AISI 1090M Hot Formed-Accelerated Cooled Steel Iteration #7

Fatigue Behavior, Monotonic Properties and Microstructural Data

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SUMMARY

The required chemical analysis, microstructural data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for AISI 1090M Hot Form-Accelerated Cooled steel (Iteration # 7) 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 1090M Hot Form-Accelerated Cooled 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.

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Appendix 1

Monotonic Properties for AISI 1090M Hot Form-Accelerated Cooled steel

Average Elastic Modulus, E	=	217 GPa
Upper Yield Strength	=	987.50 MPa
Lower Yield Strength	=	978.60 MPa
Monotonic Yield Strength, (0.2% offset)	=	1065 MPa
Ultimate tensile Strength	=	1388 MPa
% Elongation	=	14.00 %
% Reduction of Area	=	25.00 %
True fracture strain, $Ln\ (A_i / A_f)$	=	29 %
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$	=	1735.60 MPa

Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \Big/ \left(1 + \frac{4R}{D_f}\right) Ln\left(1 + \frac{D_f}{4R}\right)$ =1426.80 MPa

Monotonic strength coefficient, K	=	2202 MPa
Monotonic strain hardening exponent, n	=	0.1682
Hardness, Rockwell C (HRC)	=	38 HRC
Hardness, Brinell	=	357

Cyclic Properties for AISI 1090M Hot Form-Accelerated Cooled steel

Cyclic Yield Strength, (0.2% offset) = $K'(0.002)^{n'}$		= 730.20 MPa
Cyclic strength coefficient, K'	=	2004.50 MPa
Cyclic strain hardening exponent, n'	=	0.1625
Fatigue Strength Coefficient, σ'_f	=	2174.55 MPa
Fatigue Strength Exponent, b	=	-0.1160
Fatigue Ductility Coefficient, ε'_f	=	0.7406
Fatigue Ductility Exponent, c	=	-0.6260

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.

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 pearilitic-martensitic microstructure of AISI 1090M Hot Form-Accelerated Cooled steel. A type A inclusion rate of 1 was obtained based on the severity level number according to ASTM E45 method A. Inclusions of types B, C, and D were not observed. Figure 3 presents the observed inclusions of AISI 1090M Hot Form-Accelerated Cooled steel. The inclusion area was measured using a JAVA image analysis system. The volume fraction of pearlitic structure based on ASTM E562-95 and using the JAVA image analysis system was over 95%. The chemical composition of AISI 1090M Hot Form-Accelerated Cooled 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 1090M Hot Form-Accelerated Cooled 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 1090M Hot Form-Accelerated Cooled 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 =2174.55 MPa, **b** = -0.1160, ε'_f = 0.7406 and **c** = -0.6260. 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:

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

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

Where $\mathbf{K'} = 2004.50$ MPa and $\mathbf{n'} = 0.1625$.

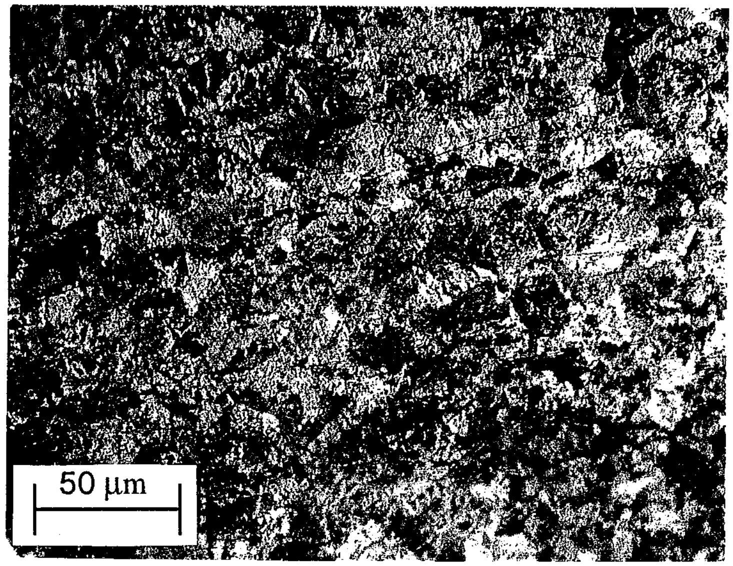
D) Mechanical Properties

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 1090M Hot Form-Accelerated Cooled 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

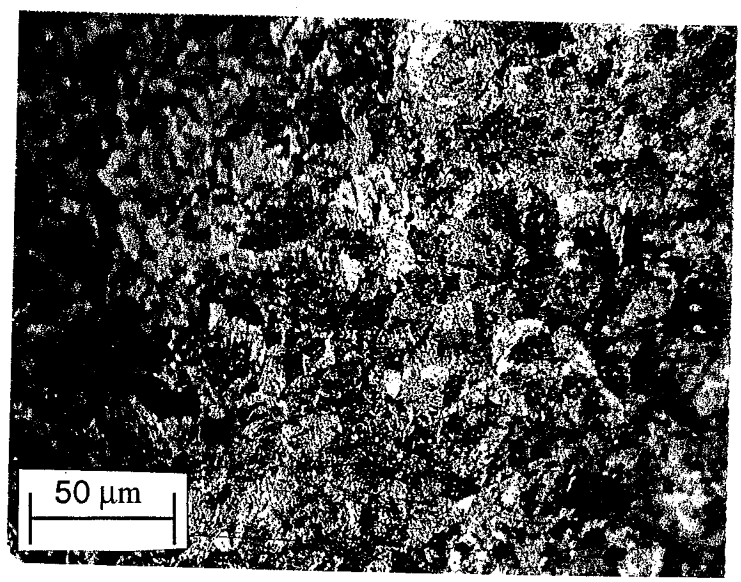
[1] Pompetzki, M.A., Saper, R.A., and Topper, T.H., "Software for High Frequency Control of Variable Amplitude Fatigue Tests," Canadian Metallurgical Quarterly, Vol. 25, No. 2, pp. 181-194, 198.

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



ITER 7: Photomicrograph of SAE 1090M steel, Hot Forged and Forced Air Cooled to Rc-38. 500X Mag.

(a) Longitudinal direction



(b) Transverse direction

Fig. 2 Photomicrograohs of AISI 1090M Hot Form-Accelerated Cooled steel (X500): (a) Longitudinal direction, and (b) Transverse direction.

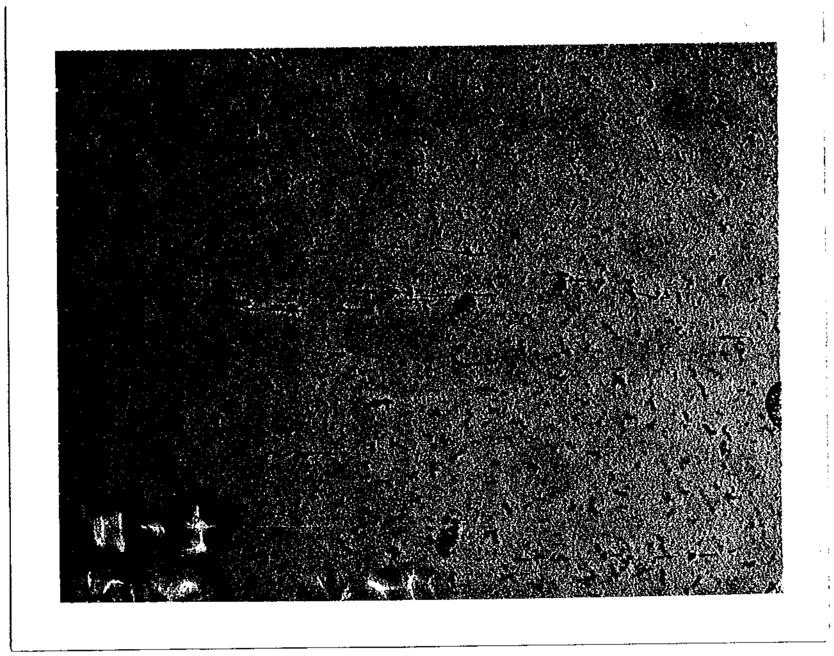


Fig. 3 Inclusions photomicrograoh of AISI 1090M Hot Form-Accelerated Cooled steel (X200)

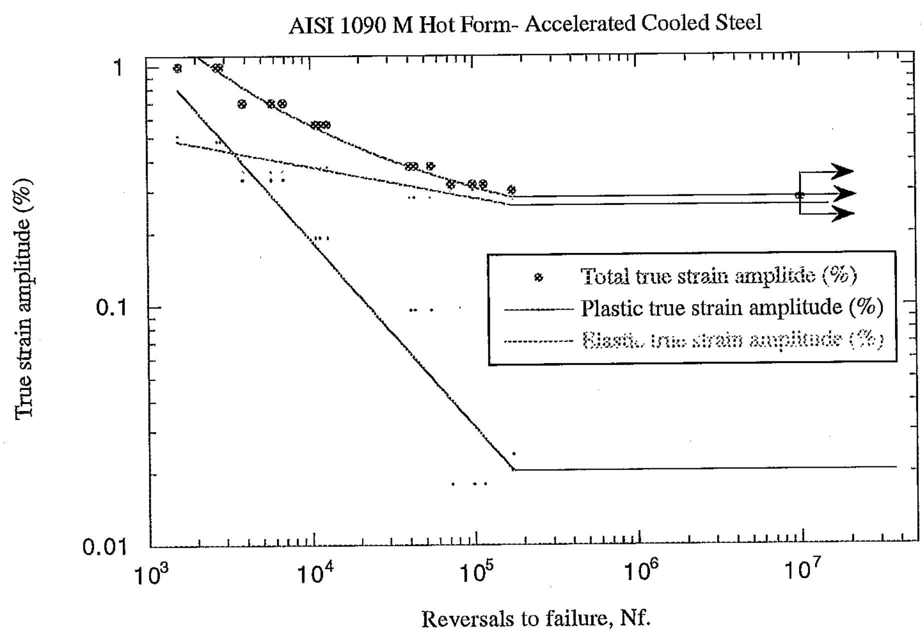


Fig. 4 Constant amplitude fully reversed strain-life curve for AISI 1090M Hot Form-Accelerated Cooled steel.

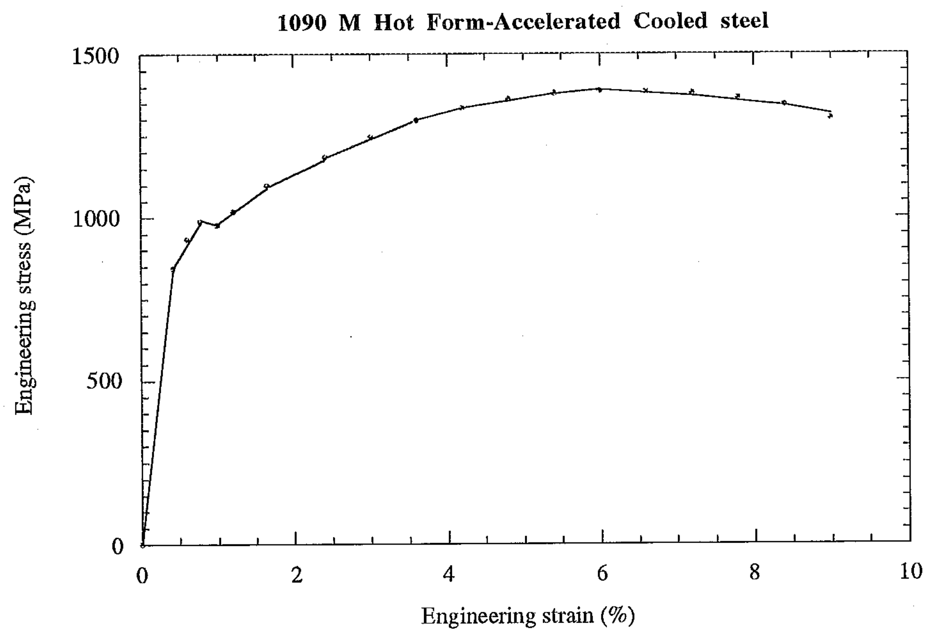


Fig. 5 Monotonic stress-strain curve for AISI 1090M Hot Form-Accelerated Cooled steel

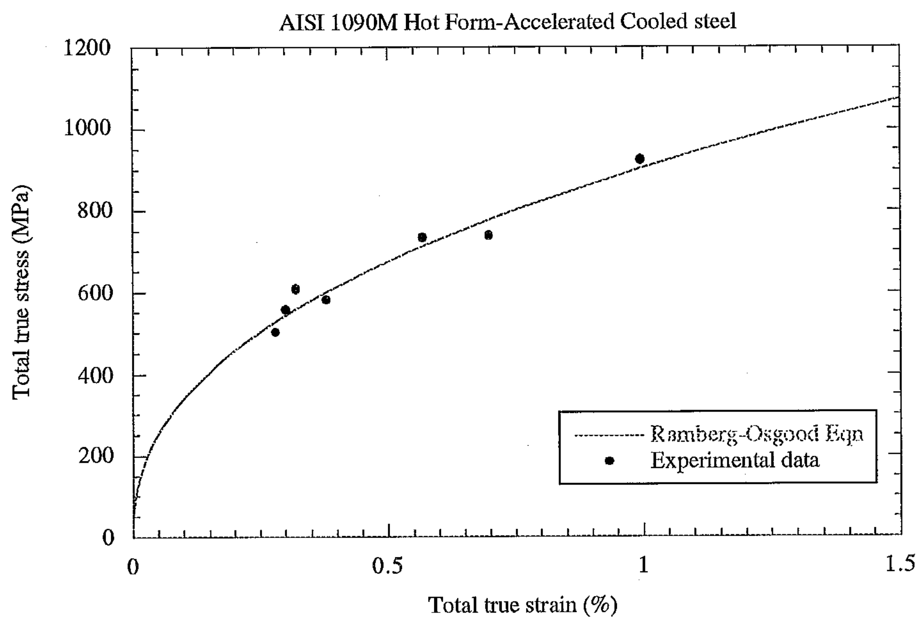


Fig. 6 Cyclic stress-strain curve for AISI 1090M Hot Form-Accelerated Cooled steel

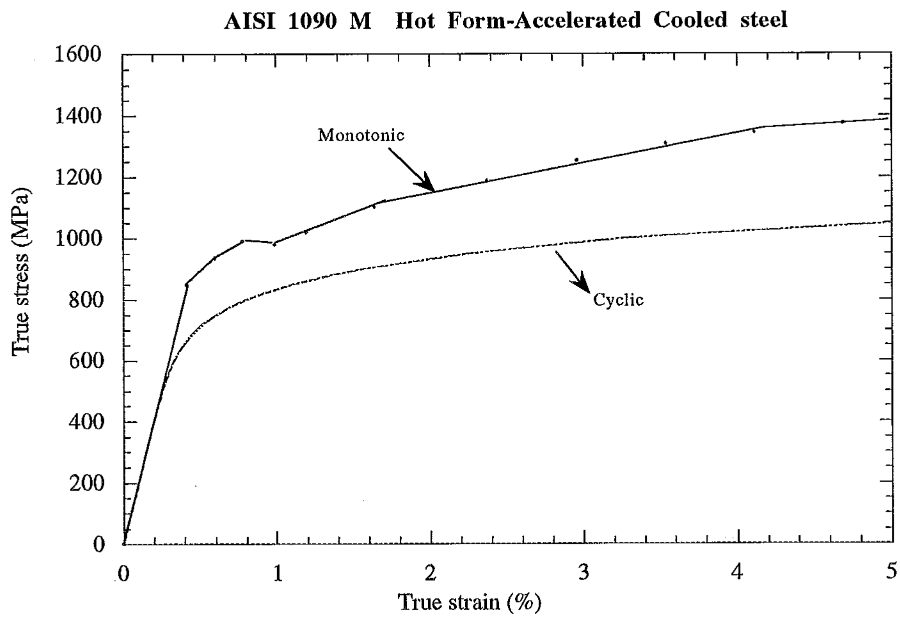


Fig. 7 Monotonic and Cyclic stress-strain curves for AISI 1090M Hot Form-Accelerated Cooled steel

Table 1 Chemical composition of AISI 1090M Hot Form-Accelerated Cooled steel

Carbon, C	0.87%
Manganese, Mn	1.00%
Phosphorous, P	0.017%
Sulfur, S	0.026%
Silicon, Si	0.58%
Copper, Cu	0.12%
Nickel, Ni	0.05%
Chromium, Cr	0.15%
Molybdenum, Mo	0.05%
Vanadium, Va	0.094%
Niobium	0.006%

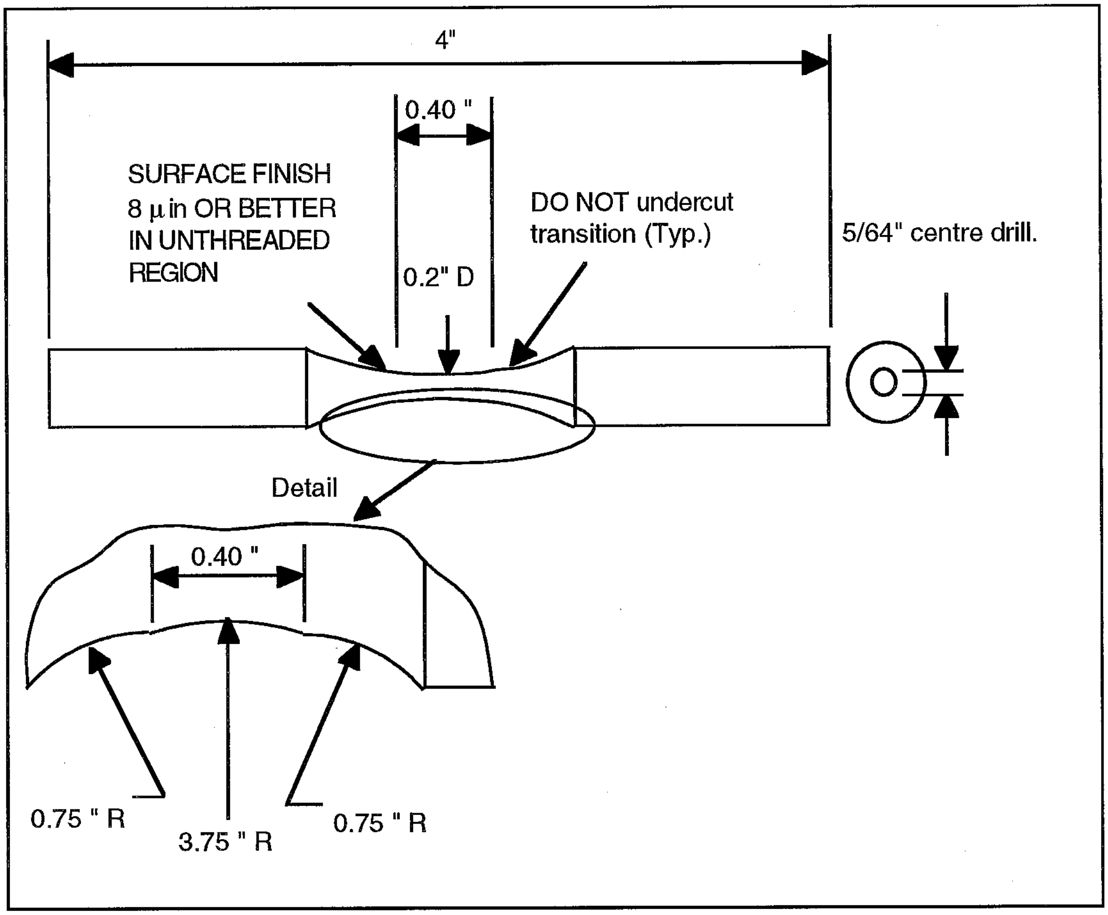


Fig. 1 Smooth cylindrical fatigue specimen

Table 2 Tensile and Fatigue Test Data for 1090M Hot Form-Accelerated Cooled steel

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)
4	0.995	924.90	0.576	0.421	2814.0	219.50	38
23	0.995	889.83	0.592	0.405	2698.0	219.50	
21	0.995	990.65	0.546	0.450	1562.0	219.50	
17	0.697	732.04	0.364	0.334	5774.0	219.50	37.50
25	0.697	806.34	0.330	0.368	3852.0	219.50	
5	0.697	797.59	0.334	0.364	6800.0	219.50	
15	0.568	733.28	0.233	0.335	12658	204.88	
24	0.568	724.55	0.237	0.331	10640	204.88	
27	0.568	783.47	0.210	0.358	11404	204.88	37.50
12	0.379	566.34	0.119	0.259	43078	219.50	
7	0.379	638.23	0.086	0.292	40568	219.50	
11	0.379	638.23	0.086	0.292	54534	219.50	
19	0.319	607.37	0.040	0.278	1.1464e+05	219.50	
14	0.319	607.37	0.040	0.278	98062	219.50	38
2	0.319	544.24	0.069	0.249	72068	219.50	
10	0.299	557.19	0.043	0.255	1.7101e+05	219.00	
17	0.279	502.67	0.048	0.230	1.0000e+07*	219.00	
23	0.279	537.49	0.032	0.246	1.0000e+07*	219.00	
21	0.279	574.48	0.016	0.263	1.0000e+07*	219.00	38

* Run out

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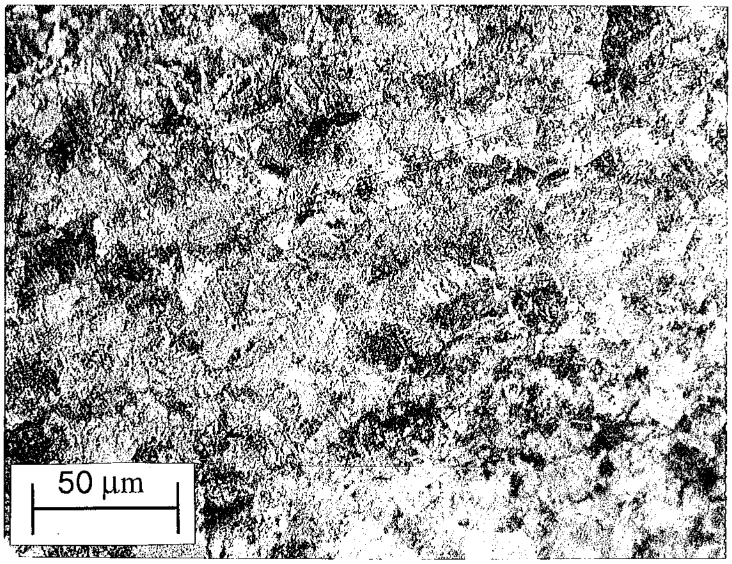

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(a) Longitudinal direction

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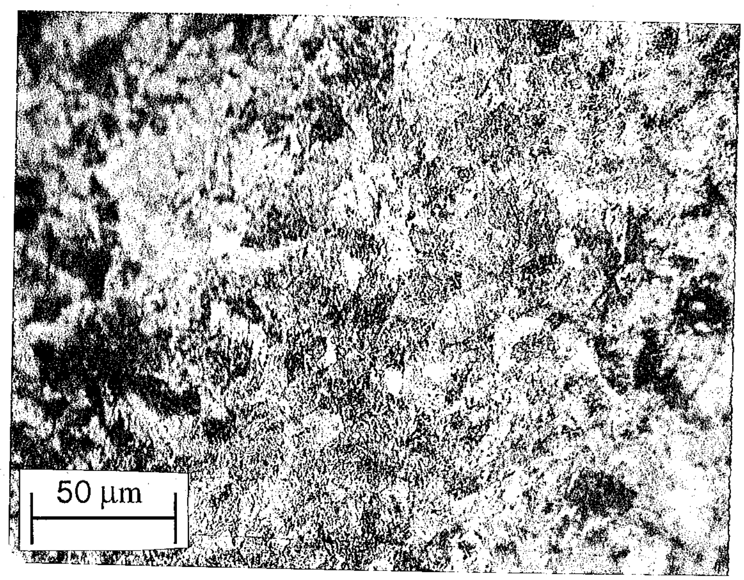

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