Fatigue Behavior and Monotonic Properties For AISI 9310 Steel Four Point Bending Iteration 180 and 181

Wanhua Liang, T. H. Topper and F. A. Conle

Department of Civil and Environmental Engineering
University of Waterloo
Waterloo, Ontario, Canada, N2L 3G1

Prepared for:
The AISI Bar Steel Applications Group

October 27, 2017

Contents

List of Figures

List of Tables

Summary

The required strain-life fatigue data for AISI Iteration 180 and Iteration 181 have been obtained using bending tests. The American Iron and Steel Institute (AISI) provided the material in the form of metal bars. These bars were machined into bending fatigue specimens, polished, carburized and then tested. The Rockwell C hardness (RC) was determined as the average of twelve measurements. Constant-amplitude and overload tests under bending were conducted in the laboratory at room temperature to establish the strain-life curve.

Introduction

This report presents the results of fatigue tests performed on a group of 9310 Steel specimens (Iteration 180/181). The American Iron and Steel Institute provided the material. The objective of this investigation is to obtain the constant amplitude and the overload strain-life curves of the material under a four-point bending cyclic test.

Experimental Procedure

Specimen Preparation

Bending fatigue specimens, shown in 1 and 2, were machined from the metal bars and polished with a small 500 grit wheel that was spinning in the same direction as the beam length. The samples were then carburized and quenched in oil by the AISI group and returned for fatigue testing. 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 in Table 4. 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 bending rig was installed in the hydraulic testing machine as shown in Figure 3. An extensometer was installed on the bending specimen to measure the strain as shown in Figure 4. Epoxy was applied to attach the extensometer onto the specimen to prevent slipping.
A process control computer, controlled by FLEX software [1] was used to output constant stroke amplitudes and overload stroke amplititudes for Iteration 180 and 181 respectively.
After failure was indicated by the 50% load drop the specimens were often only partially cracked. In order to observe the fracture surface these specimens were held in a vice at one end and then struck with a hammer on the other end. Specimen fracture surfaces that indicated subsurface "Fisheye" cracks were photographed and are shown in Figures 9 to 15. Note that the fast fracture darker regions are created by opening the crack. In order to conform with the AISI database structure Tables 2 and 3 also report a "bending stress" that assumes no plasticity in the beam. The stress is the bending moment, M, multiplied by the half height, c, of the beam section and divided by the

moment of Inertia I as per Stress = M*c/I. Similarly the “Modulus” reported in the tables is simply the Stress Amplitude divided by the Strain Amplitude.

Results

Chemical Composition

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

Constant Amplitude Fatigue Data

Constant strain amplitude, fully reversed (R=-1) stroke-controlled fatigue tests were performed on bending specimens. The tests were run under stroke control and the corresponding strain measurements were recorded. The load-strain limits for each specimen were recorded at logarithmic intervals throughout the test via a peak reading oscilloscope. 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 0.5 Hz to 25 Hz. Constant amplitude fatigue test data obtained in this investigation are given in Table 2. A constant strain- amplitude fatigue life curve for the steel is given in Figure 5.

Overload Fatigue Data

Overload fatigue tests were performed on bending specimens under stroke control. Stroke corresponding to the strain at fatigue life of 10,000 cycles were used for the overloads. The overload frequency ranges from 50 to 100 small cycles/overload. Damages caused by the overloads varies from 2% to 52%. Overload amplitude fatigue test data obtained in this investigation are shown in Table 3. The overload strain-amplitude fatigue life curve is presented in Figure 6 along with the constant amplitude curve.

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

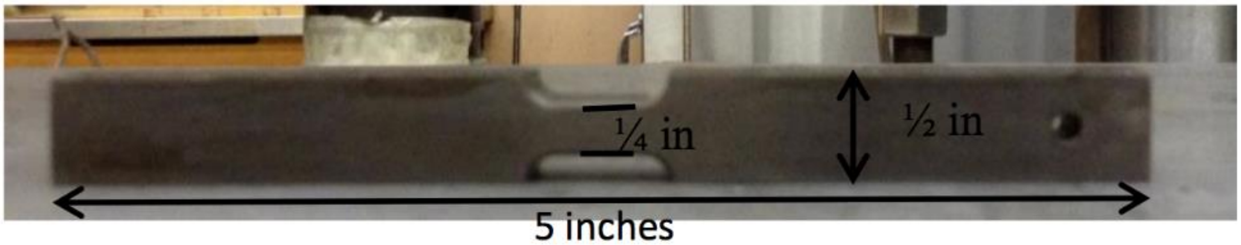

Figure 1: Bending specimen side view

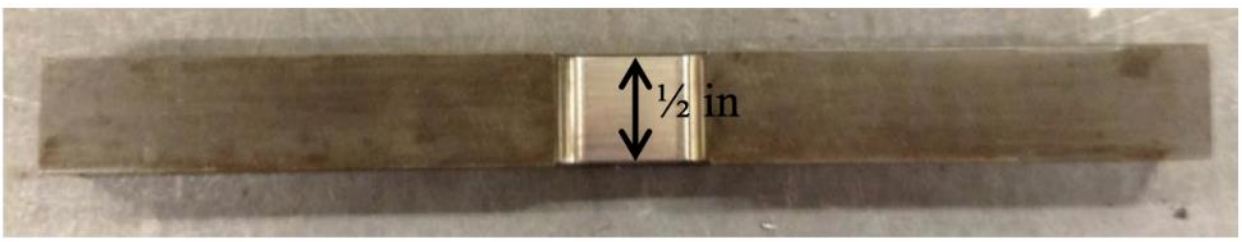

Figure 2: Bending specimen top view

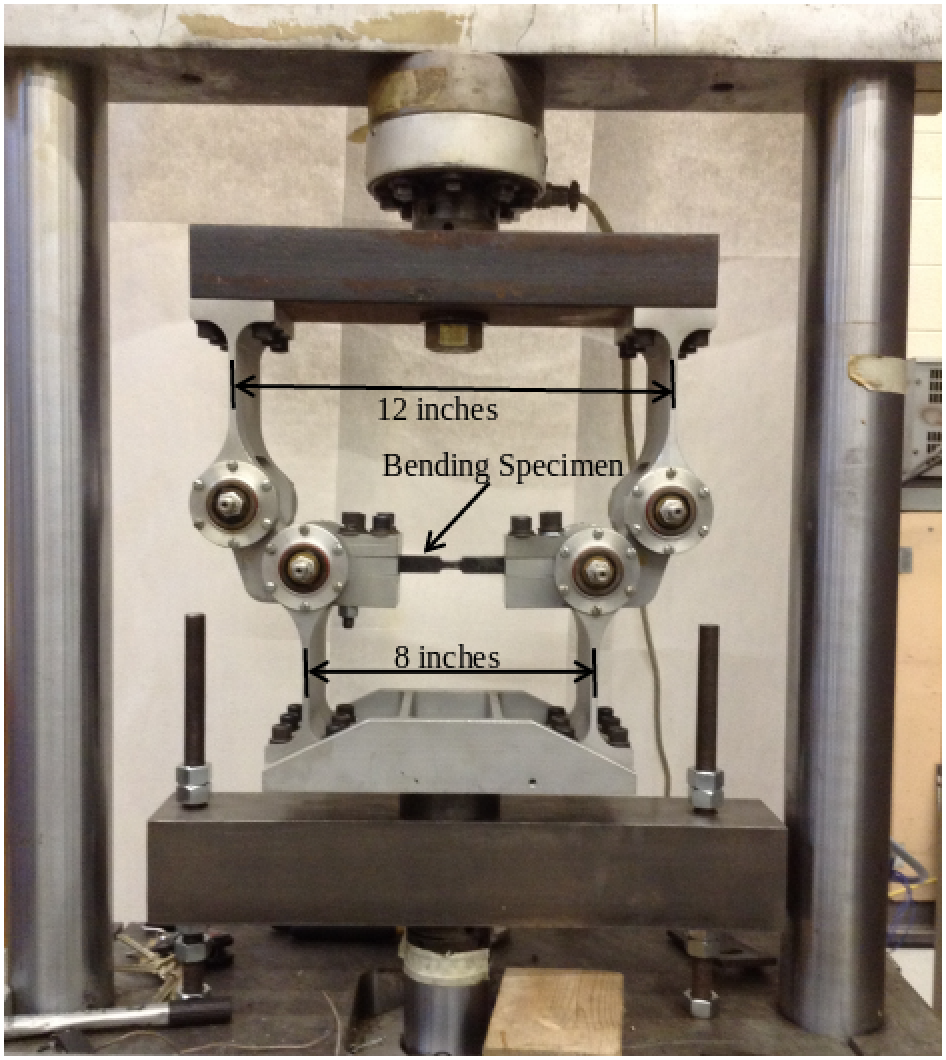

Figure 3: Bending Rig in the testing frame

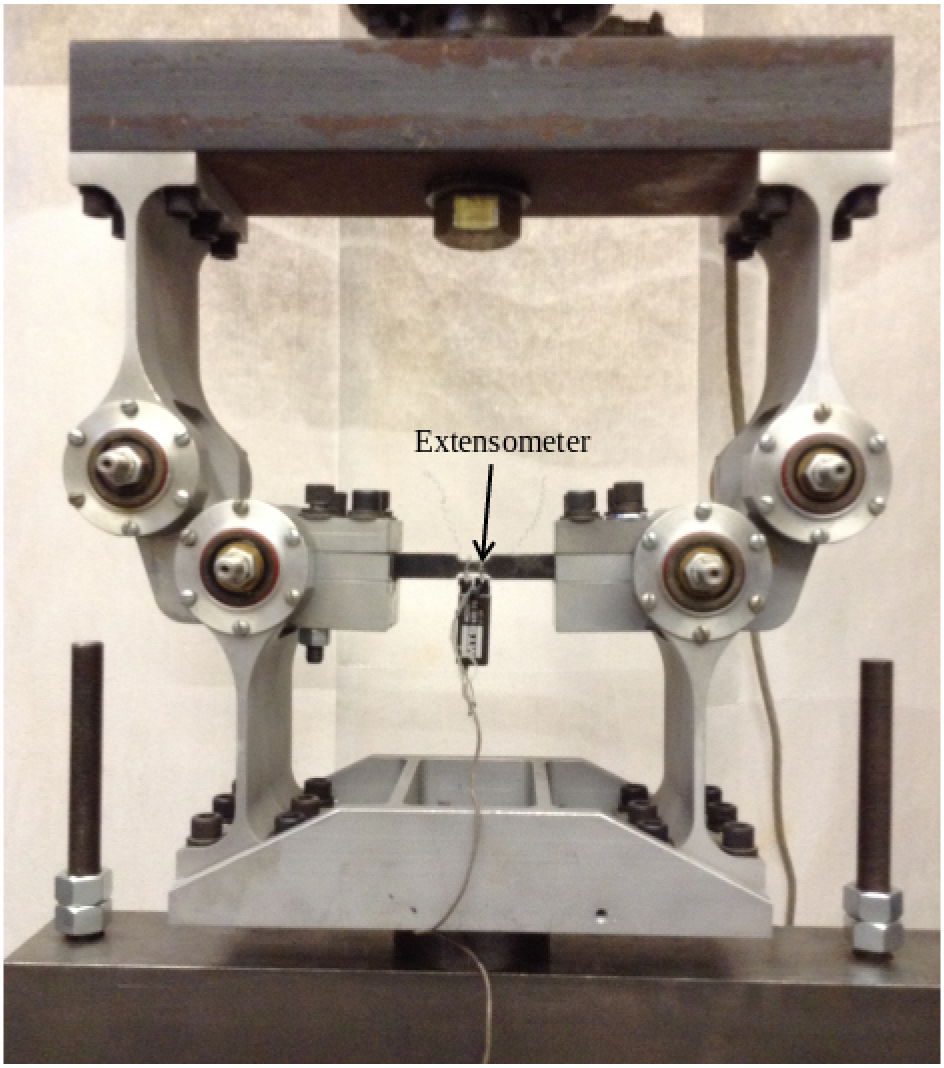

Figure 4: Extensometer installed on the bending specimen to measure the strain

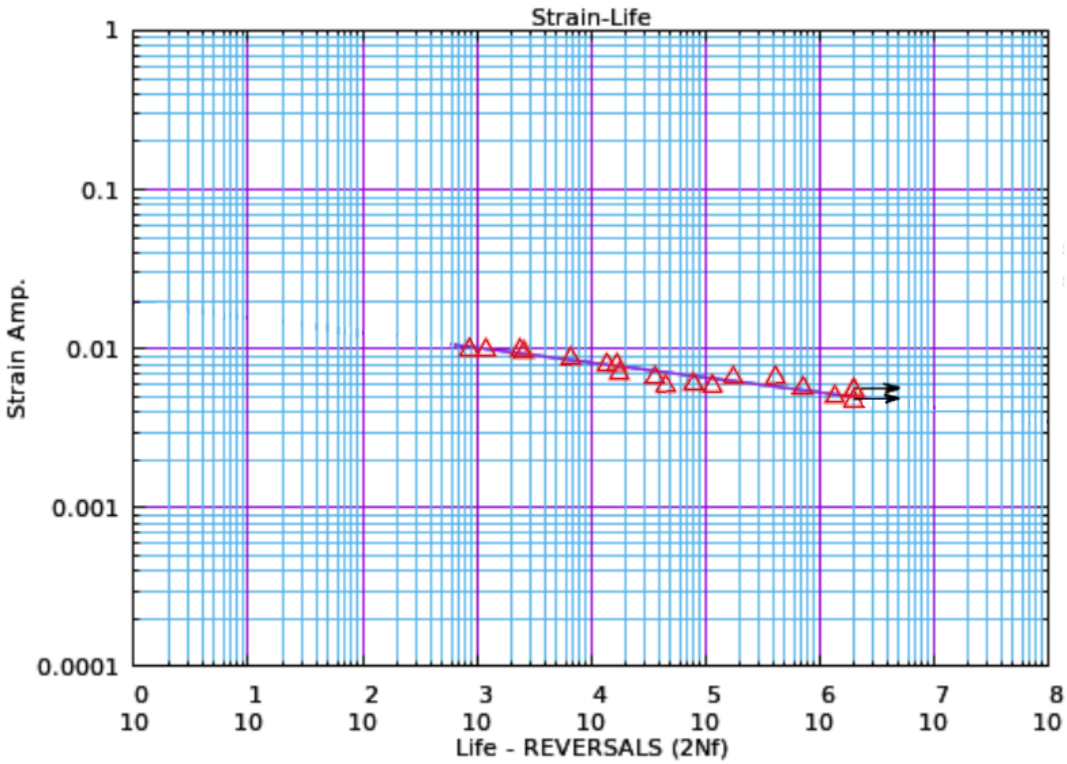

Figure 5: Strain-life fatigue curves for AISI 9310 (IT 180)

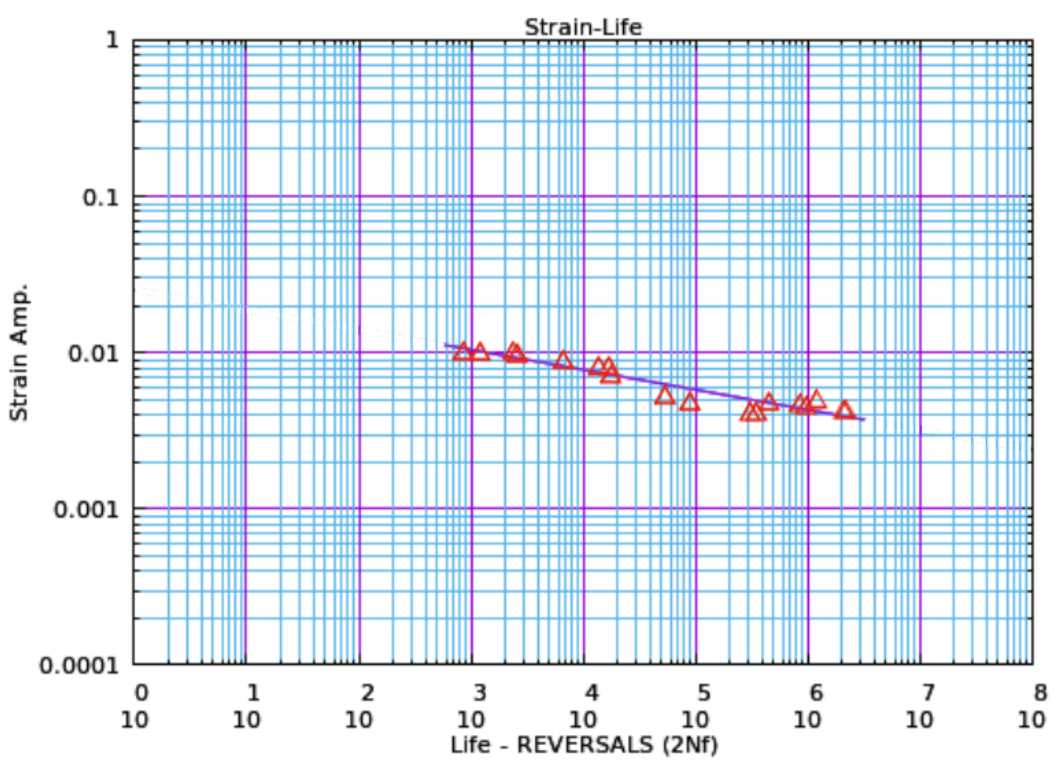

Figure 6: Strain-life fatigue curves for AISI 9310 (IT 181)

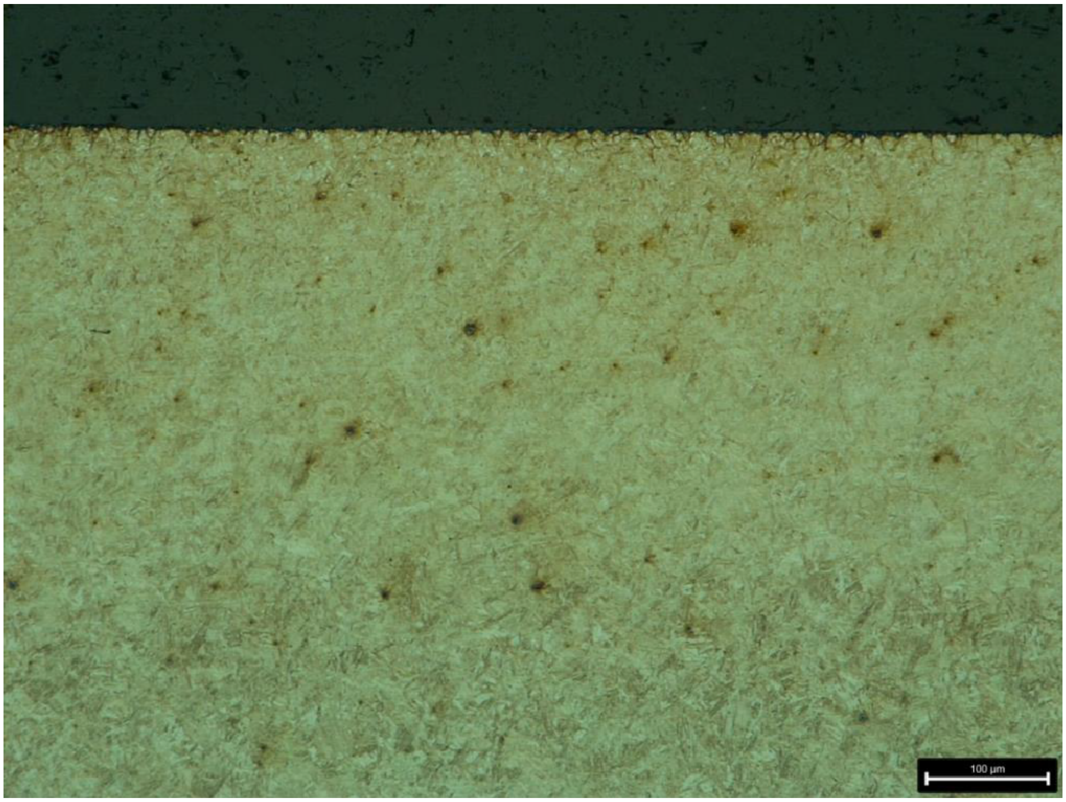

Figure 7: General microstructure at the surface of iteration 180/181 at 500X (Micrographs provided by FCA)

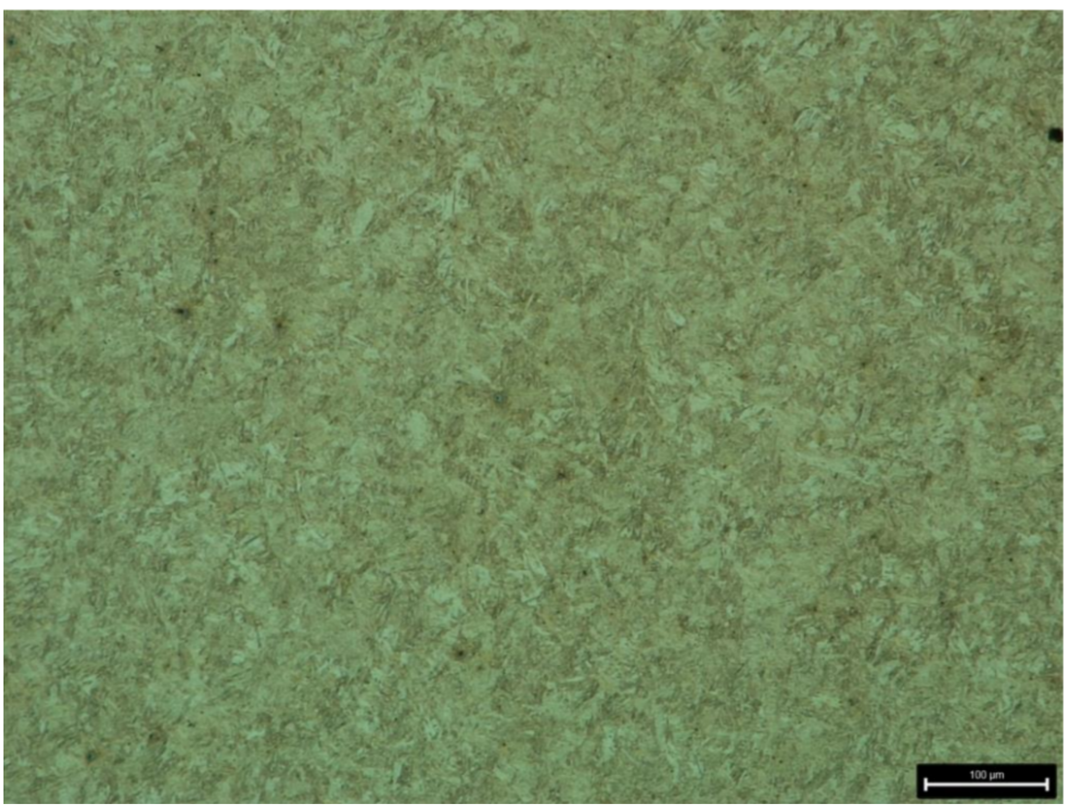

Figure 8: General microstructure in the core of iteration180/181 at 500X (Micrographs provided by FCA)

Figure 9: Fracture surface of specimen IT180-7

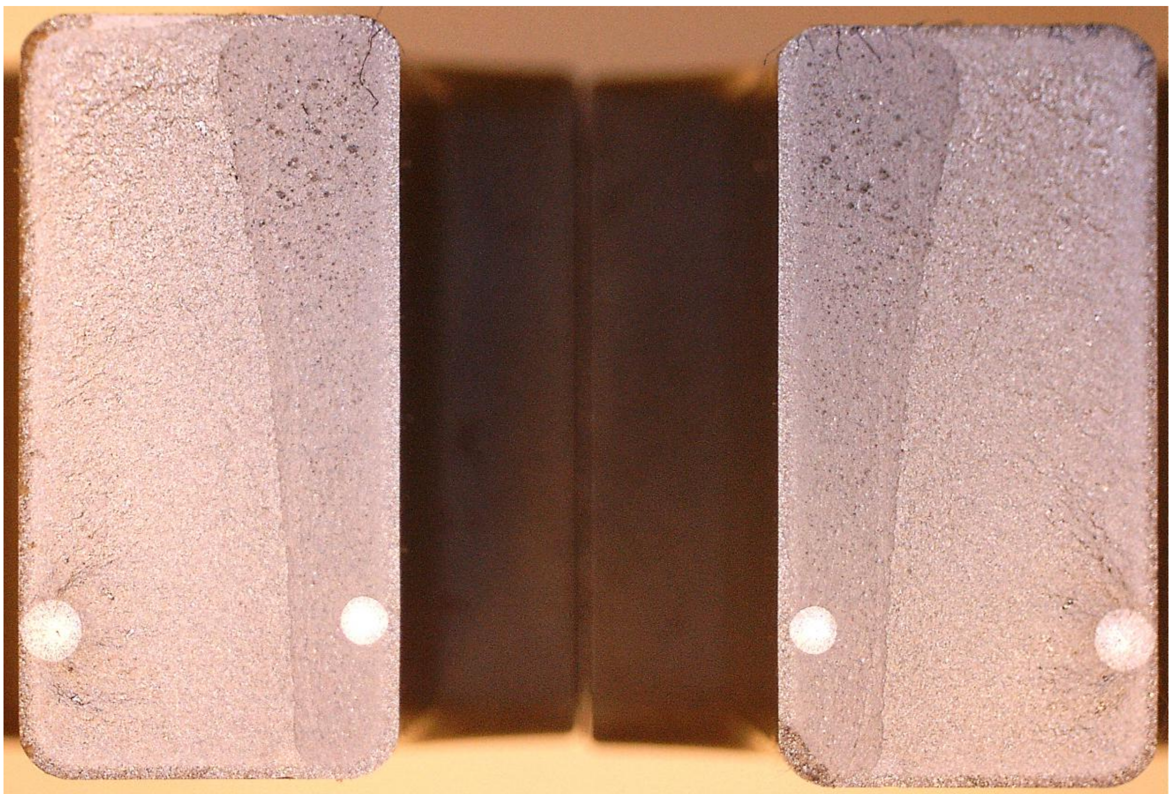

Figure 10: Fracture surface of specimen IT180-11
(Dark region is due to fast fracture when specimen crack was opened after end of test)

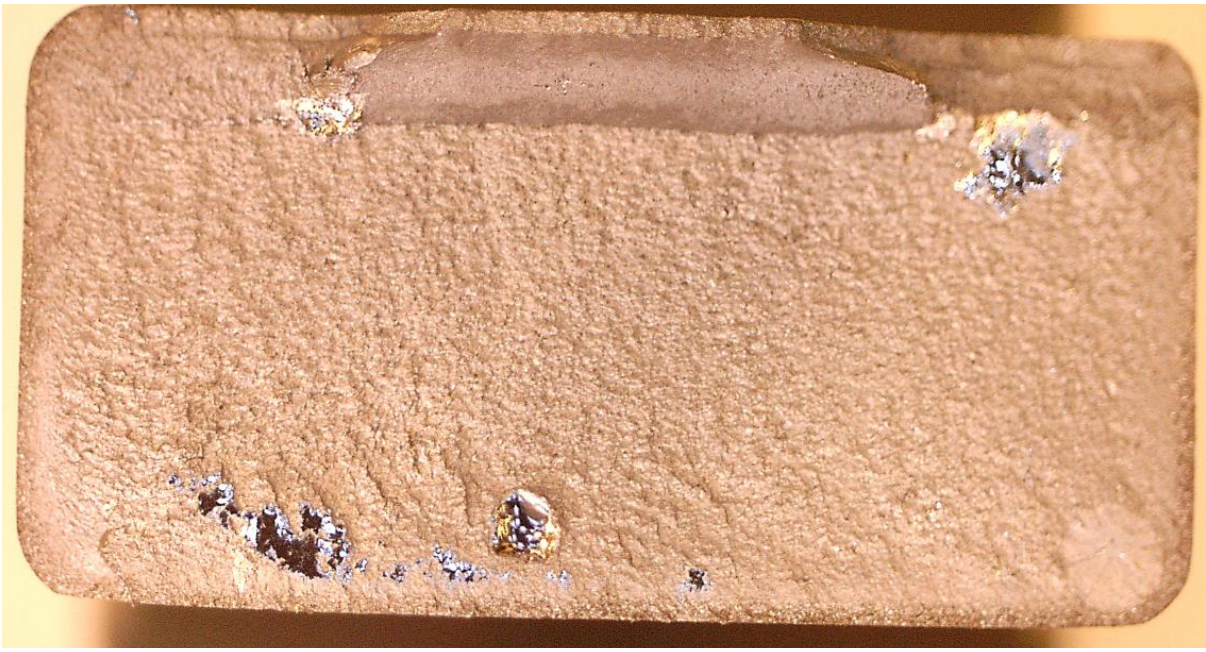

Figure 11: Fracture surface of specimen IT180-12 (Note "Fisheye" at lower right. Dark spots are from impacts on extensometer clips that entering crack during final failure cycles)

Figure 12: Fracture surface of specimen IT181-1

Figure 13: Fracture surface of specimen IT181-2

Figure 14: Fracture surface of specimen IT181-7

Figure 15: Fracture surface of specimen IT181-10

Table 1: Chemical Analysis (Bar Average) for AISI 9310 Steel (Iterations 180 and 181)

C	0.12
Mn	0.62
P	0.007
S	0.014
Si	0.19
Ni	3.12
Cr	1.11
Mo	0.09
Cu	0.16
Sn	0.008
Al	0.022
V	0.003
B	0.0002
Ca	0.0012
N	0.0066
As	0.004

Table 2: Constant Strain Amplitude Data for AISI 9310 Steel (IT180)

#StrAmp	2Nf	StressAmpl*	MeanStress*	PlsStr	Modulus**	Comments		Spec ID***
#		ksi	ksi		ksi			
0.0057	2000000	147.36	0	0	26019	#runout	#fisheye	7
0.0067	415120	165.84	0	0	24808		#fisheye	11
0.0058	734280	147.84	0	0	25416		#fisheye	15
0.0060	46260	150.96	0	0	25162		#fisheye	7B
0.0073	17970	187.44	0	0	25825			2
0.0051	1388398	134.16	0	0	26531			3
0.0082	16944	190.56	0	0	23307			4
0.0090	6738	199.2	0	0	22159			5
0.0068	180098	171.6	0	0	25292			6
0.0100	2366	231.36	0	0	23106			8
0.0082	13910	197.76	0	0	24029			9
0.0067	37144	171.12	0	0	25482			10
0.0056	2000000	146.16	0	0	25915	#runout		12
0.0061	79740	157.68	0	0	25924			13
0.0048	2000000	122.64	0	0	25564	#runout		14
0.0099	2578	230.4	0	0	23367			16
0.0100	1200	239.04	0	0	24004			17
0.0100	862	223.2	0	0	22219			1 (Calib2)
1.0059	118140	153.12	0	0	25955			14B

* "Stress" implies Stress = M*c /I where M is bending moment, c is half height of beam, and I is moment of inertia

** Modulus = (StressAmpl. / StrainAmpl.)

*** Some specimen IDs, have a digital number with a letter B, such as 9B, it means that specimen no.9 was tested at a low strain amplitude without failure, and then tested again at a higher strain amplitude and given the label "9B"

Table 3: Overload Test Data for AISI 9310 Steel (IT 181)

#StrAmp #	2Nf	StressAmpl* ksi	MeanStress* ksi	PlsStr	Modulus** ksi	Comments	Spec ID
0.01005	862	223.2	0	0	22219	#CA	1 (Calib2)
0.00996	1200	239.04	0	0	24004	#CA	17
0.01001	2366	231.36	0	0	23106	#CA	8
0.00986	2578	230.4	0	0	23367	#CA	16
0.00899	6738	199.2	0	0	22159	#CA	5
0.00823	13910	197.76	0	0	24029	#CA	9
0.00818	16944	190.56	0	0	23307	#CA	4
0.00726	17970	187.44	0	0	25825	#CA	2
0.00409	354736	103.92	0	0	25429	#fisheye	1
0.005	1186571	125.04	0	0	25013	#fisheye	2
0.00472	864454	119.76	0	0	25362	#fisheye	7
0.00475	442388	121.2	0	0	25530	#fisheye	10
0.00522	54480	133.44	0	0	25546		3
0.00449	987800	117.36	0	0	26118		4
0.00421	2229841	107.76	0	0	25590		5
0.0048	88265	125.04	0	0	26061		6
0.00411	305057	106.08	0	0	25825		8
0.00421	2066465	108.24	0	0	25703		9

Table 4: Rockwell C Hardness Test Data for AISI 9310 Steel

Specimen ID	Test 1	Test 2	Test 3	Average
IT181-2	51	52	50	51
HRC 1	52	53	53	52.67
180-D1	51	52	47	50
HRC2	53	52	52	52.33

* Specimens of which ID containing “HRC”
were not tested in fatigue.