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Fatigue Behaviour, Monotonic Properties and Microstructural Data for AISI 1541 Cold Formed Steel (Iteration No. 2)

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SUMMARY

The required chemical analysis, microstructural data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for AISI 1541 cold formed steel 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. Twenty four 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 25 cold formed 1541 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 18 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 at 10% load drop and 5 extra data points were generated at 50 % load drop, to check the difference in fatigue life between 10% and 50% load drop criteria.

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 B" 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 10 percent drop in tensile peak load from the peak load observed at one half the expected specimen life. Five extra data points, one at each strain level, were generated at 50 percent load drop. 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 ferritic-pearilitic microstructure of AISI 1541 cold formed steel. The ASTM ferritic grain size number in the longitudinal direction and in the transverse direction is 10 according to ASTM E112. Type D inclusions with a rate of $2\frac{1}{2}$ were obtained based on the severity level number according to ASTM E45 method A. Inclusions of types A, B, and C were not observed. Figure 3 presents the observed inclusions of AISI 1541 cold formed 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 66%. The chemical composition of AISI 1541 cold formed 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 1541 cold formed 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. Data for a 10% load drop and a 50% load drop fell within the same scatter band.

A fatigue strain-life curve for the AISI 1541cold formed 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 = 1070 MPa, **b** = -0.085, ε'_f = 0.6170 and **c** = -0.582. 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 **K'** = 906.74 MPa and **n'** = 0.1042.

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 1541 cold formed 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.

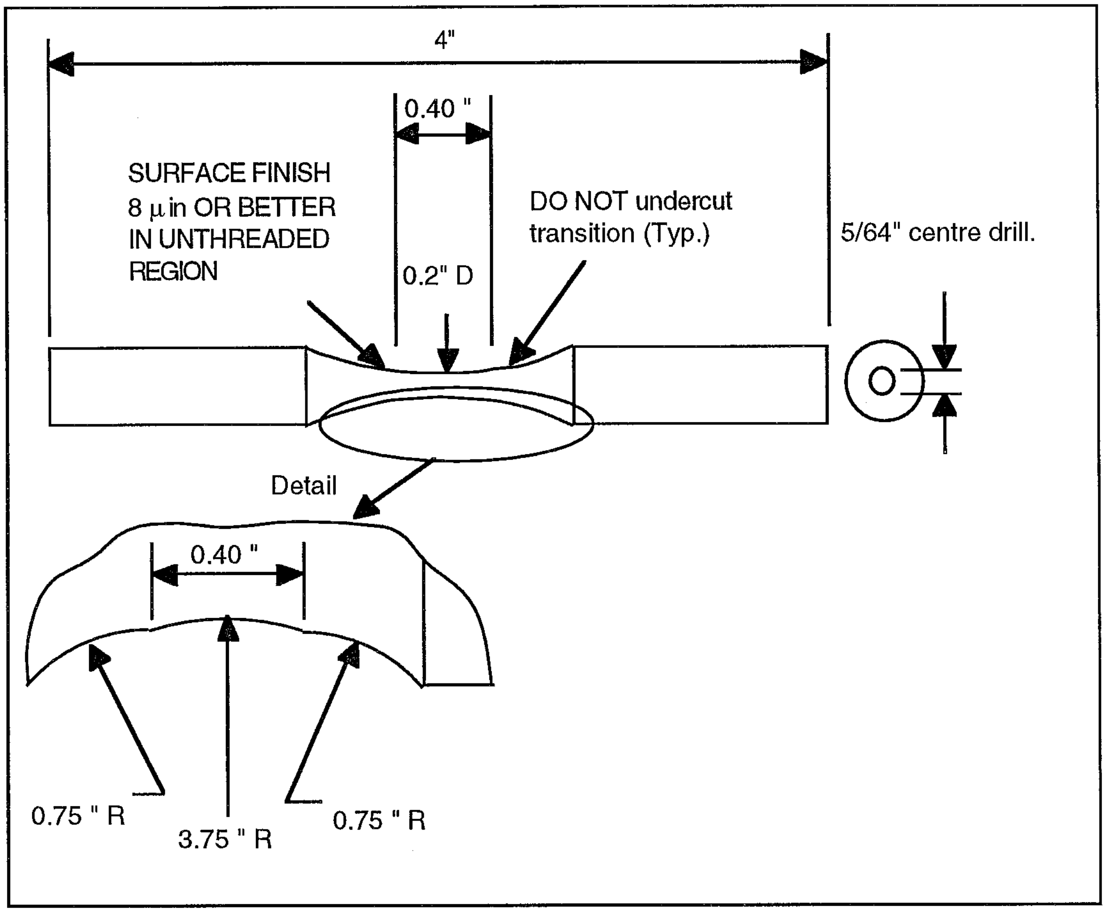
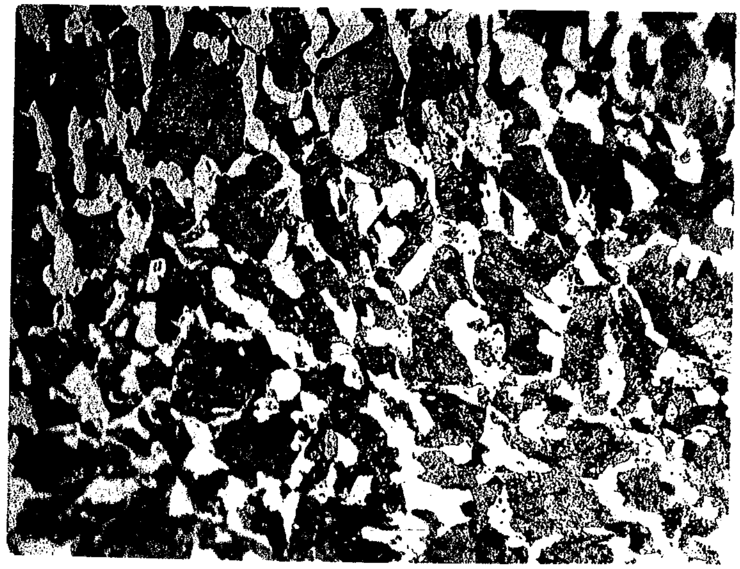
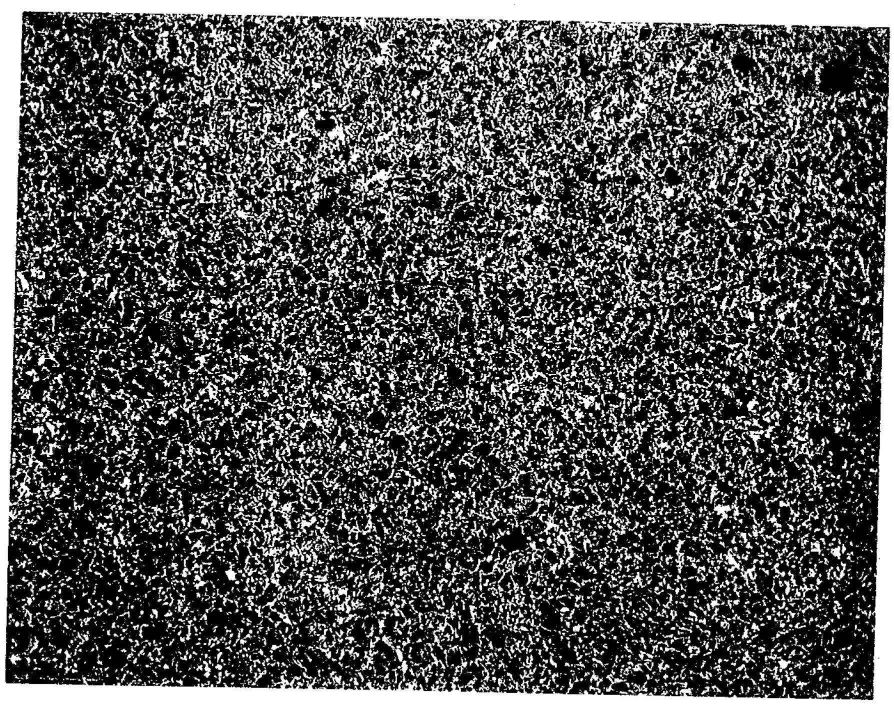


Fig. 1 Smooth cylindrical fatigue specimen



ITER 2: Photomicrograph of SAE 1541 steel, Cold Formed to Rb-96. 500X Mag.



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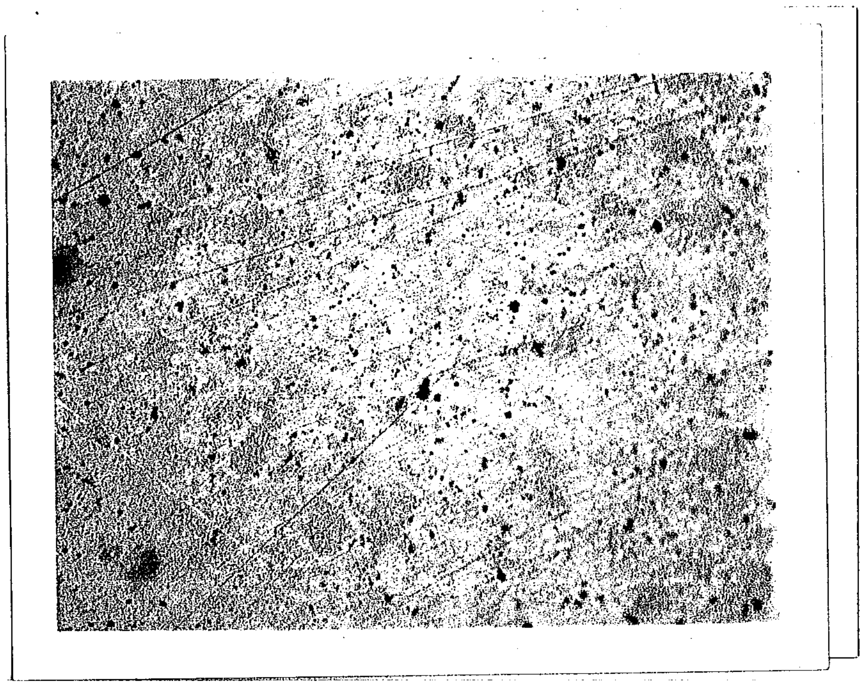

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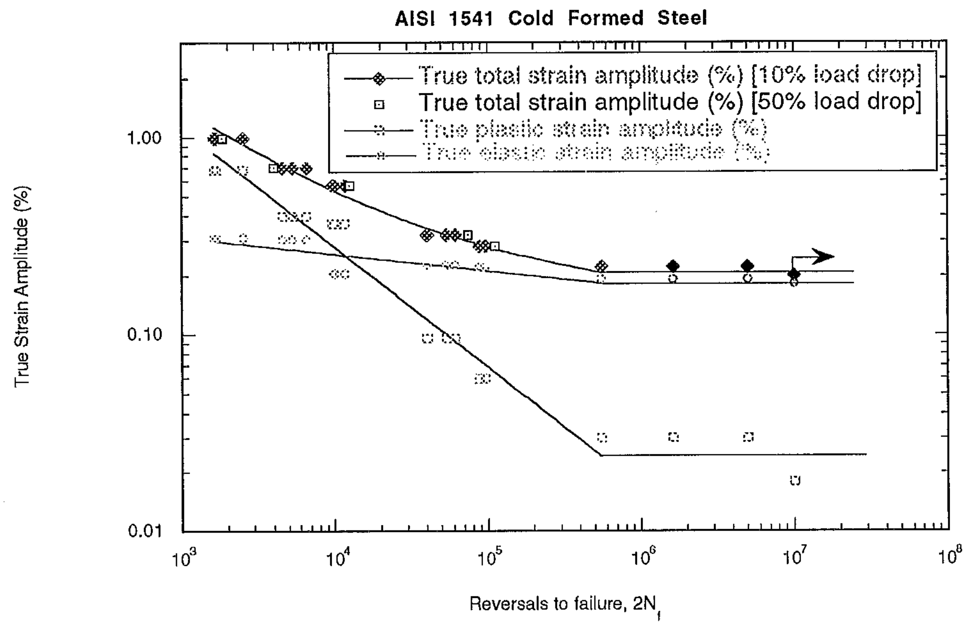

Fig. 4 Constant amplitude fully reversed strain-life curve for AISI 1541 cold formed steel

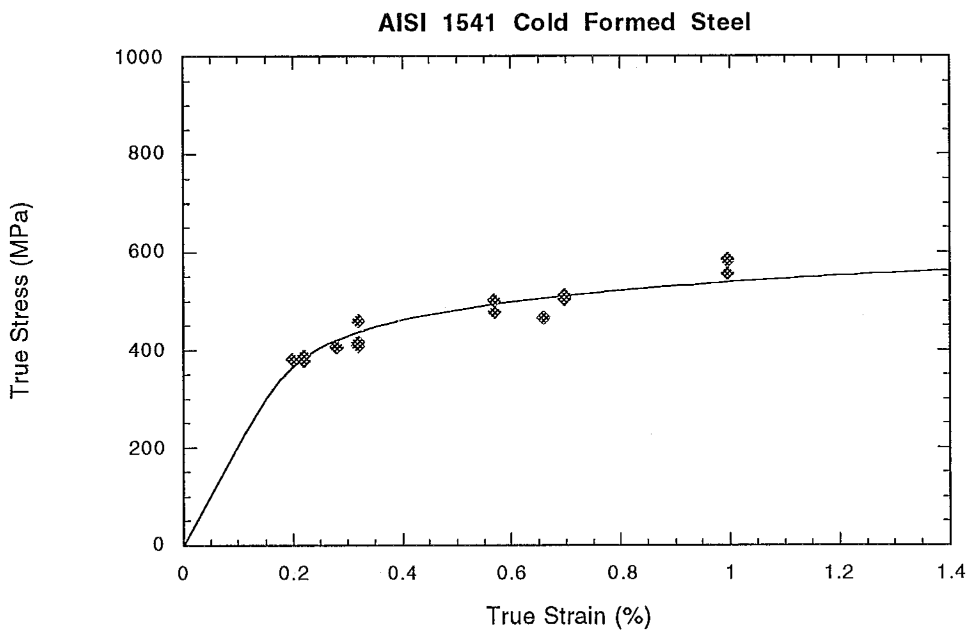

Fig. 5 Cyclic stress-strain curve for AISI 1541 cold formed steel

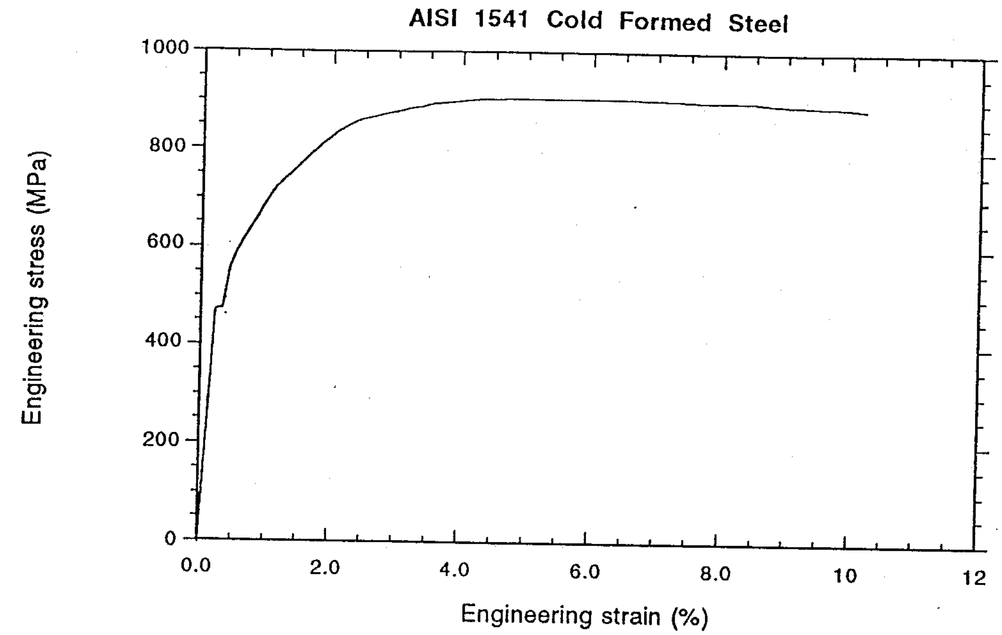

Fig. 6 Monotonic stress-strain curve for AISI 1541 cold formed steel

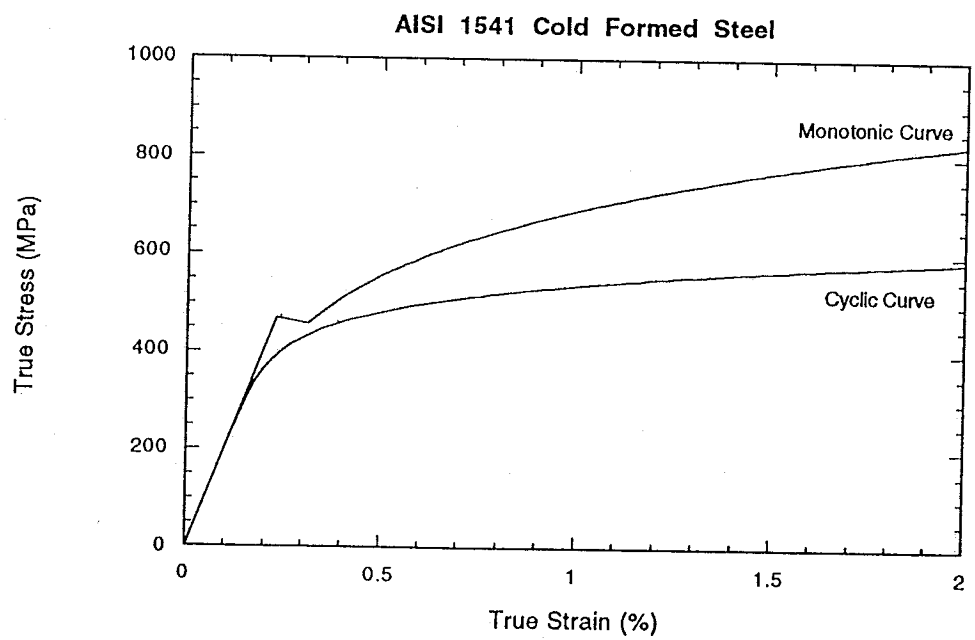

Fig. 7 Monotonic and Cyclic stress-strain curves for AISI 1541 cold formed steel

Table 1 Chemical composition of AISI 1541 cold formed steel

Carbon, C	0.42%
Manganese, Mn	1.40%
Phosphorous, P	0.011%
Sulfur, S	0.10%
Silicon, Si	0.18%
Copper, Cu	0.1%
Nickel, Ni	0.05%
Chromium, Cr	0.07%
Molybdenum, Mo	0.01%
Vanadium, Va	0.002%
Calcium, Ca	0.001%
Boron, Bo	0.0024%
Aluminum, Al	<0.001%
Titanium, Ti	0.001%
Oxygen, O	0.0020%
Columbium, Cb	0.002%

Table 2 Tensile and Fatigue Test Data for AISI 1541 cold formed steel

Spec	TRUE Total Strain Amplitude(%)	TRUE Stress Amplitude (MPa)	TRUE Plastic Strain Amplitude(%)	TRUE Elastic Strain Amplitude(%)	Fatigue Life (Reversals, 2Nf)	MONOTONIC Young's Modulus(GPa)	Hardness (HRB)
29	0.995	585.17	0.702	0.294	1634	207.50	
12	0.279	411.63	0.070	0.208	88018	195	
27	0.697	512.24	0.440	0.258	5256	199.23	
17	0.568	499.72	0.316	0.252	10000	206	94.5
5	0.319	407.85	0.113	0.206	53984	193	93
28	0.199	379.81	0.007	0.192	10000000*	193	
28	0.995	581.21	0.704	0.292	1696	183	
4	0.219	387.76	0.023	0.196	4999800	195	
18	0.219	377.92	0.028	0.192	1636400	195	
16	0.219	389.73	0.022	0.197	554910	195	
2	0.995	497.89	0.746	0.250	2520	191	
8	0.697	508.28	0.442	0.256	6510	191	
21	0.697	502.35	0.445	0.253	4552	188	
26	0.568	476.02	0.328	0.240	11676	199	94.5
13	0.568	464.17	0.334	0.234	9666	191	
14	0.319	415.73	0.109	0.210	61490	198	
7	0.319	451.20	0.090	0.228	40000	198	
6	0.279	405.72	0.074	0.205	96166	198	
20	0.279	407.69	0.073	0.206	88470	198	
11	0.995	684.36	0.652	0.344	1856	205	
9	0.697	524.10	0.434	0.264	4002	194	
15	0.568	493.80	0.319	0.249	12510	202	
24	0.319	419.67	0.106	0.212	74142	202	
22	0.279	423.44	0.064	0.214	111208	197	

* Run out

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Appendix 1

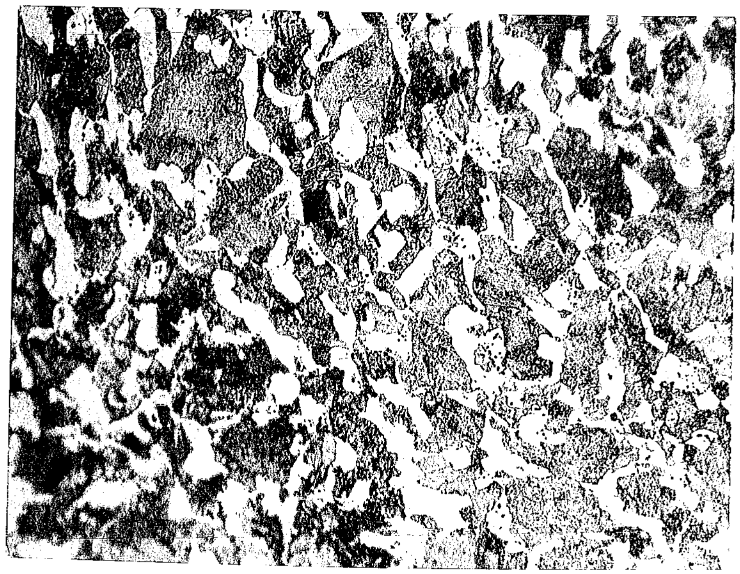
Monotonic Properties for AISI 1541 Cold Formed Steel

AverageElastic Modulus, E	=	196.40 GPa
Upper Yield Strength	=	471.95 MPa
Lower Yield Strength	=	460.98 MPa
Ultimate tensile Strength	=	905.50 MPa
% Elongation	=	28.66 %
% Reduction of Area	=	41.72 %
True fracture strain, $Ln\ (A_i / A_f)$	=	54 %
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$	=	1516.50 MPa
Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$	=	1246.70 MPa
Monotonic strength coefficient, K	=	1543.50 MPa
Monotonic strain hardening exponent, n	=	0.1625
Hardness,Rockwell B (HRB)	=	95.5
Hardness, Brinell	=	195

Cyclic Properties for AISI 1541 Cold Formed Steel

Cyclic Yield Strength, (0.2% offset) = $K'(0.002)^{n'}$	=	474.5 MPa
Cyclic strength coefficient, K'	=	906.74 MPa
Cyclic strain hardening exponent, n'	=	0.1042
Fatigue Strength Coefficient, σ'_f	=	1070 MPa
Fatigue Strength Exponent, b	=	-0.085
Fatigue Ductility Coefficient, ε'_f	=	0.6170
Fatigue Ductility Exponent, c	=	-0.5820

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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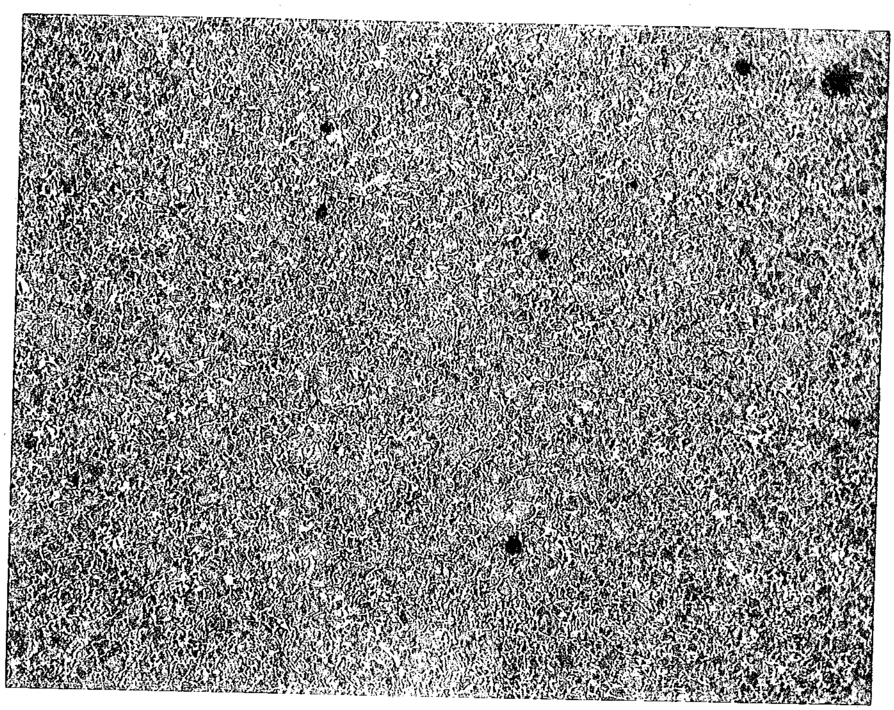

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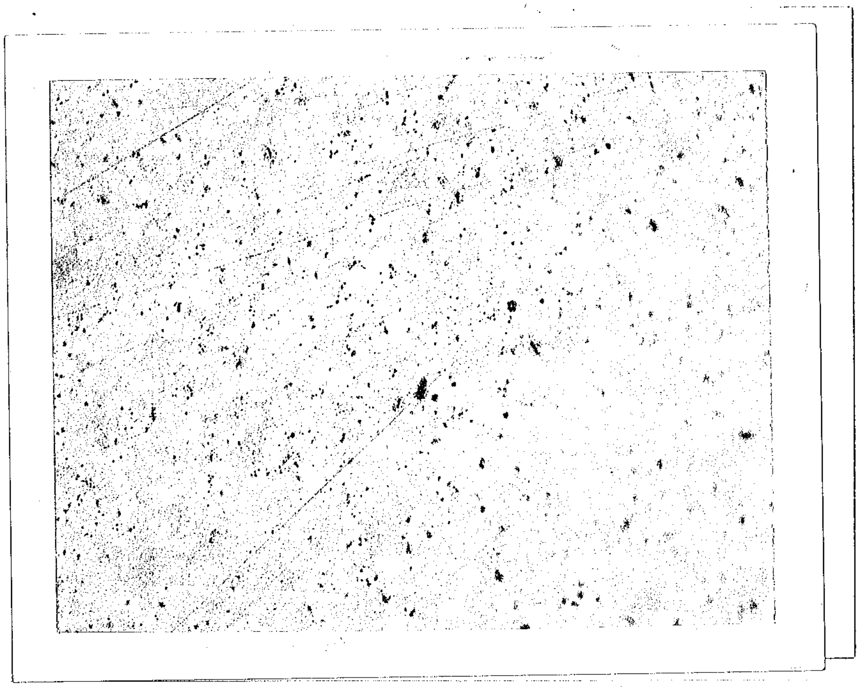

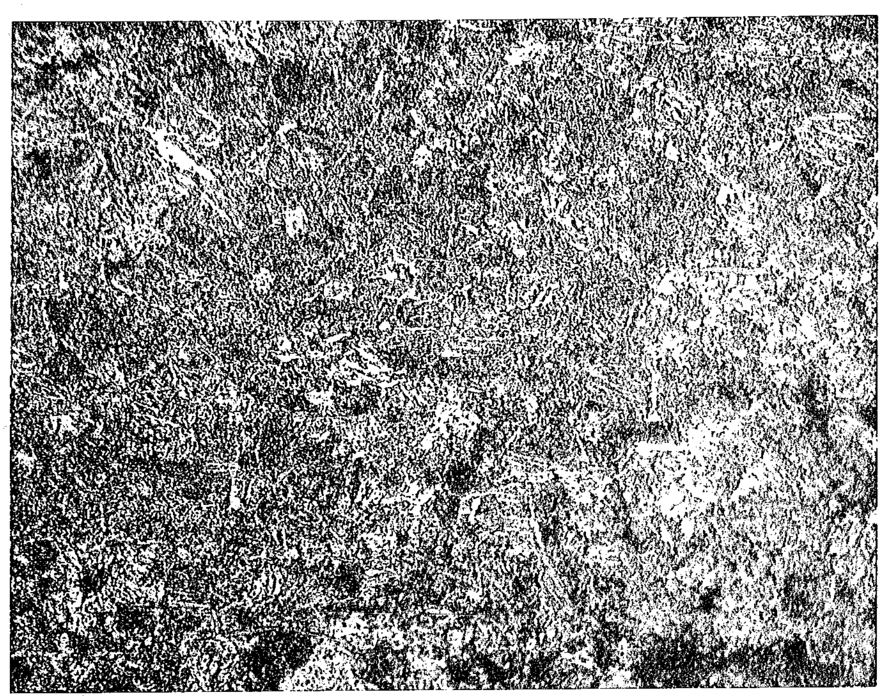

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