Cr	**0.57**
Mo	**0.21**
Cu	**0.21**
Sn	**0.009**
Al	**0.024**
V	**0.002**
Nb	**0.003**

Table 2: Monotonic and Cyclic Properties for AISI 8620 Steel
(IT 165 and 166)

Monotonic Properties	
Average elastic modulus, E (GPa)	203
Yield strength (MPa)	690
Ultimate tensile strength (MPa)	757
% Elongation (%)	0.5%
% Reduction of area (%)	0.24%
True fracture strain, $Ln\ (A_i / A_f)$ (%)	0.5%
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$ (MPa)	757
Monotonic tensile strength coefficient, K (MPa)	2710
Monotonic tensile strain hardening exponent, n	0.214
Hardness, Rockwell C (HRC)	60-63
Cyclic Properties	
Cyclic Yield Strength, (0.2% offset)$= K'(0.002)^{n'}$ (MPa)	3590
Cyclic strength coefficient, K' (MPa)	72987
Cyclic strain hardening exponent, n'	0.485
Cyclic elastic modulus, E_c (GPa)	203
Fatigue strength coefficient, σ'_f (MPa)	2404
Fatigue strength exponent, b	-0.159
Fatigue ductility coefficient, ε'_f	0.0006
Fatigue ductility exponent, c	-0.295

Table 3: Constant Strain Amplitude Data for AISI 8620 Steel (IT 165)

Sp. Id	True	True	True Plastic	True Elastic	Reversals	Hardness
	Strain (%)	Stress (MPa)	Strain (%)	Strain (%)	to Failure	
53	0.500	1,018	-	0.500	470	
52B	0.489	995	-	0.489	180	
41	0.486	975	0.007	0.479	326	
56	0.496	975	0.017	0.479	140	
42	0.395	789	0.007	0.388	1,010	
58	0.391	776	0.010	0.381	88	
57	0.389	773	0.009	0.380	104	Average
51B	0.294	598	-	0.294	36,760	HRC 60-63
61	0.288	580	0.003	0.285	72,636	
43	0.291	579	0.006	0.285	61,552	
44	0.276	562	-	0.276	1,898	
45	0.260	529	-	0.260	36,548	
46	0.223	468	-	0.223	34,304	
59	0.205	419	-	0.205	113,660	
60	0.200	414	-	0.200	104,178	
47	0.200	411	-	0.200	101,960	
48	0.172	361	-	0.172	260,294	
49	0.149	304	-	0.149	364,876	
106	0.150	300	0.002	0.148	1,461,998	
54	0.120	244	-	0.120	301,340	
55	0.120	244	-	0.120	10,000,000	
50	0.120	242	0.001	0.119	307,526	
52	0.100	204	-	0.100	10,000,000	
62	0.100	204	-	0.100	10,000,000	
105	0.100	203	-	0.100	10,000,000	
51	0.077	156	-	0.077	10,000,000	

Table 4: Overload Data for AISI 8620 Steel (IT 166)

Specimen	Stress Amplitude for Small Cycles	Strain Amplitude for Small Cycles	Number of Small Cycles between Overloads	Total Number of Cycles to Failure (N_f)	Equivalent Small Cycles Fatigue Life (N_f)
70	200	0.100	50	9,170	4,578
63	180	0.090	50	62,508	34,922
64	160	0.080	50	129,606	85,179
65	140	0.070	500	63,730	32,211
66	120	0.060	500	40,697	20,474
67	100	0.050	500	158,692	81,778
68	80	0.040	500	685,307	396,160
69	70	0.035	500	104,209	53,105
71	60	0.030	500	2,451,874	2,396,163
99	60	0.030	1,000	1,055,244	589,209
72	50	0.025	500	206,539	107,495
100	40	0.020	1,000	10,000,000	5,000,000