Fatigue Behavior, Monotonic Properties
and
Microstructure Data
for
1070, As Received Steel
(Iteration No. 36)

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SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for 1070 As Received steel (Iteration No. 36) have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of 2" bars. These bars were machined into smooth axial fatigue specimens. The specimens were tested as received with a hardness of about 30 Rc. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Twenty-two specimens were fatigue tested in laboratory air at room temperature to establish a strain-life curve.

INTRODUCTION

This report presents the results of tensile and fatigue tests performed on a group of 24, 1070 As Received steel samples. The material was provided by the American Iron and Steel Institute.

The objectives of this investigation were to obtain the chemical analysis, and microstructural data, mechanical properties, cyclic stress-strain data and strain-life fatigue data requested by the AISI bar group.

EXPERIMENTAL PROCEDURE

Specimen Preparation

The material for the study was received in the form of bars. Smooth cylindrical fatigue specimens, shown in Figure 1, were machined from the metal bars. The gauge sections of the fatigue specimens were mechanically polished in the loading direction using 240, 400, 500, and 600 emery paper. After polishing, 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. In total, 22 fatigue data points were generated.

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 electrohydraulic testing machine. A process control computer, controlled by FLEX software [1] was used to output constant strain and stress amplitudes in the form of a sinusoidal wave.

Axial, constant amplitude, fully reversed (R=-1) strain-controlled fatigue tests were performed on smooth specimens. The stress-strain limits for a given cycle of 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 tensile peak load from the peak load observed at one half the expected specimen life. For fatigue lives greater than 100,000 reversals, the specimens were tested in stress-control once the stress-strain loops had stabilized. For the stress-controlled tests, failure was defined as the separation of the smooth specimen into two pieces. For strain-controlled tests the loading frequency varied from 0.03 Hz to 5 Hz while in stress-controlled tests the frequency used was up to 110 Hz.

The first reversal of each fatigue test was recorded on a x-y plotter, allowing the elastic modulus (E) and the monotonic yield strength to be determined.

RESULTS

A) Microstructure Data

Figure 2 presents the 69% Pearlite and 31% Ferrite microstructure of the 1070 As Received steel. A Type D inclusion severity level of 1 was obtained based on ASTM E45 (Method A). Inclusions of types A, B and C were not observed. Figure 3 shows the inclusions observed in the 1070 As Received steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 1070 As Received steel was provided by the USS KOBE Steel Company, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for 1070 As Received steel obtained in this investigation are given in Table 2. The stress amplitude corresponding to each strain-amplitude was calculated from the peak load amplitude at the specimen half-life.

A fatigue strain-life curve for the 1070 As Received steel is shown in Figure 4, and is described by the following equation:

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

where $\frac{\Delta\varepsilon}{2}$ = True total strain amplitude
$2N_f$ = Number of reversals to failure
σ'_f = Fatigue strength coefficient
b = Fatigue strength exponent
ε'_f = Fatigue ductility coefficient
c = Fatigue ductility exponent

Where $\sigma'_f = 1289$ MPa, $b = -0.092$, $\varepsilon'_f = 0.361$ and $c = -0.494$. These values of the strain-life parameters were determined from fatigue testing over the range: $0.0022 < \frac{\Delta\varepsilon}{2} < 0.02$.

C) Cyclic Stress-Strain Curves

Stabilized and half-life stress data obtained from strain-life fatigue tests were used to obtain the companion cyclic stress-strain curve shown in Figure 5. The cyclic stress-strain curve is described by the following equation:

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

where ε = True total strain amplitude
σ = Cyclically stable true stress amplitude
K' = Cyclic strength coefficient
n' = Cyclic strain hardening exponent

Where $K' = 2176$ MPa and $n' = 0.247$.

D) Mechanical Properties

The engineering monotonic stress-strain curve is given in Figure 6. The monotonic and cyclic properties are included in Appendix 1. The Hardness of the 1070 As Received steel was taken as the average of three randomly chosen fatigue specimens and is given in Appendix 1. The individual hardness measurements are also given in Table 2. The true monotonic and true cyclic stress-strain curves plotted together are given in Figure 7.

REFERENCES

[1] Pompetzki, M.A., Saper, R.A., and Topper, T.H., "Software for High Frequency Control of Variable Amplitude Fatigue Tests," Canadian Metallurgical Quarterly, Vol. 25, No. 2, pp. 181-194, 198.

[2] J. A. Bannantine, J. J. Comer, and J. L. Handrock (1990), In :Fundamentals of Metal Fatigue Analysis, Prentice Hall, London.

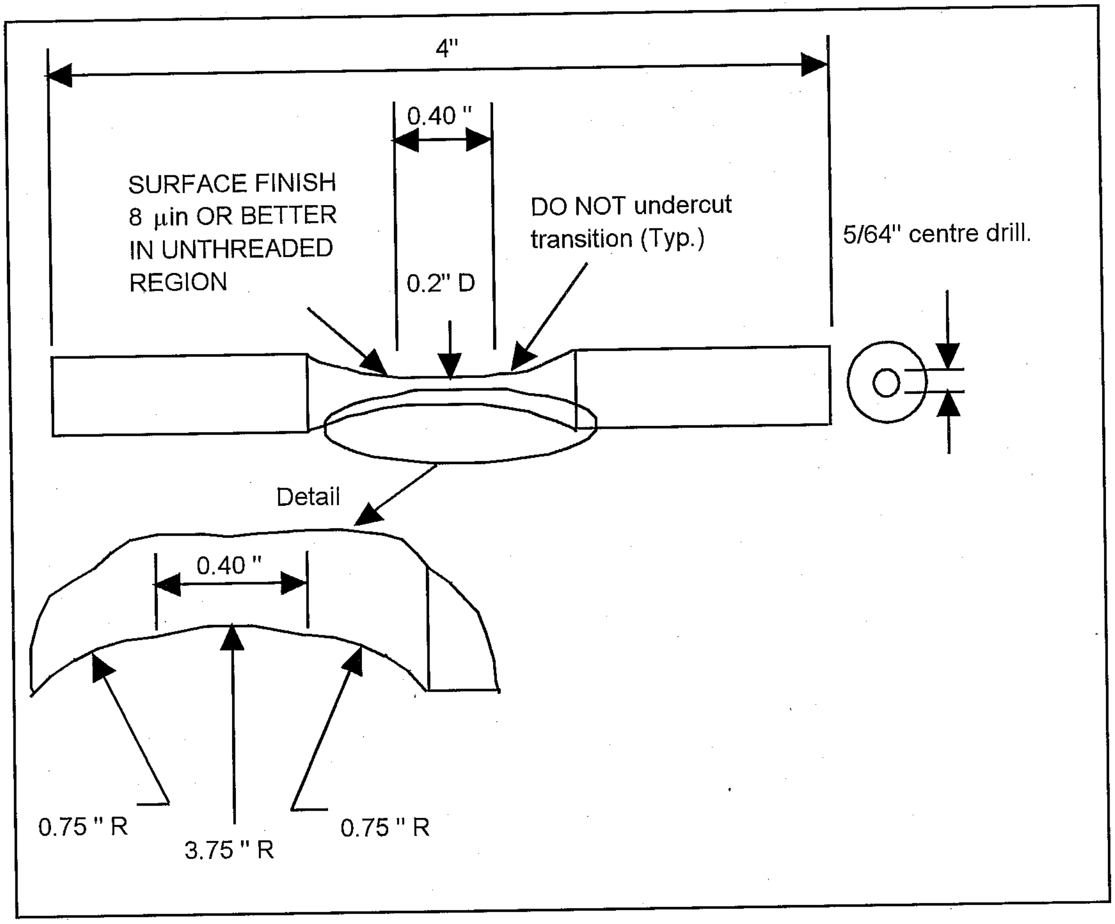
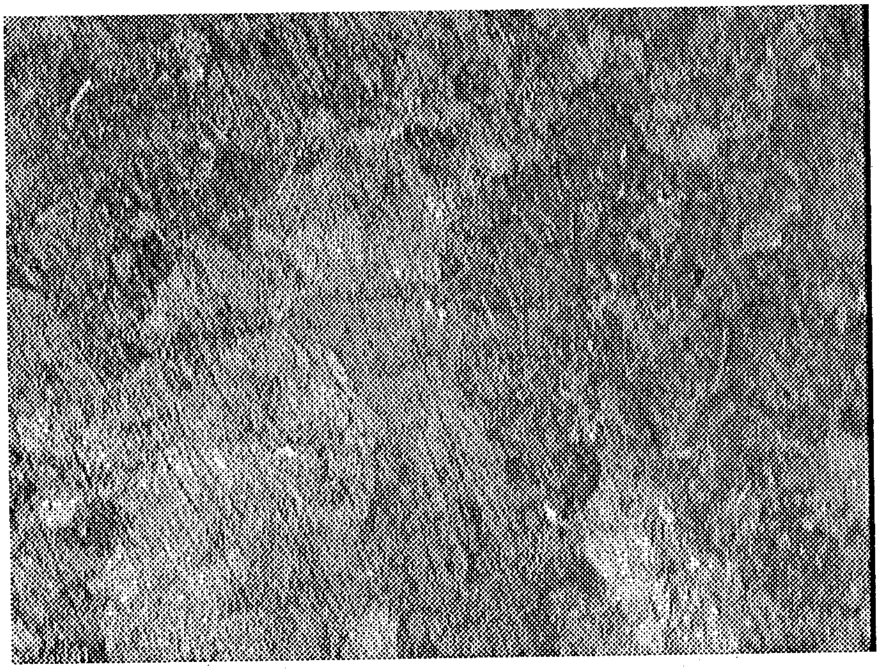
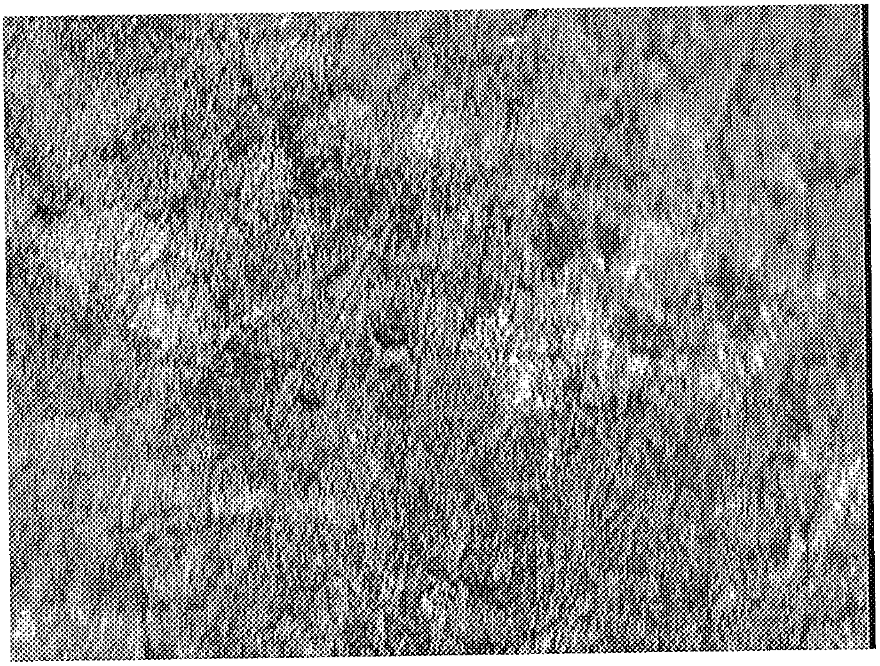


Fig. 1 Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

Fig. 2 Photomicrographs of 1070 As Received steel (X500)

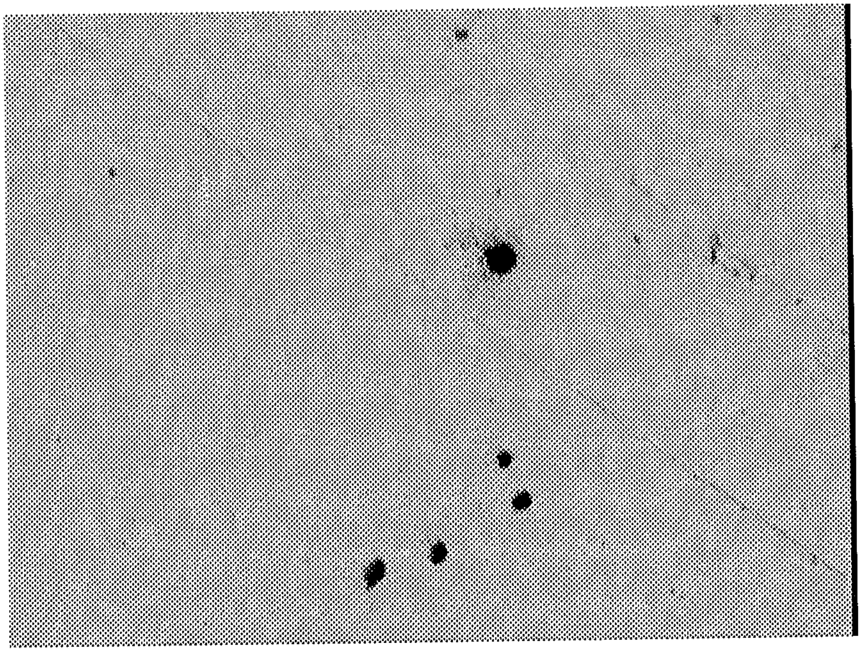


Fig. 3 Inclusions photomicrograph of 1070 As Received steel (X500)

Iter 36 1070 Core 500X

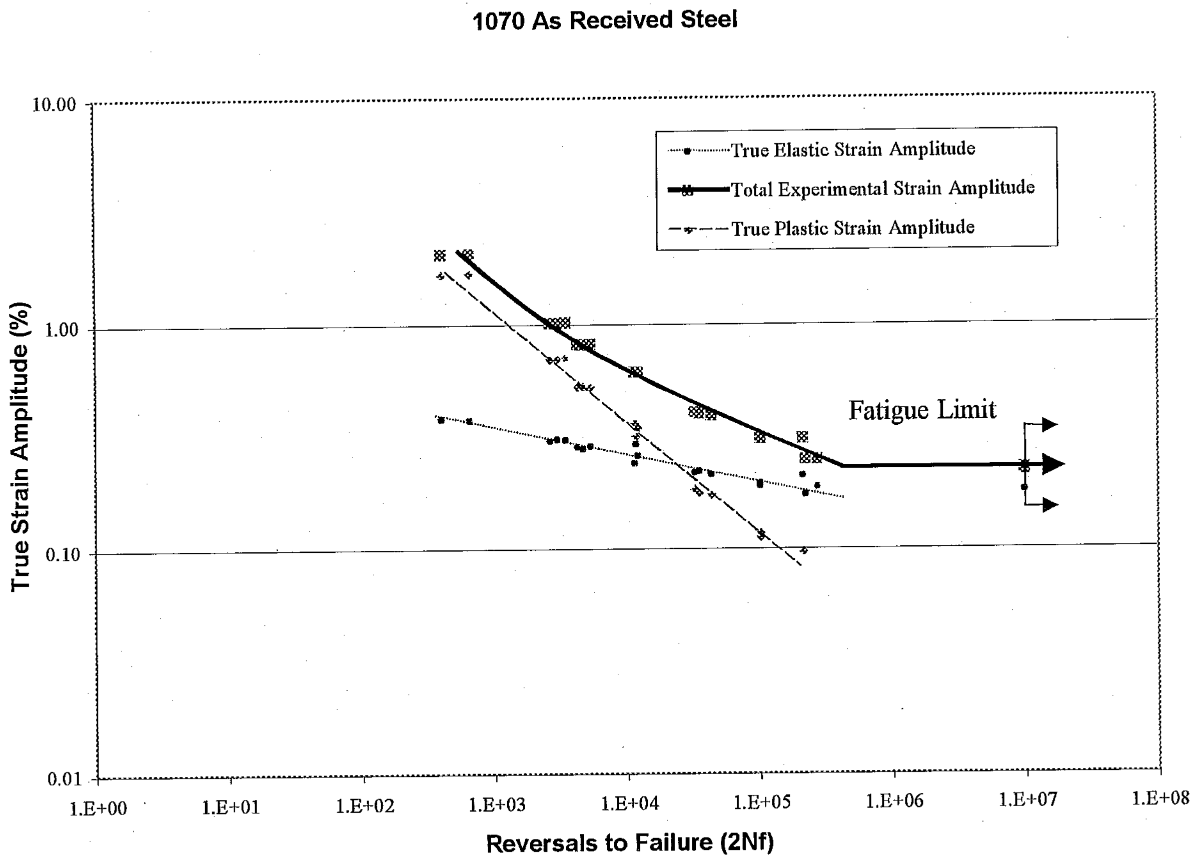


Figure 4. Constant amplitude fully reversed strain-life curve for 1070 As Received steel.

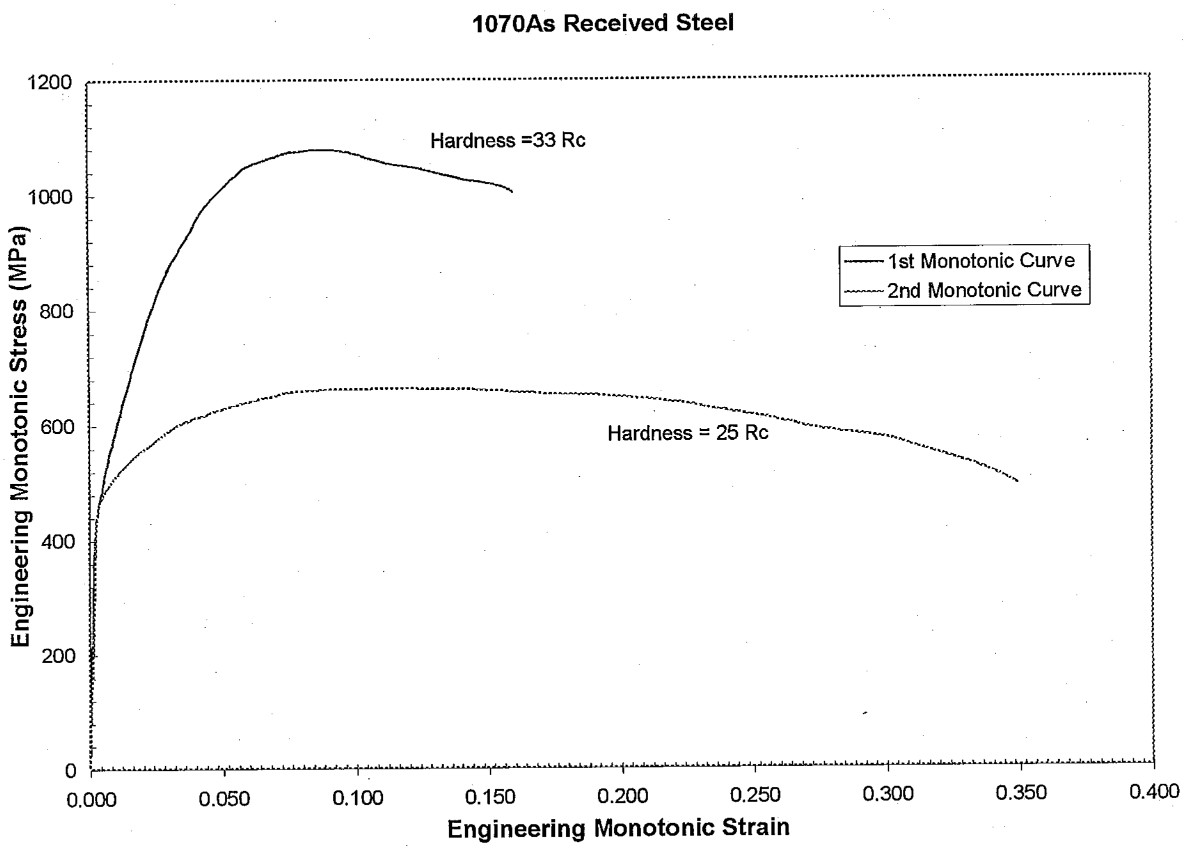


Figure 5. Monotonic stress-strain curves for two 1070 As Received steel specimens.

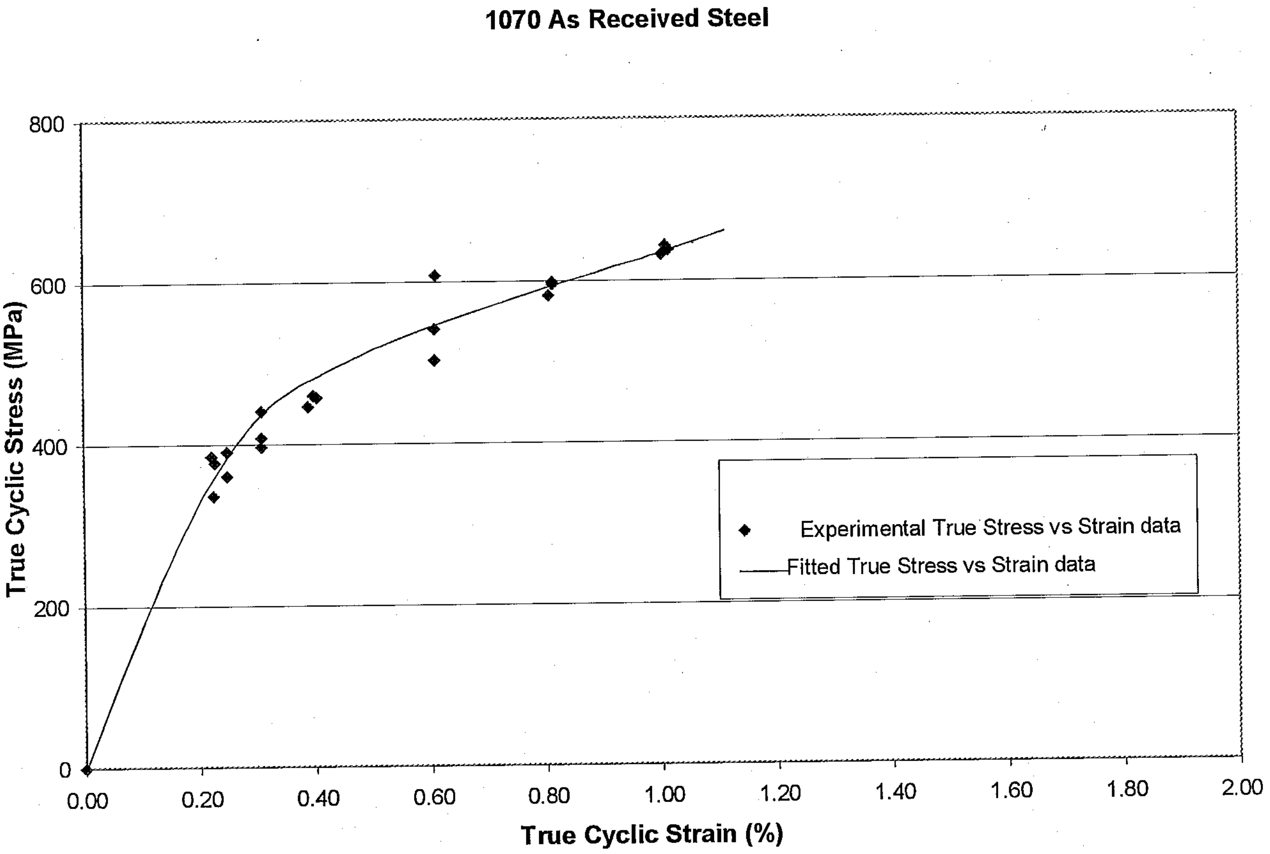


Figure 6. Cyclic stress-strain curve for 1070 As Received steel.

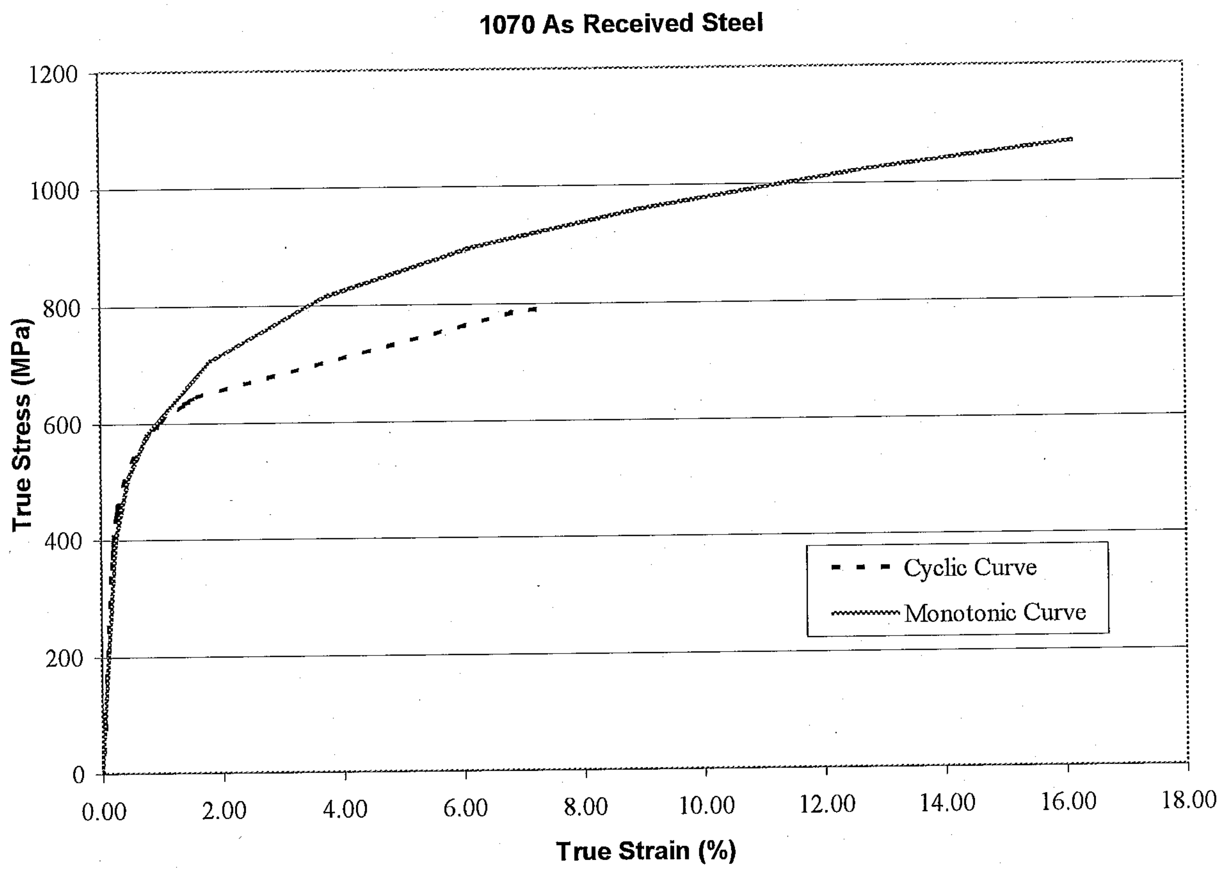


Fig. 7 Monotonic and Cyclic stress-strain curves for 1070 As Received steel.

Table 1 Chemical composition of 1070 As Received steel.

Carbon, C	0. 7%
Manganese, Mn	0.98%
Phosphorous, P	0.014%
Sulfur, S	0.024%
Silicon, Si	0.28%
Copper, Cu	0.015%
Nickel, Ni	0.01%
Chromium, Cr	0.11%
Molybdenum, Mo	0.049%
Sn	
Al	0.031%
Vanadium, Va	
N	33 PPM
Ti	
B	
Zn	
Pb	
Co	

Table 2 Tensile and Fatigue Test Data for 1070 As Received steel.

Sp#	Total Strain Amplitude(%)	Stress Amplitude (MPa)	Plastic Strain Amplitude(%)	Elastic Strain Amplitude(%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	MONOTONIC Young's Modulus(GPa)	Hardness (HRC)
1	2.049	784	1.672	0.377	660	206	28
19	2.034	790	1.654	0.380	404	207	32
3	1.015	638	0.708	0.307	3484	215	30
24	1.009	643	0.700	0.309	3022	212	26
27	1.003	632	0.699	0.304	2666	208	30
38	0.813	595	0.527	0.286	4304	211	31
23	0.813	598	0.525	0.287	5384	206	28
22	0.807	581	0.527	0.279	4726	207	32
18	0.610	608	0.318	0.292	11862	212	29
5	0.607	503	0.366	0.242	11640	211	26
8	0.607	541	0.347	0.260	12320	203	28
31	0.404	457	0.184	0.220	33066	204	26
20	0.398	460	0.177	0.221	35598	203	32
13	0.389	446	0.175	0.215	44002	207	33
15	0.309	396	0.118	0.191	102222	206	30
26	0.309	407	0.113	0.196	102642	210	30
14	0.309	441	0.097	0.212	216102	212	29
6	0.249	360	0.076	0.173	225688	206	33
12	0.249	391	0.062	0.188	278078	212	34
4*	0.228	377	0.047	0.181	10000000	210	33
2*	0.225	336	0.063	0.161	10000000	207	29
21*	0.222	385	0.037	0.185	10000000	209	33

* Run out

Appendix 1

Monotonic Properties for 1070 As Received steel.

Average Elastic Modulus, E = 207 GPa
Yield Strength = 520 MPa
Ultimate tensile Strength = 659 MPa
% Elongation = 25.1 %
% Reduction of Area = 36.2 %
True fracture strain, $Ln\ (A_i / A_f)$ = 45.9 %
True fracture stress, $\sigma_f = \dfrac{P_f}{A_f}$ = 1599 MPa
Bridgman correction, $\sigma_f = \dfrac{P_f}{A_f} \Big/ \left(1 + \dfrac{4R}{D_f}\right) Ln \left(1 + \dfrac{D_f}{4R}\right)$ =1360 MPa
Monotonic strength coefficient, K = 1485 MPa
Monotonic strain hardening exponent, n = 0.177
Hardness, Rockwell C (HRC) = 30
Hardness, Brinell = 280

Cyclic Properties for 1070 As Received steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ = 468 MPa
Cyclic strength coefficient, K' = 2176 MPa
Cyclic strain hardening exponent, n' = 0.247
Fatigue Strength Coefficient, σ'_f = 1289 MPa
Fatigue Strength Exponent, b = -0.092
Fatigue Ductility Coefficient, ε'_f = 0.361
Fatigue Ductility Exponent, c = -0.494

P_f:	Load at fracture.
A_i and A_f:	Specimen cross-section area before and after fracture.
R:	Specimen neck radius.
D_f	Specimen diameter at fracture.