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Fatigue Behavior, Monotonic Properties and Microstructure Data for Induction Hardened (Case) 1070 Steel (Iteration No. 37)

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SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for 1070 Induction Hardened (Case) steel (Iteration No. 37) 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 induction hardened at Daimler Chrysler Corporation to reach a hardness of about 60 Rc. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Twenty-three 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 23, 1070 Induction Hardened (Case) 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, 18 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 73% Pearlite and 27% Ferrite microstructure of the 1070 Induction Hardened (Case) steel. A Type D inclusion with 25% thick series severity level of 1 1/2 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 Induction Hardened (Case) steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 1070 Induction Hardened (Case) 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 Induction Hardened (Case) 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 Induction Hardened (Case) 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 σ'_f = 3466 MPa, b = -0.129, ε'_f = 0.136 and c = -0.926. These values of the strain-life parameters were determined from fatigue testing over the range: $0.0016 < \frac{\Delta\varepsilon}{2} < 0.01$.

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' = 2977 MPa and n' = 0.059.

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 Induction Hardened (Case) 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.

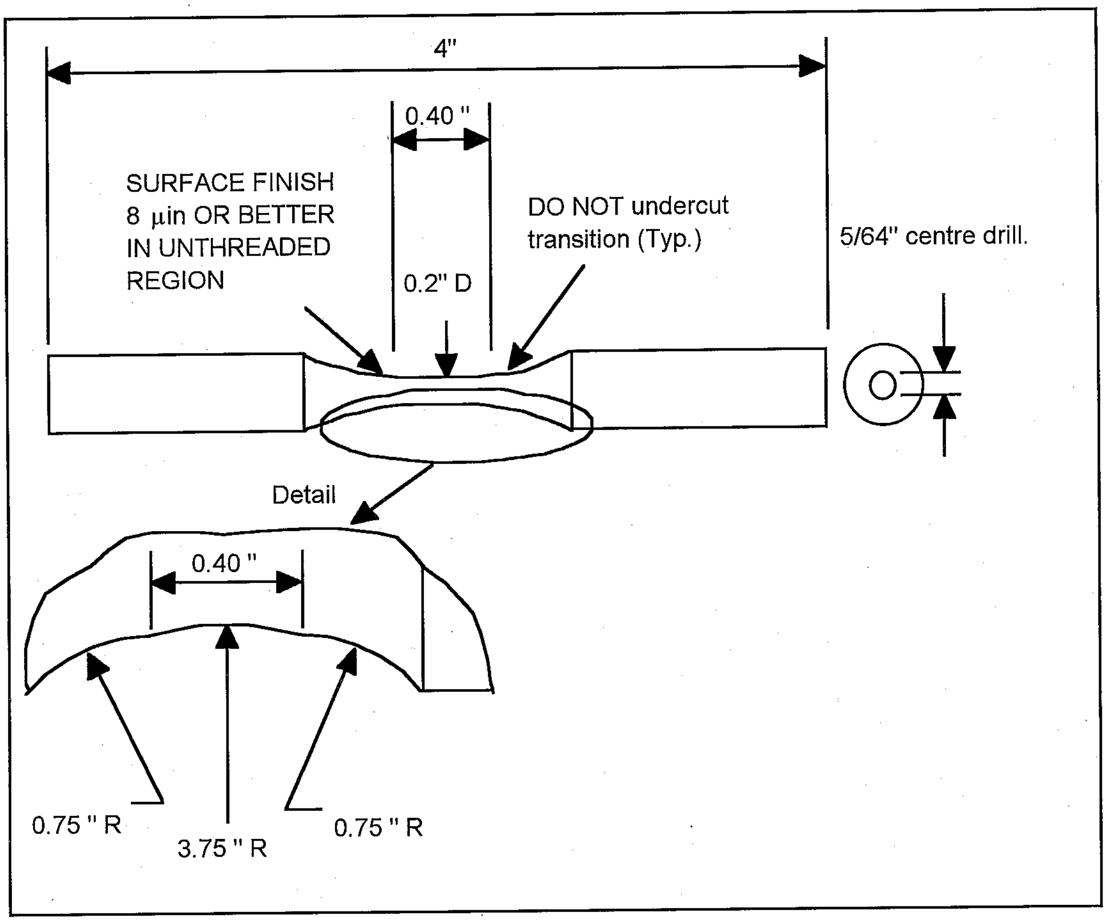
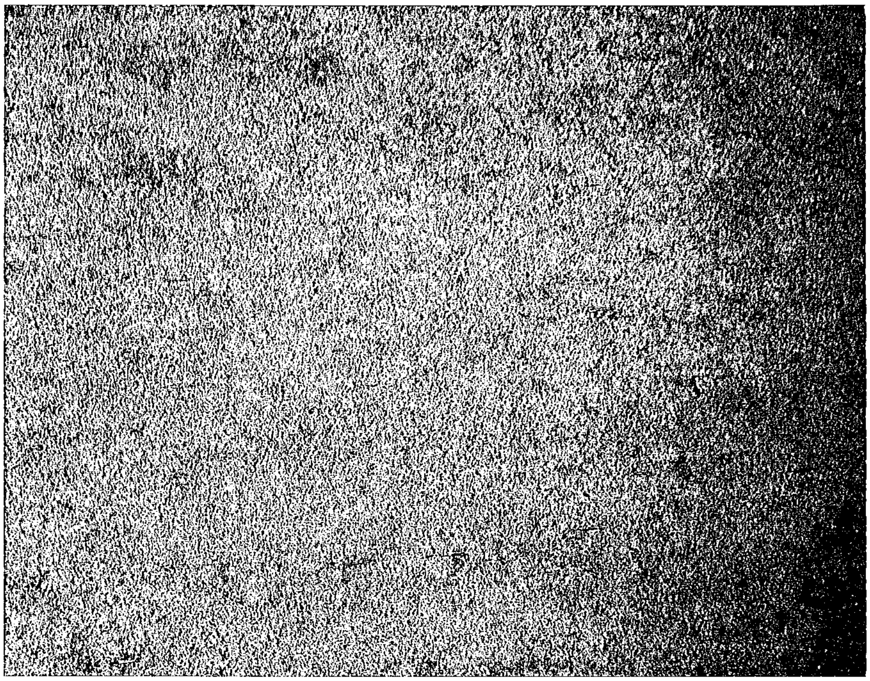
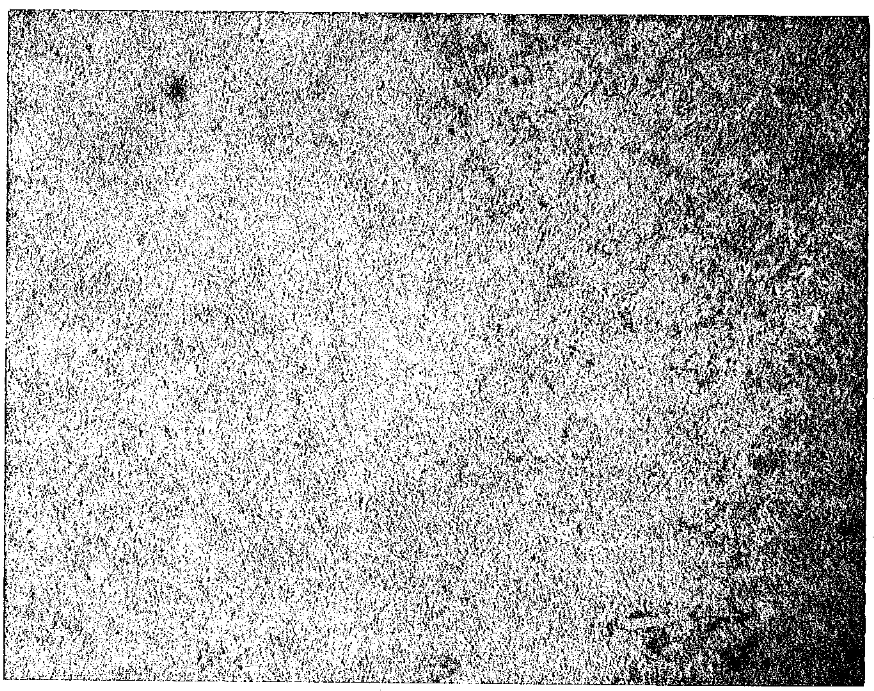
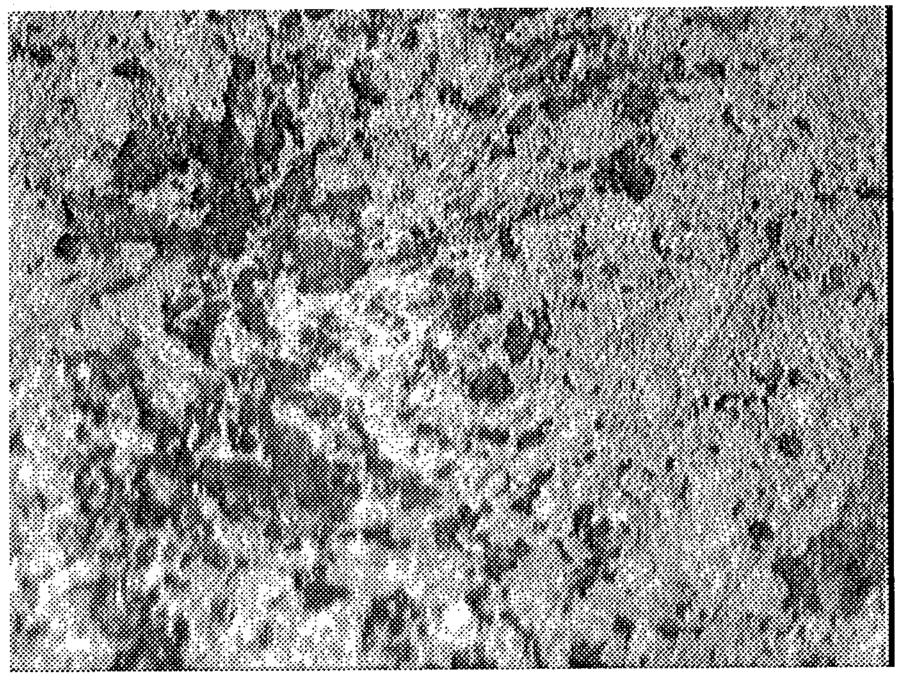


Fig. 1 Smooth cylindrical fatigue specimen

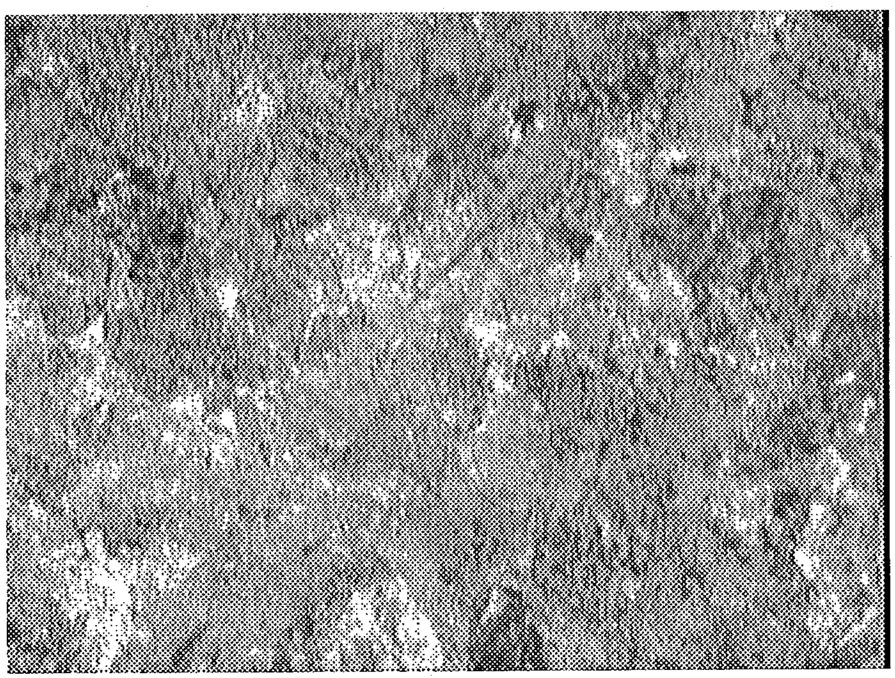




Iter 37 SAE 1070 Induction Hardened Case 100X 500X



(a) Longitudinal Direction



(b) Transverse Direction

Fig. 2 Photomicrographs of 1070 Induction Hardened (Case) steel (X500)

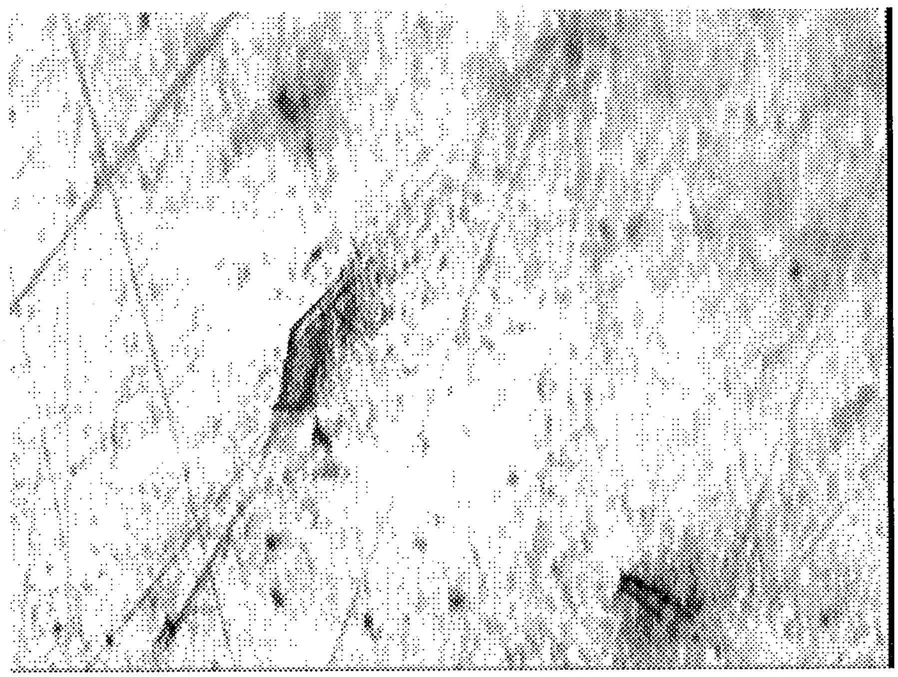


Fig. 3 Inclusions photomicrograph of 1070 Induction Hardened (Case) steel (X500)

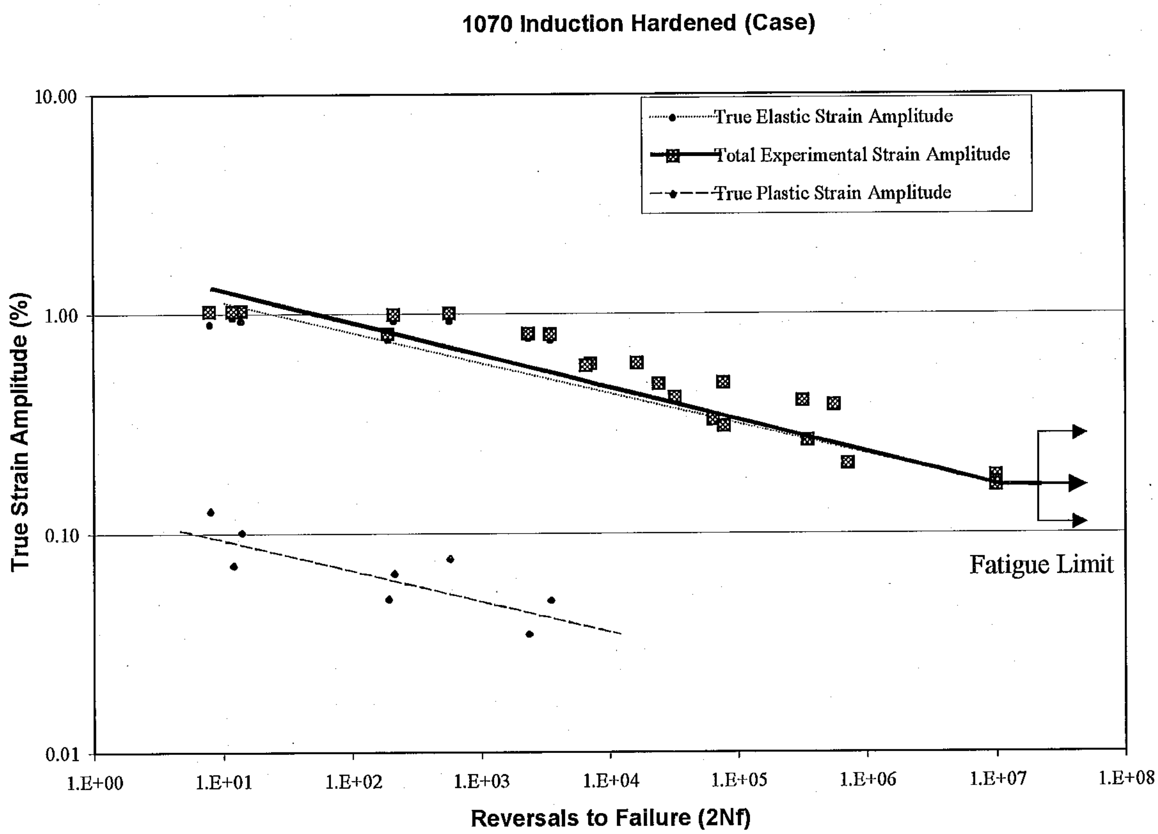


Figure 4. Constant amplitude fully reversed strain-life curve for 1070 Induction Hardened (Case) steel.

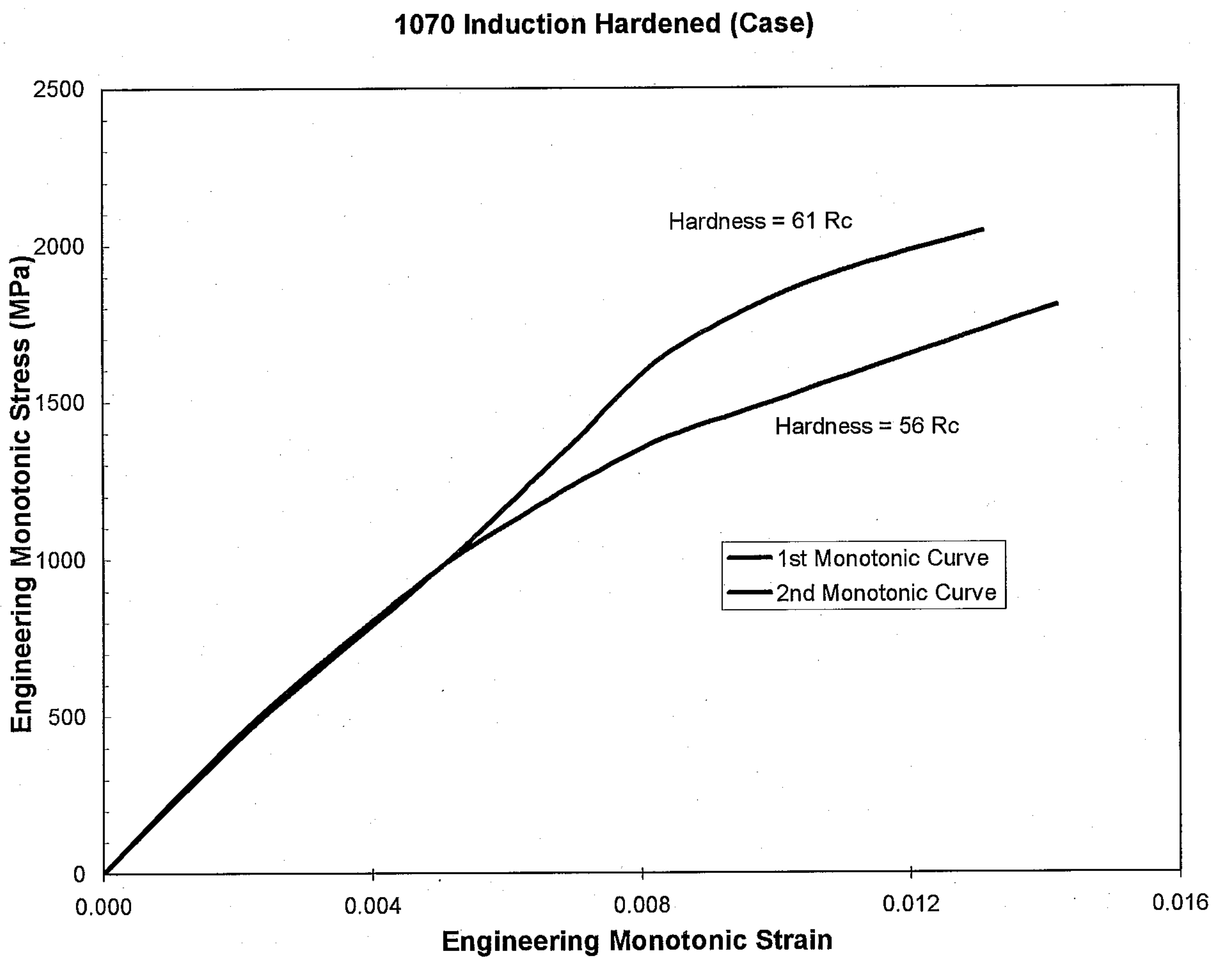


Figure 5. Monotonic stress-strain curve for 1070 Induction Hardened (Case) steel.

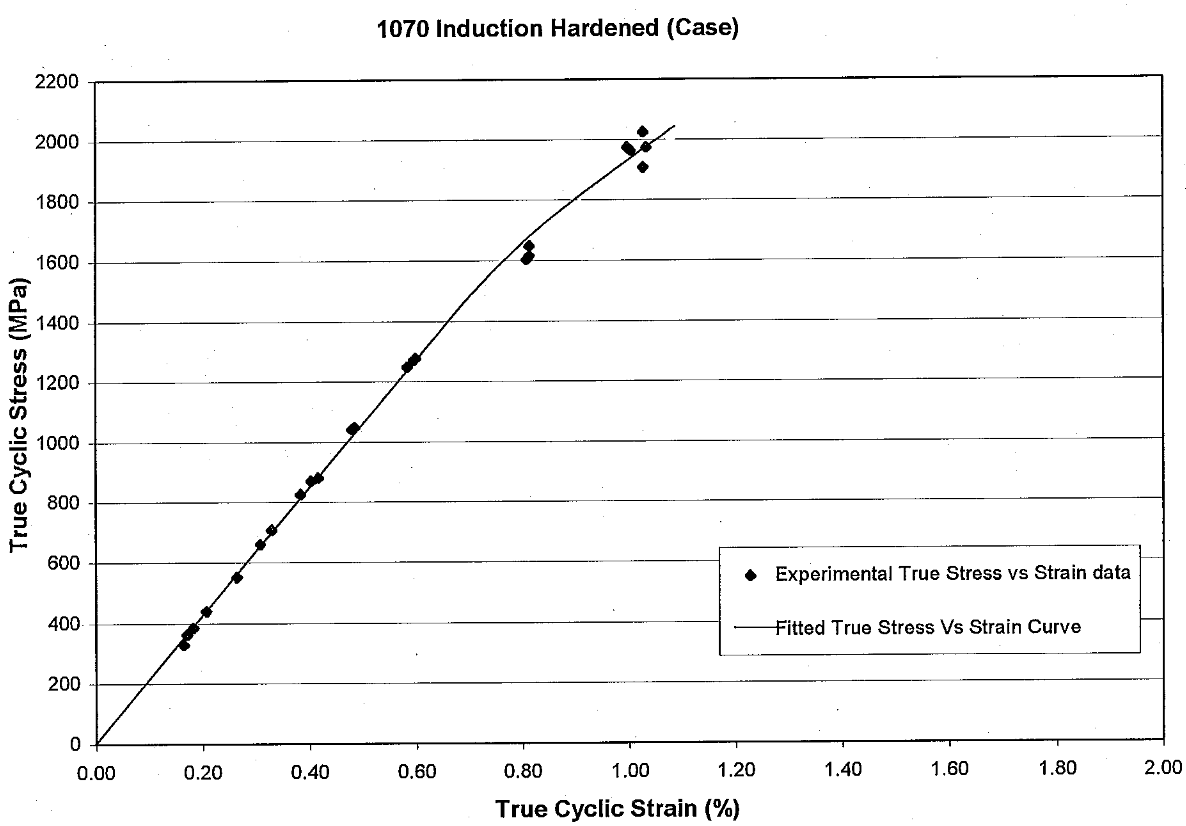


Figure 6. Cyclic stress-strain curve for 1070 Induction Hardened (Case) steel.

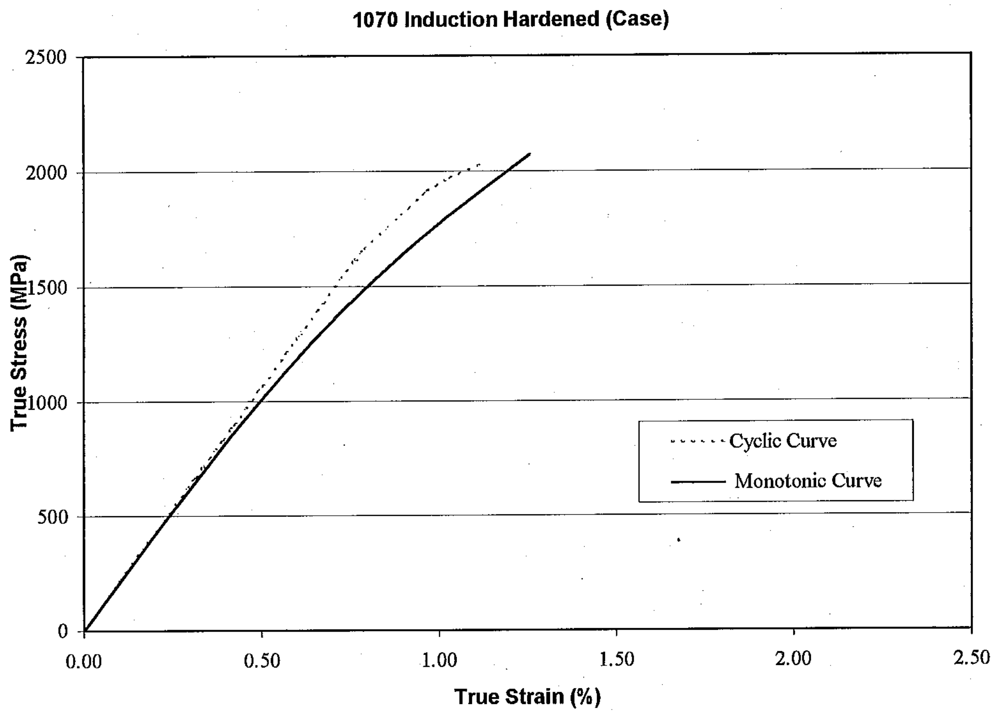


Fig. 7 Monotonic and Cyclic stress-strain curves for 1070 Induction Hardened (Case) steel.

Table 1 Chemical composition of 1070 Induction Hardened (Case) 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 Induction Hardened (Case) 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)
9	1.033	1975	0.102	0.931	14	215	59
18	1.027	2024	0.072	0.955	12	213	53
24	1.027	1908	0.127	0.900	8	208	61
20	1.003	1963	0.077	0.926	574	209	60
28	0.997	1974	0.066	0.931	212	210	58
31	0.807	1605	0.050	0.757	3500	207	61
12	0.813	1649	0.035	0.778	2358	203	60
23	0.813	1616	0.050	0.762	192	212	58
16	0.598	1276	0.000	0.598	16516	213	60
8	0.595	1271	0.000	0.595	7136	214	62
4	0.583	1248	0.000	0.583	6602	214	59
14	0.485	1048	0.000	0.485	77220	216	57
18	0.479	1043	0.000	0.479	24520	218	60
27	0.416	882	0.000	0.416	32340	212	57
1	0.403	871	0.000	0.403	318698	216	59
11	0.383	827	0.000	0.383	558752	216	62
22	0.329	708	0.000	0.329	64388	215	60
21	0.309	661	0.000	0.309	78506	214	60
3	0.264	553	0.000	0.264	349234	209	61
2	0.207	440	0.000	0.207	724196	213	58
5*	0.183	385	0.000	0.183	10000000	211	60
6*	0.171	363	0.000	0.171	10000000	212	58
7*	0.165	330	0.000	0.165	10000000	200	61

* Run out

Appendix 1

Monotonic Properties for 1070 Induction Hardened (Case) steel.

Average Elastic Modulus, E	=	212	GPa
Yield Strength	=	1950	MPa
Ultimate tensile Strength	=	2069	MPa
% Elongation	=	3.3	%
% Reduction of Area	=	2.3	%
True fracture strain, $Ln\ (A_i / A_f)$	=	3.2	%
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$	=	2116	MPa

Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \Big/ \left(1 + \frac{4R}{D_f}\right) Ln\left(1 + \frac{D_f}{4R}\right)$ =1744 MPa

Monotonic strength coefficient, K	=	10875	MPa
Monotonic strain hardening exponent, n	=	0.282	
Hardness, Rockwell C (HRC)	=	60	
Hardness, Brinell	=	613	

Cyclic Properties for 1070 Induction Hardened (Case) steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$	=	2063	MPa
Cyclic strength coefficient, K'	=	2977	MPa
Cyclic strain hardening exponent, n'	=	0.059	
Fatigue Strength Coefficient, σ'_f	=	3466	MPa
Fatigue Strength Exponent, b	=	-0.129	
Fatigue Ductility Coefficient, ε'_f	=	~~0.136~~ .0014	
Fatigue Ductility Exponent, c	=	-0.926	

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.