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Fatigue Behaviour, Monotonic Properties
and
Microstructural Data
for
AISI 1050M Hot Forged-Cold Extruded Steel
(Iteration No. 4)

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TABLE OF CONTENTS

SUMMARY

The required chemical analysis, microstructural data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for AISI 1050M Hot Forged-Cold Extruded steel (Iteration # 4) 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. A monotonic tensile test was performed to measure yield strength, tensile strength and reduction of area. Nineteen 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 20 AISI 1050M Hot Forged-Cold Extruded steel samples. The material was provided by the American Iron and Steel Institute.

The objectives of this investigation were to obtain a chemical analysis, and the microstructural data, mechanical properties, cyclic stress-strain data and strain-life tests 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, 19 fatigue data points were generated.

Test Equipment and Procedure

A monotonic tension test was 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 30 Hz.

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

RESULTS

A) Microstructural Data

Figure 2 presents the **martensite** microstructure of AISI AISI 1050M Hot Forged-Cold Extruded steel. A type A inclusion rate of $\frac{1}{2}$ was obtained based on the severity level number according to ASTM E45 method A. Inclusions of types B, C, and D were not observed. The ASTM ferritic grain size number in the longitudinal direction and in the transverse direction is 7.2 according to ASTM E112. Figure 3 presents the observed inclusions of AISI AISI 1050M Hot Forged-Cold Extruded steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of AISI AISI 1050M Hot Forged-Cold Extruded steel was provided by SCI-Lab materials testing inc., 25 McIntyre place, unit 2, Kitchener, Ontario, N2R 1H1, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for AISI 1050M Hot Forged-Cold Extruded 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 one half the expected specimen life.

A fatigue strain-life curve for the AISI 1050M Hot Forged-Cold Extruded steel is shown in Figure 4, and may 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 =1153 MPa, **b** = -0.08021, ε'_f = 0.3090 and **c** = -0.5030. These values of the strain-life parameters were determined from fatigue testing over the range: $0.002 < \frac{\Delta\varepsilon}{2} < 0.01$.

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 true cyclic stress-strain curve is described by the following equation:

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

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

Where $\mathbf{K'}$ = 1167.80 MPa and $\mathbf{n'}$ = 0.1304.

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 AISI 1050M Hot Forged-Cold Extruded steel 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.

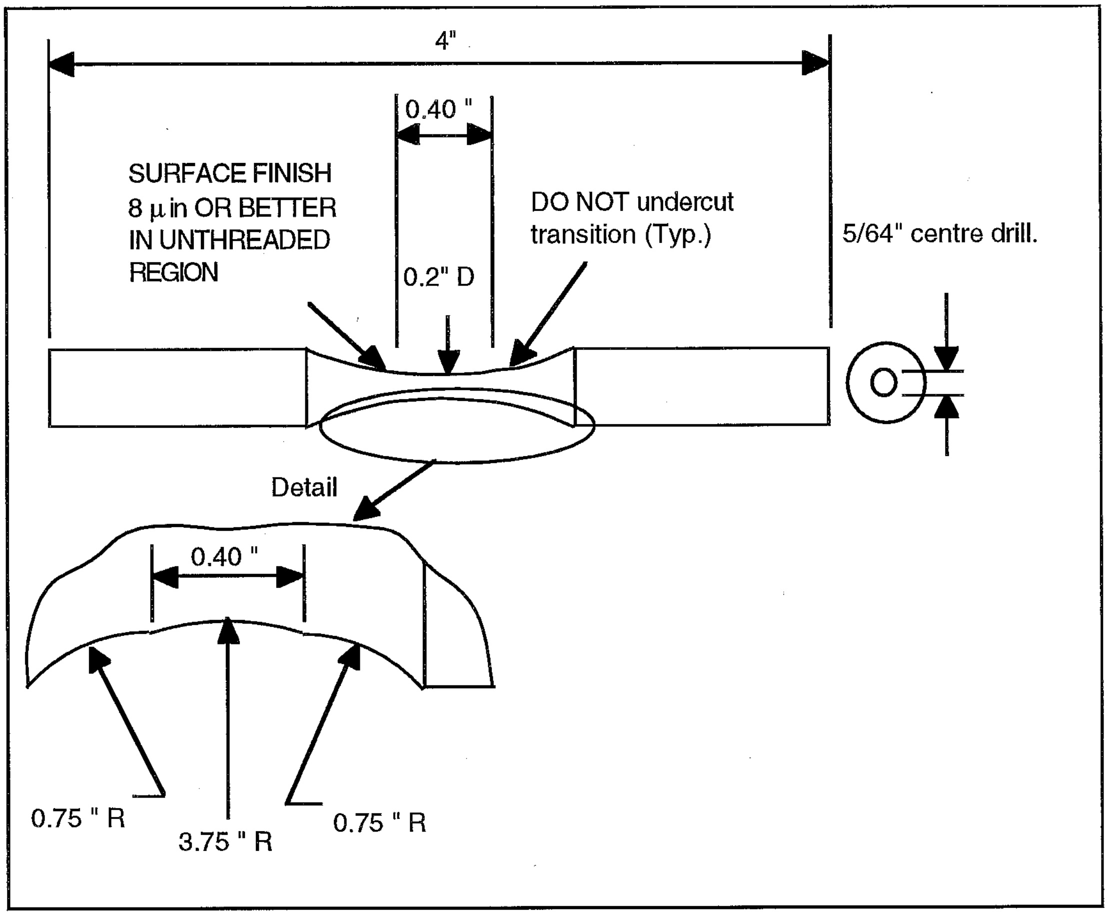
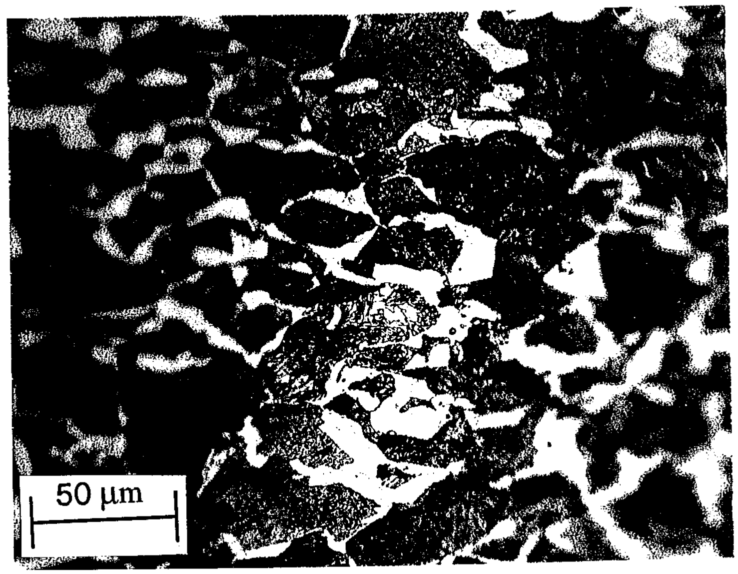


Fig. 1 Smooth cylindrical fatigue specimen



ITER 4: Photomicrograph of SAE 1050 steel, Hot Rolled, and Cold Extruded to Rb-98. 500X Mag.

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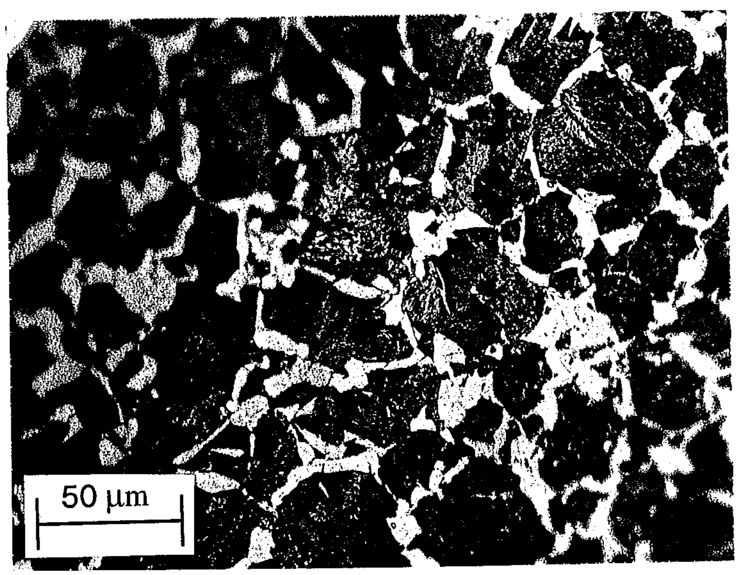


(b) Transverse direction

Fig. 2 Photomicrograohs of AISI 1050M Hot Forged-Cold Extruded steel (X500): (a) Longitudinal direction, and (b) Transverse direction.

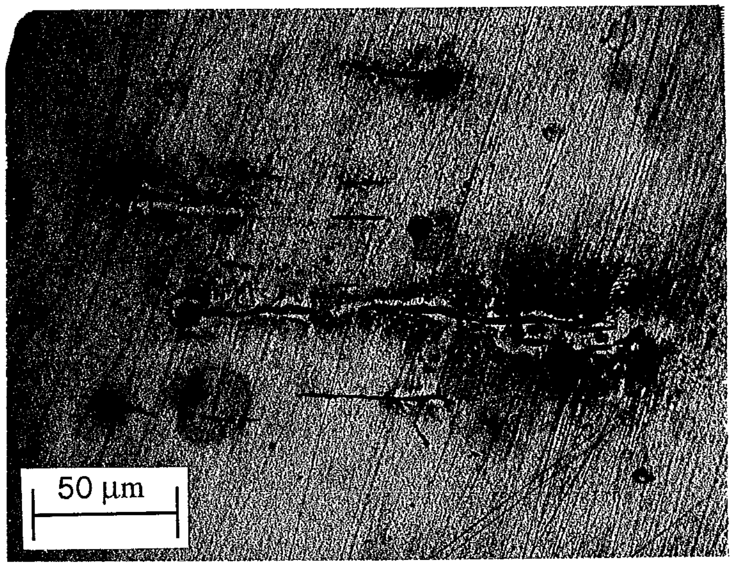


Fig. 3 Inclusions photomicrograoh of AISI 1050M Induction Surface Hardened steel (X500)

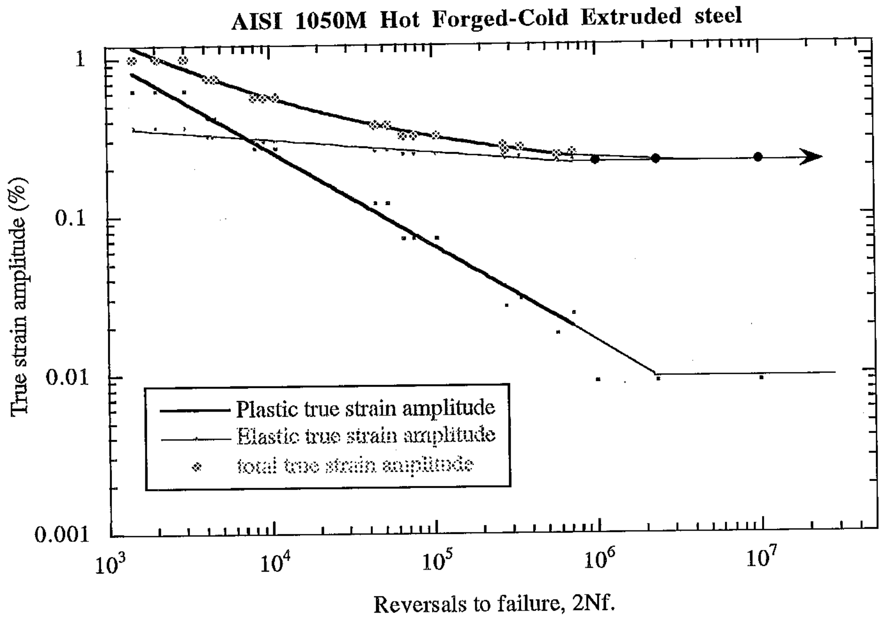


Fig. 4 Constant amplitude fully reversed strain-life curve for AISI 1050M Hot Forged-Cold Extruded steel.

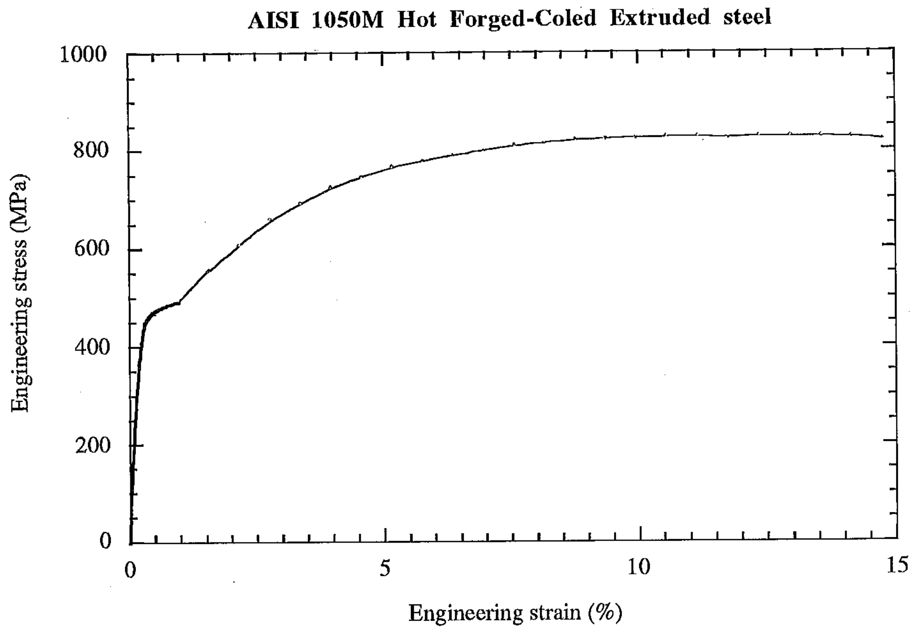


Fig. 5 Monotonic stress-strain curve for AISI 1050M Hot Forged-Cold Extruded steel

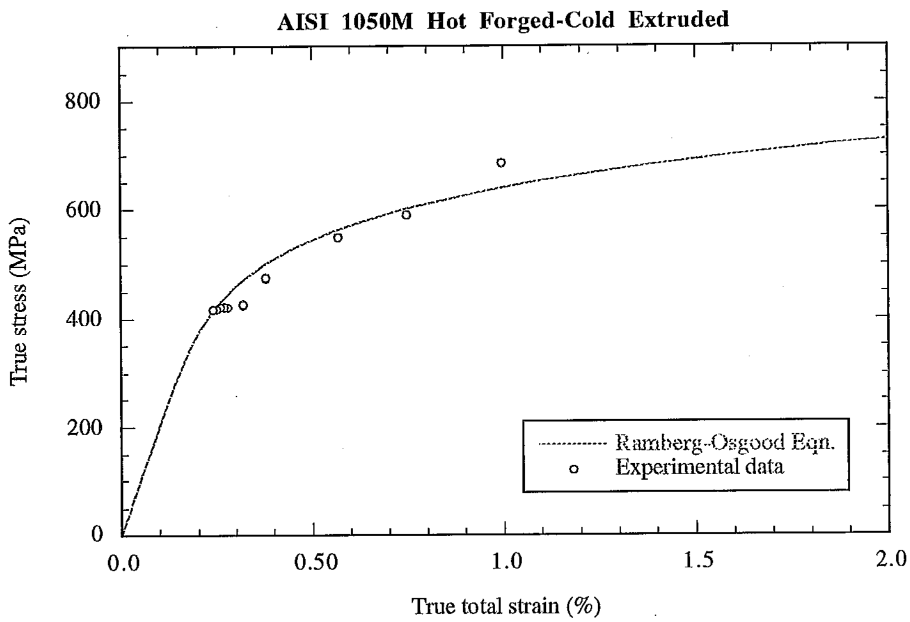


Fig. 6 Cyclic stress-strain curve for AISI 1050M Hot Forged-Cold Extruded steel

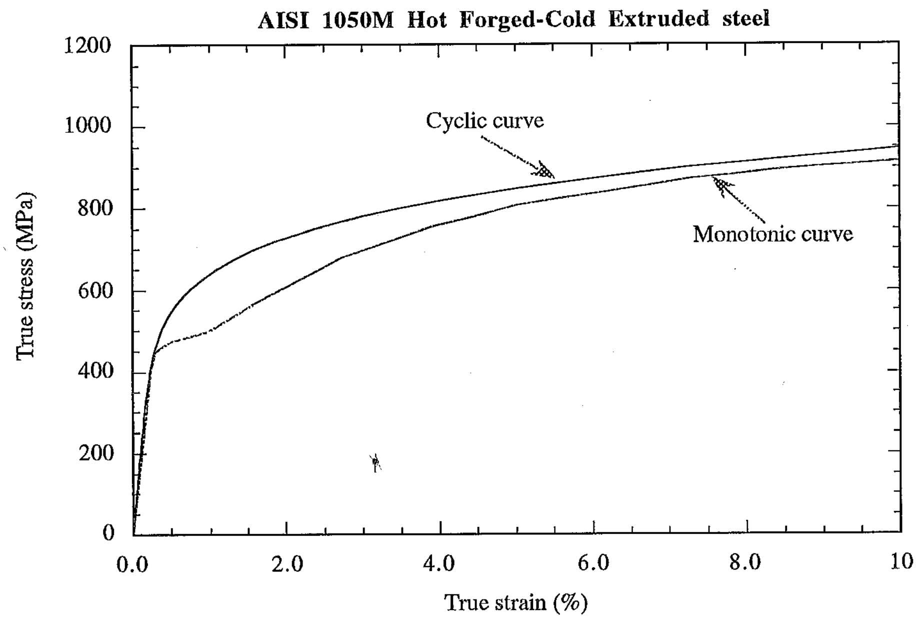


Fig. 7 Monotonic and Cyclic stress-strain curves for AISI 1050M Hot Forged-Cold Extruded steel

9/98

Table 1 Chemical composition of AISI 1050M Hot Forged-Cold Extruded steel

Carbon, C	0.52%
Manganese, Mn	0.88%
Phosphorous, P	0.012%
Sulfur, S	0.023%
Silicon, Si	0.22%
Copper, Cu	0.03%
Nickel, Ni	0.02%
Chromium, Cr	0.08%
Molybdenum, Mo	<0.01%
Vanadium, Va	0.001%
Niobium	0.006%

Table 2 Tensile and Fatigue Test Data for 1050M Hot Forged-Cold Extruded steel

$\Delta\sigma/2$ $\Delta\varepsilon_p/2$ $\Delta\varepsilon_e/2$

Sp#	TRUE Total Strain Amplitude(%)	TRUE Stress Amplitude (MPa)	~~TRUE~~ Plastic Strain Amplitude(%)	~~TRUE~~ Elastic Strain Amplitude(%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	MONOTONIC Young's Modulus(GPa)	Hardness (HRC)
11	0.995	684.78	0.658	0.338	1454.0	205.5	20
25	0.995	682.76	0.659	0.337	3000.0	205.5	
13	0.995	684.78	0.658	0.338	2014.0	205.0	
21	0.747	539.34	0.481	0.266	4474.0	204.5	20
27	0.747	559.54	0.471	0.276	4588.0	205	
24	0.747	511.06	0.495	0.252	4188.0	205	
9	0.568	547.42	0.298	0.270	9166.0	200.5	
6	0.568	610.04	0.267	0.301	10832	200	
22	0.568	632.26	0.256	0.312	8056.0	200	20
3	0.379	470.66	0.146	0.232	44160	200	
8	0.379	462.58	0.150	0.228	52728	200.85	
20	0.379	470.66	0.146	0.232	52720	200.85	
23	0.319	450.46	0.096	0.222	1.0544e+05	200.50	
7	0.319	353.50	0.144	0.174	65568	205.50	19.5
19	0.319	444.40	0.099	0.219	76464	205.0	
2	0.279	452.48	0.055	0.223	2.7167e+05	200	
5	0.269	446.42	0.048	0.220	3.4142e+05	200	20.0
1	0.259	418.14	0.052	0.206	2.7807e+05	198	
14	0.249	422.18	0.040	0.208	7.1944e+05	196	
26	0.239	426.22	0.028	0.210	5.7867e+05	196	
10	0.219	406.02	0.018	0.200	1.0012e+06	205	
12	0.219	404.00	0.019	0.199	2.3473e+06	205.50	20.5
15	0.219	406.02	0.018	0.200	1.0000e+07*	205.50	

* Run out

9/98

Appendix 1

Monotonic Properties for AISI 1050M Hot Forged-Cold Extruded steel

Average Elastic Modulus, E	=	202 GPa
Upper Yield Strength	=	460.00 MPa
Lower Yield Strength	=	450.00 MPa
Ultimate tensile Strength	=	828.50 MPa
% Elongation	=	17.66 %
% Reduction of Area	=	34.0 %
True fracture strain, $Ln\ (A_i / A_f)$	=	41.60 %
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$	=	1295 MPa

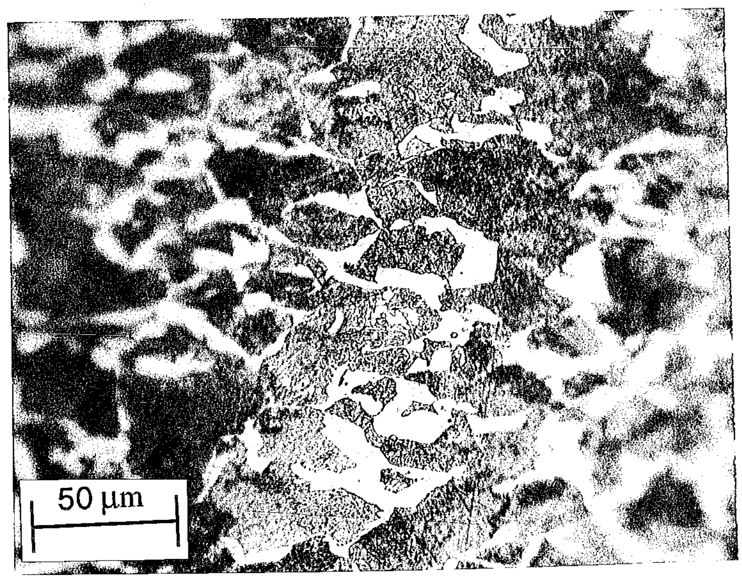
Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$ =1064.60 MPa

Monotonic strength coefficient, K	=	1309 MPa
Monotonic strain hardening exponent, n	=	0.1628
Hardness, Rockwell B (HRB)	=	98 HRB
Hardness, Brinell	=	220

Cyclic Properties for AISI 1050M Hot Forged-Cold Extruded steel

Cyclic Yield Strength, (0.2% offset) = $K'(0.002)^{n'}$	=	520 MPa
Cyclic strength coefficient, K'	=	1167.80 MPa
Cyclic strain hardening exponent, n'	=	0.1304
Fatigue Strength Coefficient, σ'_f	=	1153 MPa
Fatigue Strength Exponent, b	=	-0.08021
Fatigue Ductility Coefficient, ε'_f	=	0.309
Fatigue Ductility Exponent, c	=	-0.503

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.



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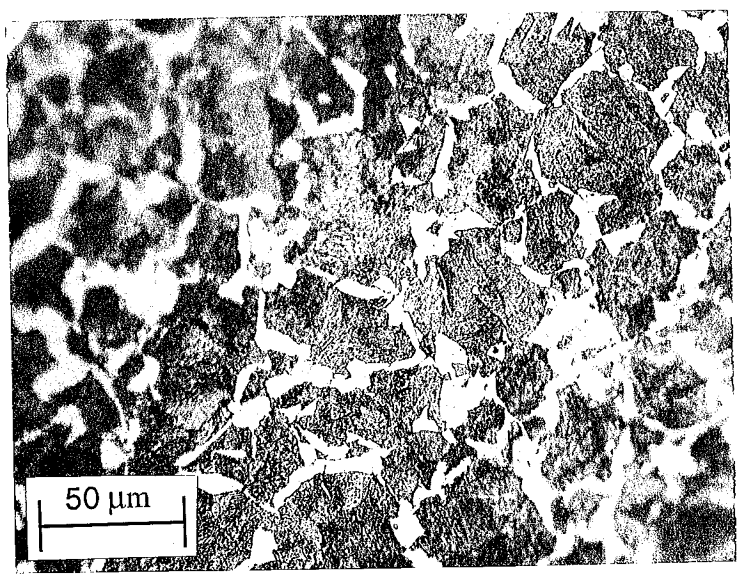

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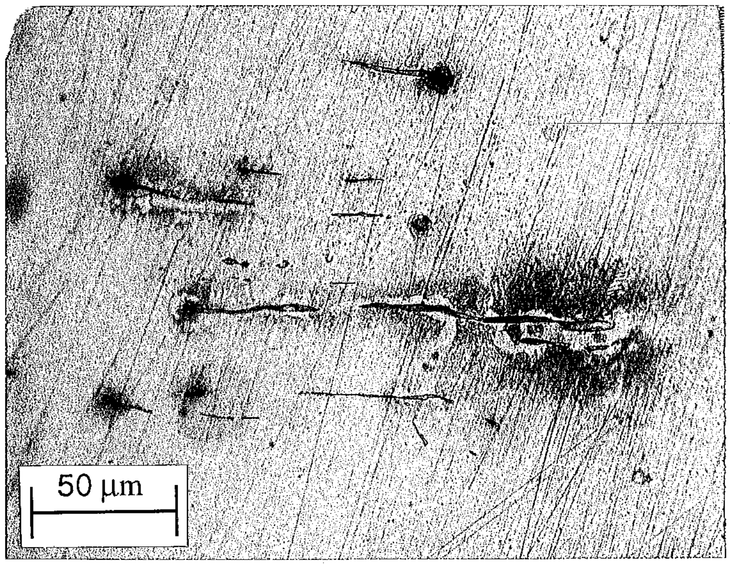

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