Fatigue Behavior and Monotonic Properties

For

AISI 16MnCr5 Steel
Four Point Bending

Iteration 190 & 191

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Summary

The required strain-life fatigue data for AISI Iterations 190 & 191 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. The Rockwell C hardness (RC) was determined as the average of nine 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 16MnCr5 Steel specimens (Iteration 190 & 191). The American Iron and Steel Institute provided the material. The objective of this investigation is to obtain the strain-life curve of the material under a four point bending cyclic test.

Experimental Procedure

Specimen Preparation

The material for this study was received in the form of bars. Bending fatigue specimens, shown in Figure 1, were machined from the 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

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 bending rig was installed in the hydraulic testing machine as shown in Figure 2. An extensometer was installed on the bending specimen to measure the strain as shown in Figure 3.

A process control computer, controlled by FLEX software [1] was used to output constant stroke amplitudes.

Results

Chemical Composition

The chemical composition as provided by Gerdau 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 20 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 4.

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 [2]. This effective strain-life curve is derived from periodic overload tests consisting of two blocks of repeated load cycles. The first block consists of a single R=-1 overload (tensile and compressive overload peaks) cycle, and it 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 [3] and the equivalent failure life of the small cycles in each test was calculated. The overload fatigue data are given in Table 3. The equivalent strain-life fatigue curve is shown together with constant amplitude fatigue life curve in Figure 4.

References

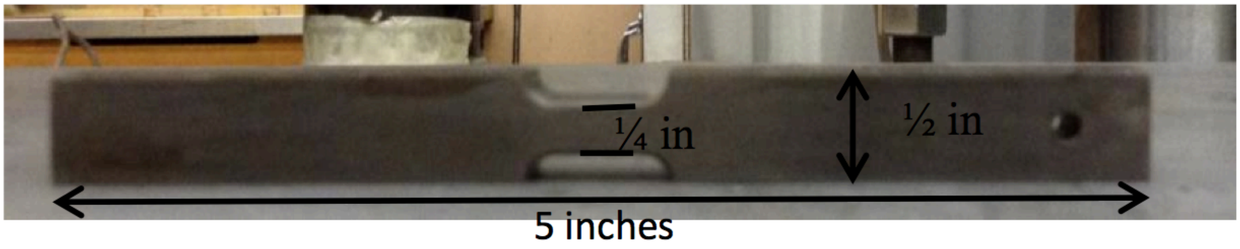
[1] M. Pompetzki, R. Saper, T. Topper, Software for rig frequency control of variable amplitude fatigue tests, Canadian Metallurgical Quarterly 25 (2) (1987) 181-194

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

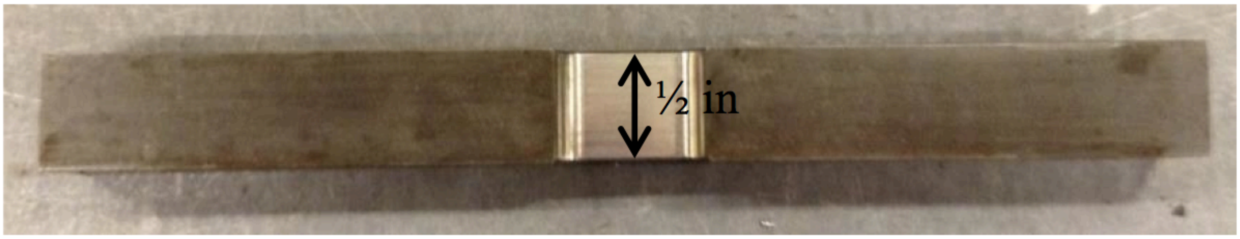
[3] I. Stephens, Metal Fatigue in Engineering, Second edition, John Wiley & Sons, 2001

Note:

Some specimen IDs, have 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).



(1-a) Bending specimen side view



(1-b) Bending specimen top view

Figure 1: Bending Fatigue Specimen

Figure 2: Bending Rig in the testing frame

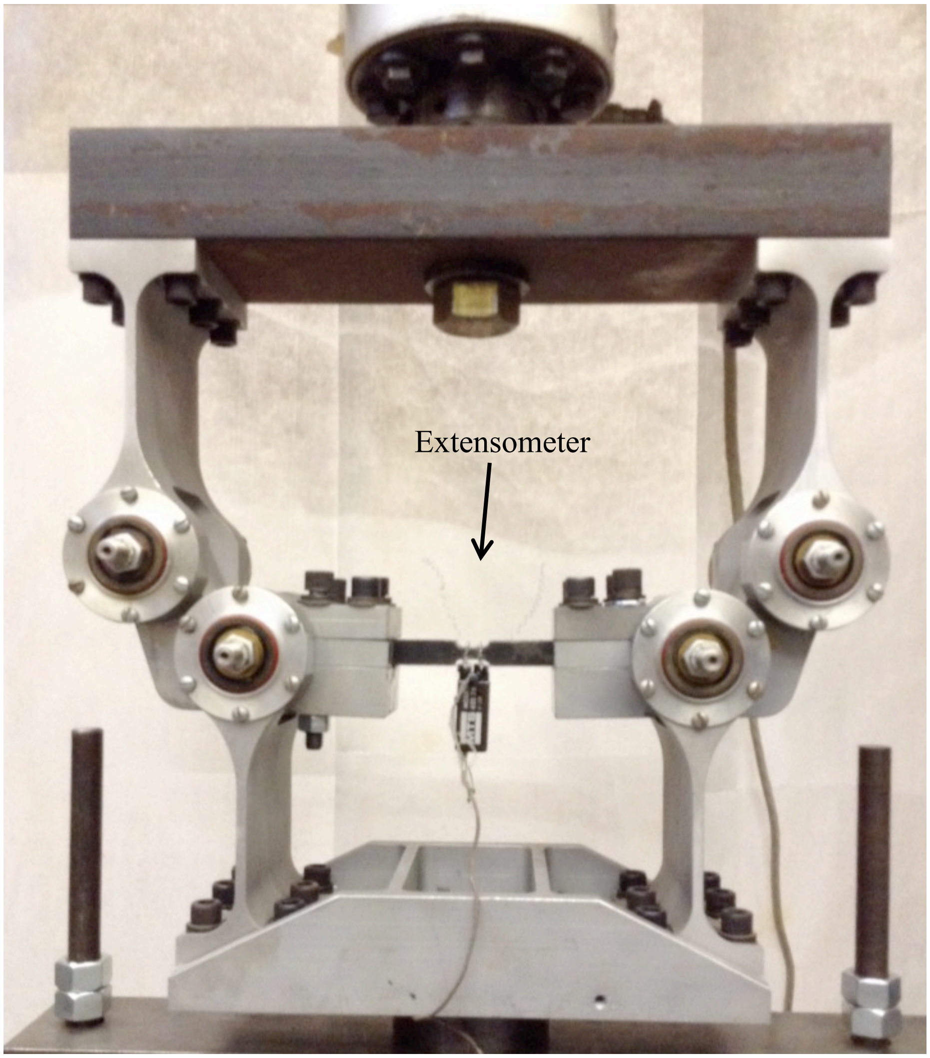


Figure 3: Extensometer installed on the bending specimen to measure the strain

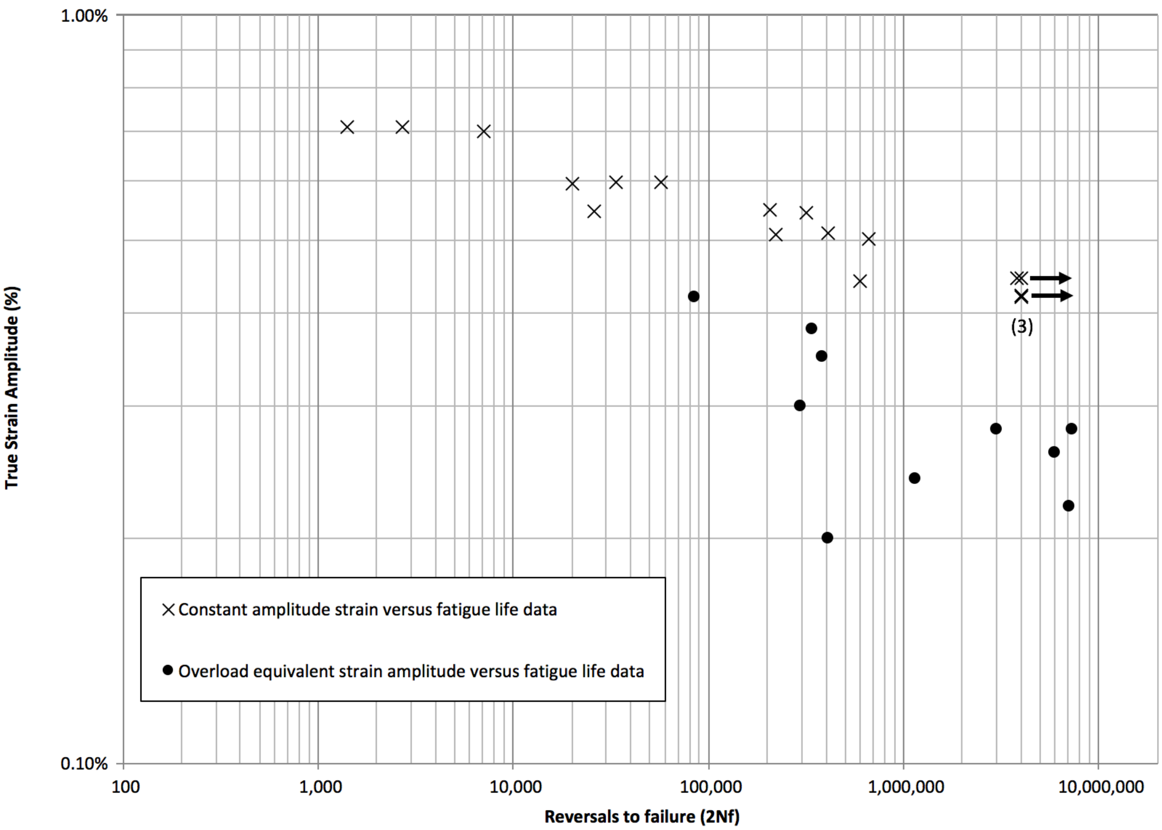


Figure 4: Strain-life fatigue curves for AISI 16MnCr5 (IT 190 & 191)

Figure 7: Microstructure of Iteration 190/191, low magnification.

Figure 8: Microstructure of Iteration 190/191, high magnification.

Table 1: Chemical Analysis (Bar Average) for AISI 16MnCr5 Steel (Iterations 190 and 191)

C	**0.16**
Mn	**1.22**
P	**0.018**
S	**0.034**
Si	**0.07**
Ni	**0.11**
Cr	**1.06**
Mo	**0.04**
Cu	**0.23**
Sn	**0.010**
Al	**0.020**
V	**0.002**
Nb	**0.002**

Table 2: Constant Strain Amplitude Data for AISI 16MnCr5 Steel (IT 190)

Specimen ID	Strain amplitude (%)	Load amplitude (lb)	Reversals to Failure (2Nf)	Hardness (HRC)
2	0.699	1,095.0	7,050	51.7
3	0.599	820.3	33,818	52.4
4	0.550	887.7	208,080	52.8
5	0.514	827.8	220,758	
6	0.514	819.0	407,974	
7	0.445	719.2	3,843,144	
8	0.445	726.7	4,000,000	
9	0.445	722.9	596,534	
10	0.422	686.7	4,000,000	
11	0.427	701.7	4,000,000	
12	0.427	681.7	4,000,000	
12B	0.711	1,088.7	1,406	
13	0.503	503.2	658,092	
11B	0.711	1,131.2	2,722	
10B	0.599	968.9	19,978	
14	0.605	963.9	57,548	
15	0.544	895.2	26,184	
16	0.538	892.7	318,368	

**Hardness obtained as average of three readings*

Table 3: Overload Strain Amplitude Data for AISI 16MnCr5 Steel (IT 191)

Specimen ID	Regular cycle	Overload cycle	Number of small cycles	Total reversals (2Nf)	Equivalent small cycle reversals
	Strain amplitude (%)	Strain amplitude (%)			
17	0.42	0.60	50	73,606	84,334
18	0.35	0.60	50	220,480	380,768
19	0.30	0.60	500	279,776	295,732
20	0.26	0.60	500	2,716,746	5,923,343
22	0.24	0.60	500	934,848	1,147,010
23	0.22	0.60	500	2,939,718	7,099,801
24	0.28	0.60	500	2,966,970	7,261,200
25	0.38	0.60	50	206,928	341,384
26	0.20	0.60	1000	391,984	407,552
27	0.28	0.60	2000	2,591,630	2,975,743