AISI 1050 Normalized Steel
Iteration #3

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 STELCO 1050 normalized steel (Iteration # 3) 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 one 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 22 normalized 1050 steel samples. The material was provided by the STELCO Company.

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, 21 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 four 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. 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 10 Hz while in stress-controlled tests the frequency used was up to 60 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 STELCO 1050 normalized steel. The ASTM ferritic grain size number in the longitudinal (extrusion) direction and in the transeverse direction are in the range of (9.0 - 9.5) according to ASTM E112. Type A inclusion rate of $\frac{1}{2}$ was obtained based on the severity level number according to ASTM E45 method A. Type D inclusion rate of $2\frac{1}{2}$ was also observed. Inclusions of types B, and C were not observed. Figure 3 presents the observed inclusions of STELCO 1050 normalized 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 68%. The chemical composition of STELCO 1050 normalized 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 STELCO 1050 normalized 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.

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A fatigue strain-life curve for the STELCO 1050 normalized 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 = ~~1560~~ 1552 MPa, **b** = ~~-0.125~~ -0.1246, ε'_f = ~~0.3768~~ 0.3770 and **c** = ~~-0.4926~~ -0.4927. These values of the strain-life parameters were determined from fatigue testing over the range: $0.00225 < \frac{\Delta\varepsilon}{2} < 0.01$.

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 $\mathbf{K}'$ = ~~1536~~ MPa and $\mathbf{n}'$ = ~~0.1810~~.

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 STELCO 1050 normalized 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.

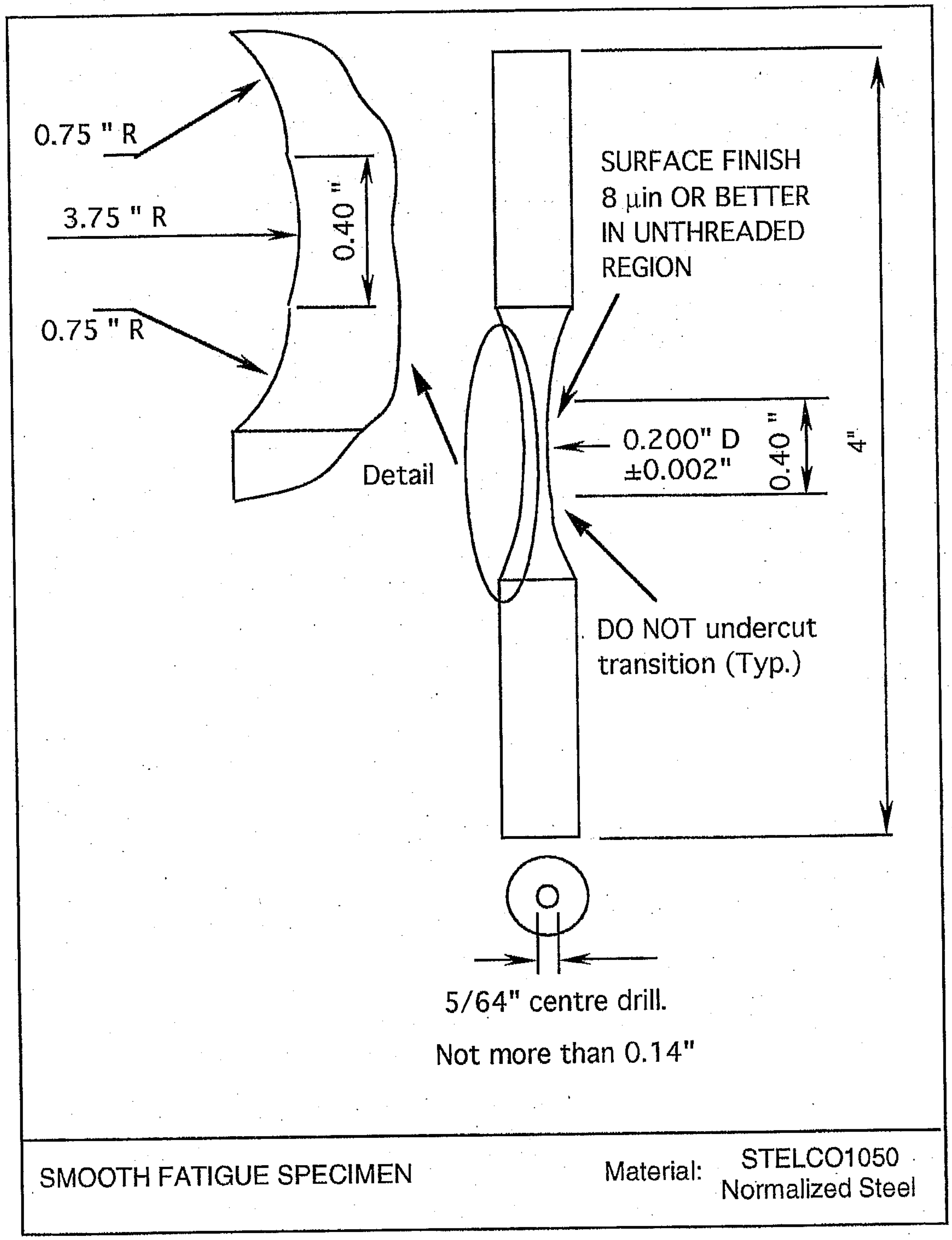
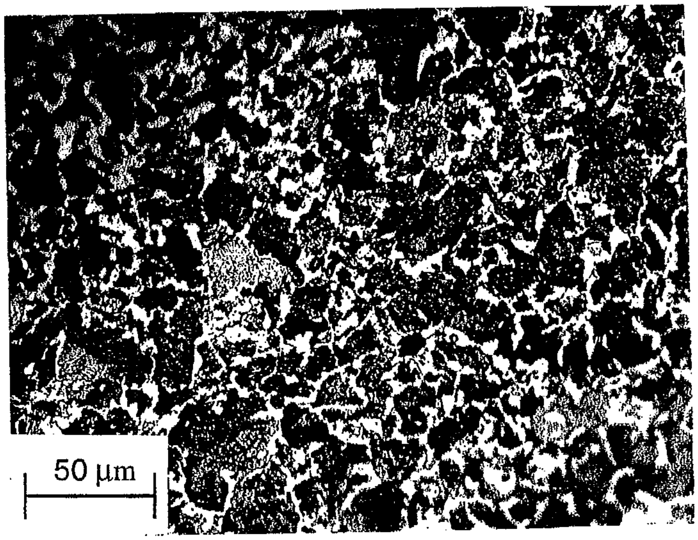


Fig. 1 Smooth cylindrical fatigue specimen



ITER 3: Photomicrograph of SAE 1050 steel, Normalized to Rb-94. **500X Mag.**

(a) Longitudinal direction

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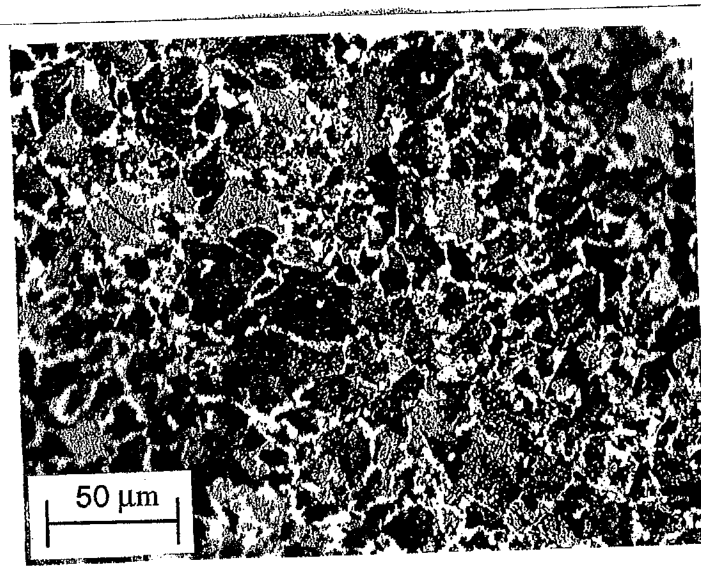

(b) Transverse direction

Fig. 2 photomicrograohs of STELCO 1050 normalized steel (X500)

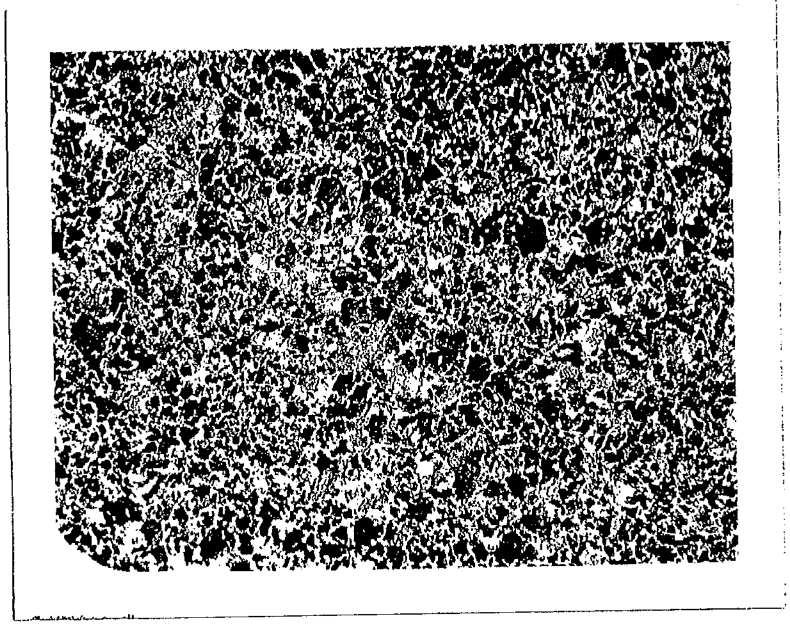

Fig. 2 A photomicrograoh of STELCO 1050 normalized steel (X200)

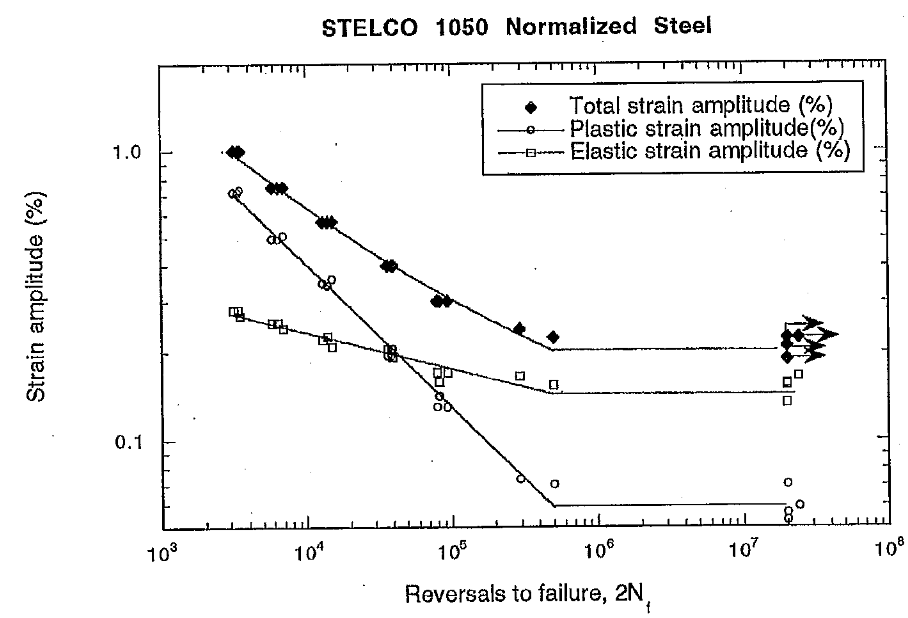

Fig. 3 Constant amplitude fully reversed strain-life curve for STELCO 1050 normalized steel

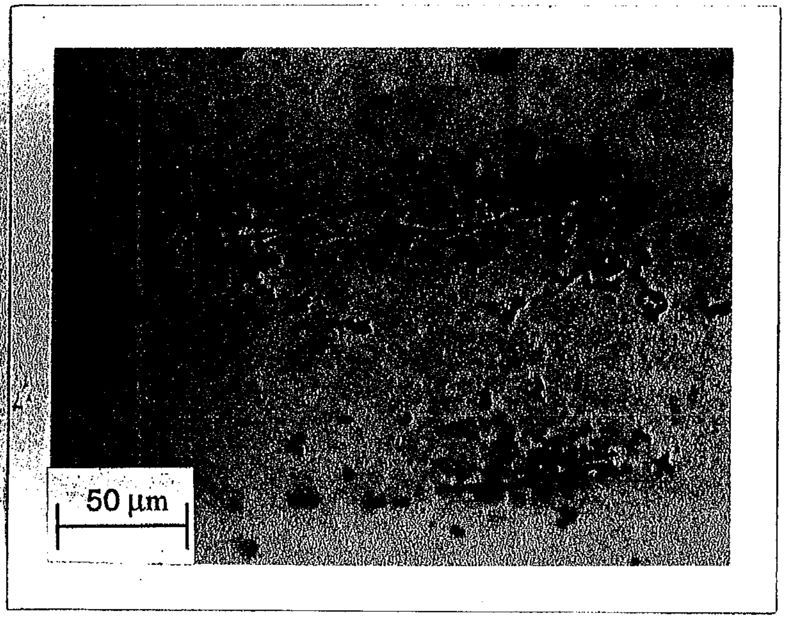

Fig. 3 Inclusions photomicrograoh of STELCO 1050 normalized steel (X500)

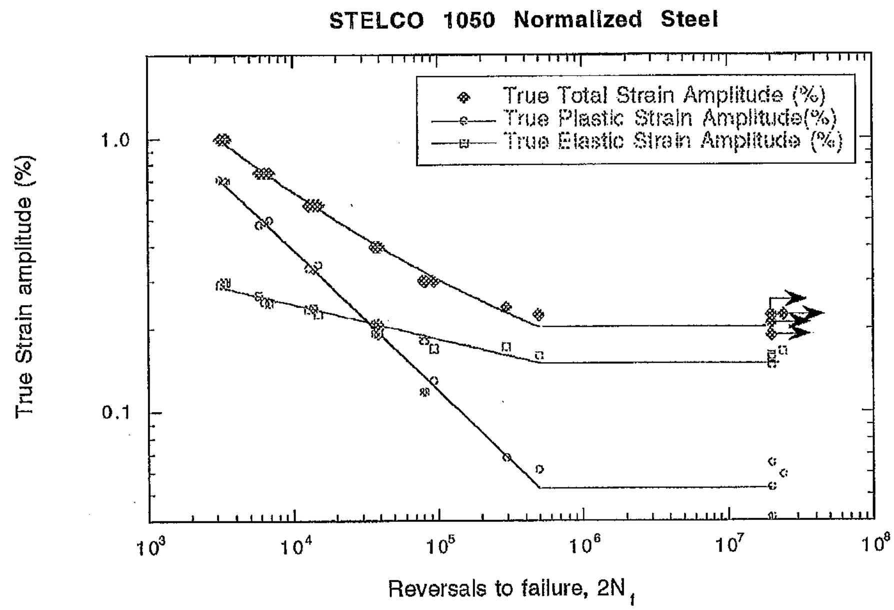

Fig. 4 Constant amplitude fully reversed strain-life curve for STELCO 1050 normalized steel

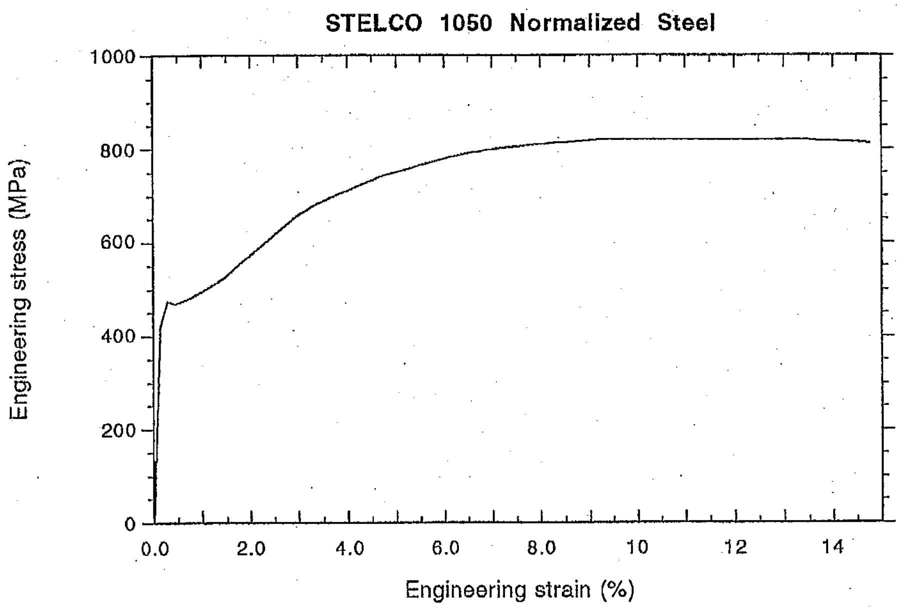

Fig. 4 Monotonic stress-strain curve for STELCO 1050 normalized steel

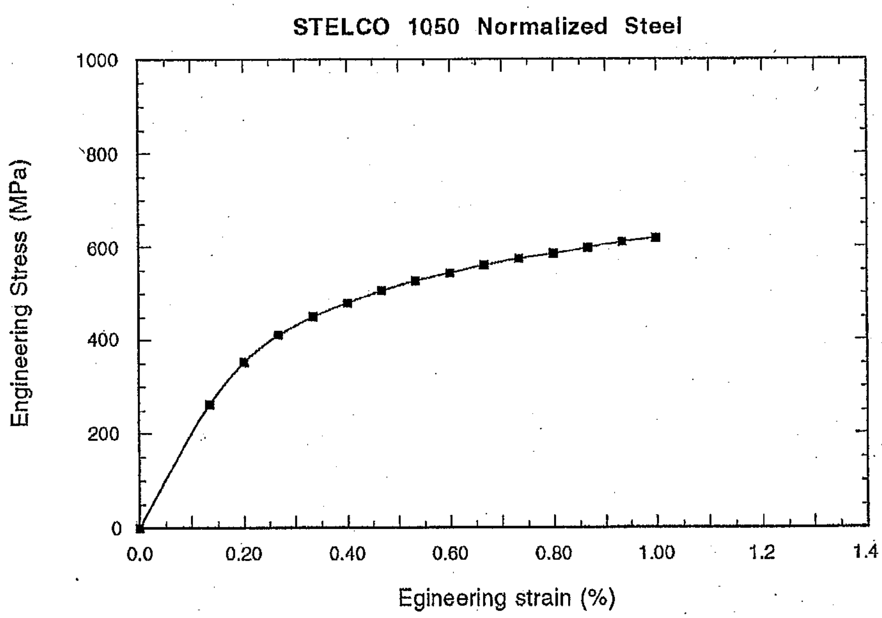

Fig. 5 Cyclic stress-strain curve for STELCO 1050 normalized steel

Appendix 1

Monotonic Properties for STELCO 1050 Normalized Steel

Elastic Modulus, E	=	210.00 GPa
Yield Strength	=	480.00 MPa
Ultimate tensile Strength	=	821.00 MPa
% Elongation	=	43.00 %
% Reduction of Area	=	49.59 %
True fracture strain	=	0.6849
True fracture stress	=	1724.0 MPa
Monotonic strength coefficient, K	=	1819.0 MPa
Monotonic strain hardening exponent, n	=	0.2744
Hardness, Rockwell B	=	94.00

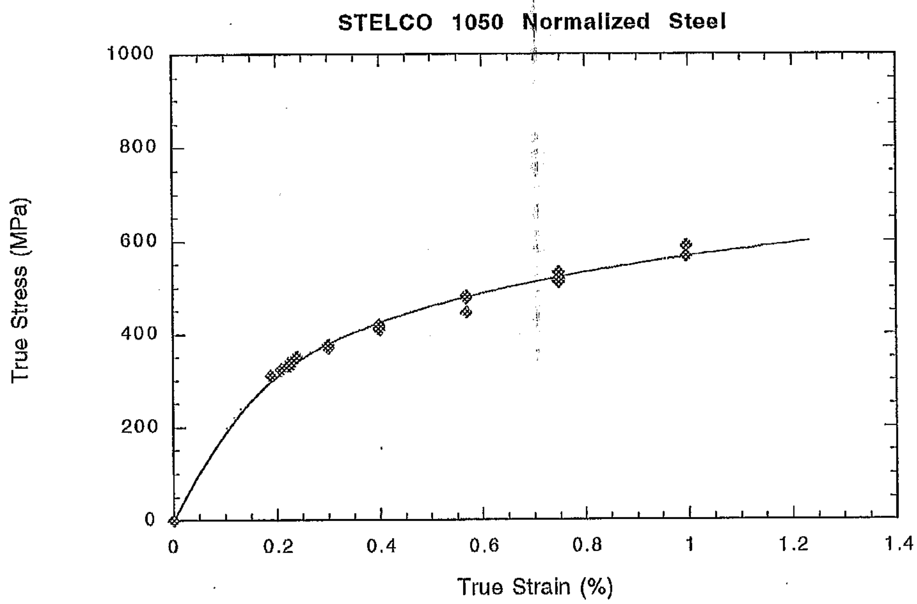

Fig. 6 Cyclic stress-strain curve for STELCO 1050 normalized steel

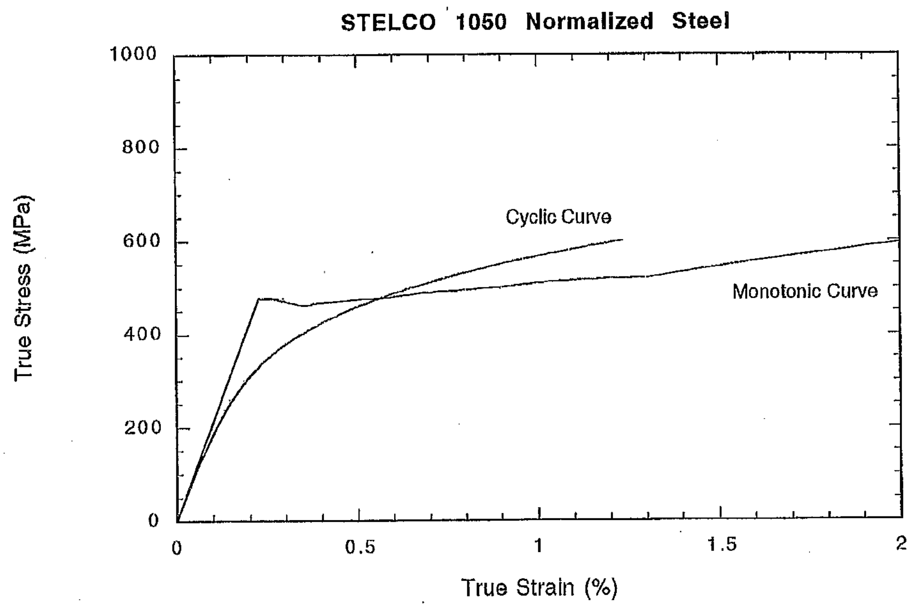

Fig. 7 Monotonic and Cyclic stress-strain curves for STELCO 1050 normalized steel

Table 1 Chemical composition of STELCO 1050 Normalized Steel

Carbon, C	0.51%
Manganese, Mn	0.87%
Phosphorous, P	0.023%
Sulfur, S	0.025%
Silicon, Si	0.23%
Copper, Cu	0.02%
Nickel, Ni	0.01%
Chromium, Cr	0.06%
Molybdenum, Mo	<0.01%
Vanadium, Va	0.003%
Columbium, Cb	0.003%

Table 2 Tensile and Fatigue Test Data for STELCO 1050 Normalized 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)	ENG. Yield Stress (MPa)	Hardness (HRB)
SA	0.29955	370.11	0.12942	0.16986	93,092	212.89	462	
SE	0.29955	369.10	0.11803	0.18168	81,934	209.76	460	
SQ	0.22475	336.76	0.058983	0.16536	24092878*	207.97		
SN	0.3992	414.65	0.19172	0.20783	36,742	211.14	475	94.5
S1	0.3992	408.63	0.19466	0.20489	39,544	211.83	473	93
S6	0.99503	589.84	0.706	0.29058	3,150	212.68		
S6	0.22475	330.74	0.064918	0.15987	20000000*	211.55		
S2	0.22475	329.74	0.061431	0.15987	500,000	206.59		
S7	0.99503	566.61	0.70004	0.29656	3,452	203.27		
S7	0.20978	323.68	0.052986	0.15638	20000000*	213.22		
S5	0.23971	350.84	0.067877	0.17185	296,790	213.8	481	
SM	0.99503	588.83	0.70004	0.29656	3,350	204.66		
SM	0.18982	309.59	0.04129	0.1483	20000000*	210.5		
S8	0.7472	518.86	0.50069	0.24769	6,832	213.56	501	94.5
SL	0.7472	531.96	0.49477	0.25318	6,342	208.64	497	
SF	0.56838	481.73	0.33295	0.23572	12,926	209.27	492	
SR	0.56838	445.53	0.34191	0.22674	15,026	210.91	472	
SP	0.29955	376.13	0.11793	0.18134	79,200	211.86	478	
SS	0.56838	476.70	0.32996	0.23871	13,872	216	484	
SK	0.7472	511.81	0.48283	0.26515	5,822	204.95		
SD	0.3992	419.67	0.18882	0.21078	38,640	207.12	492	

* Run out

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Appendix 1

Monotonic Properties for STELCO 1050 Normalized Steel

Average Elastic Modulus, E	=	210.84 GPa
Upper Yield Strength	=	475.41 MPa
Lower Yield Strength	=	449.60 MPa
Ultimate tensile Strength	=	821.00 MPa
% Elongation	=	43.00 %
% Reduction of Area	=	49.59 %
True fracture strain, $Ln\ (A_i / A_f)$	=	70 %
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$	=	1372 MPa
Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \bigg/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$	=	1128 MPa
Monotonic strength coefficient, K	=	1819.0 MPa
Monotonic strain hardening exponent, n	=	0.2744
Hardness, Rockwell B (HRB)	=	94.00

Cyclic Properties for STELCO 1050 Normalized Steel

Cyclic Yield Strength, (0.2% offset) $= K'(0.002)^{n'}$	=	~~426~~ MPa 412
Cyclic strength coefficient, K'	=	~~1672.60~~ MPa 1981
Cyclic strain hardening exponent, n'	=	~~0.2198~~ 0.2529
Fatigue Strength Coefficient, σ'_f	=	~~988.88~~ MPa 1552
Fatigue Strength Exponent, b	=	~~-0.126~~ -0.125
Fatigue Ductility Coefficient, ε'_f	=	~~0.4332~~ 0.3768
Fatigue Ductility Exponent, c	=	~~-0.5116~~ -0.4996

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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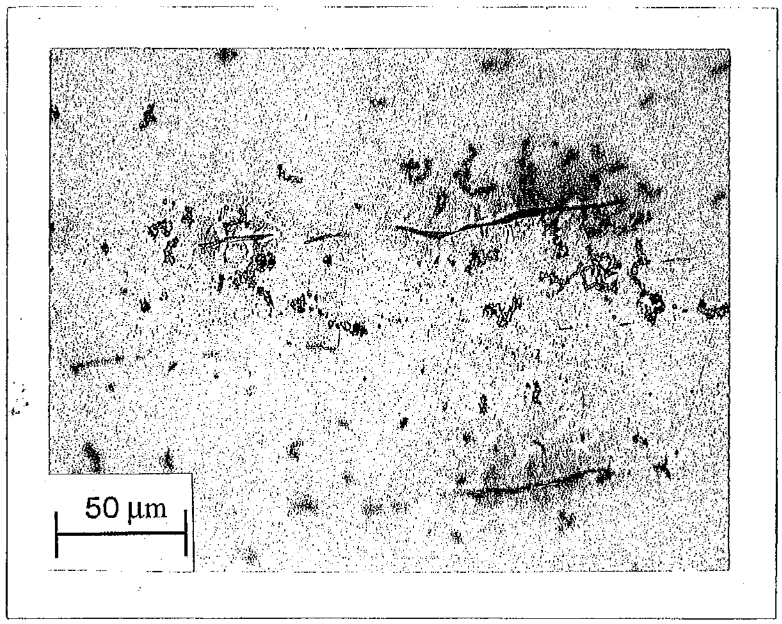
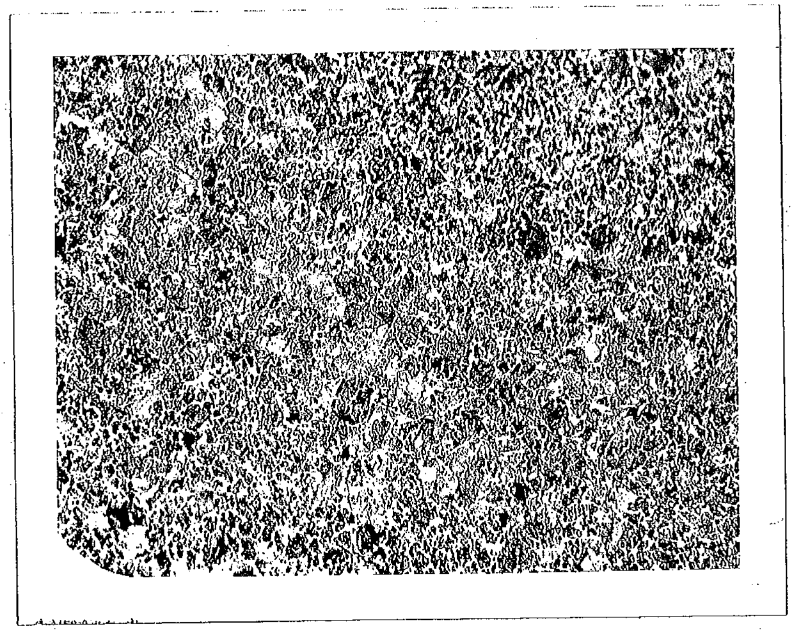


Fig. 3 Inclusions photomicrograoh of STELCO 1050 normalized steel (X500)



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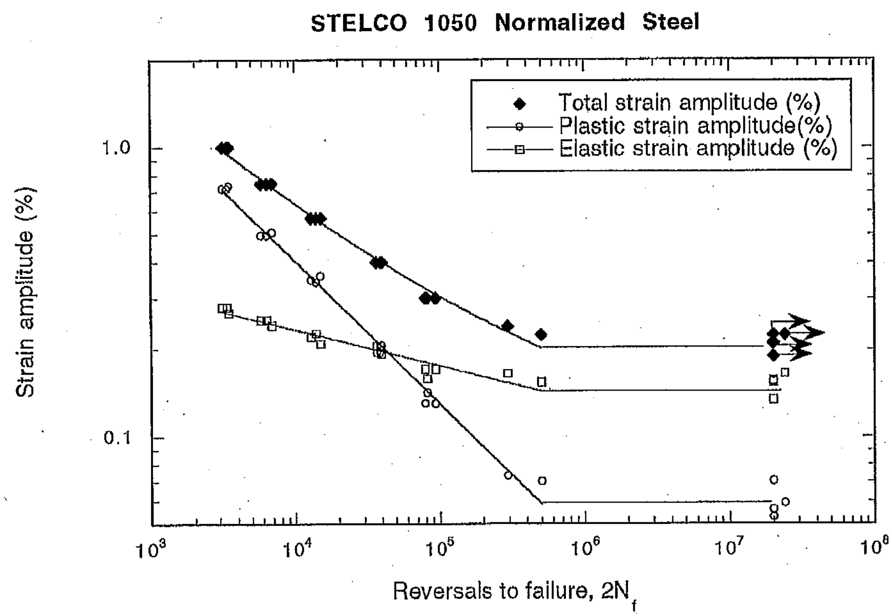
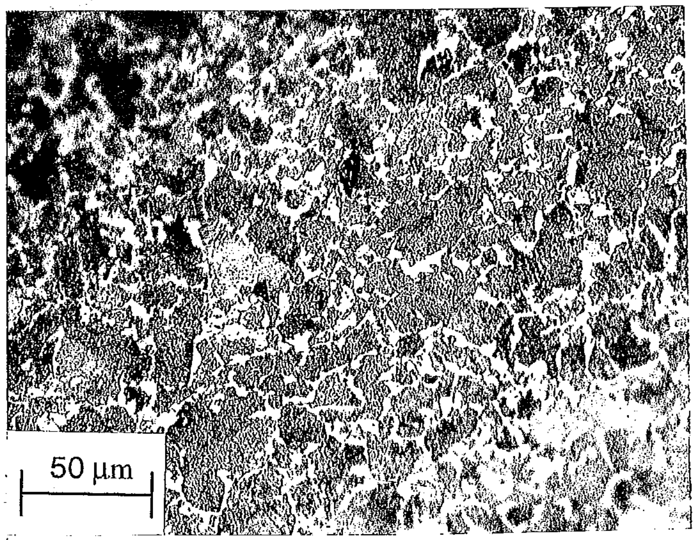


Fig. 3 Constant amplitude fully reversed strain-life curve for STELCO 1050 normalized steel



ITER 3: Photomicrograph of SAE 1050 steel, Normalized to Rb-94. 500X Mag.

(a) Longitudinal direction

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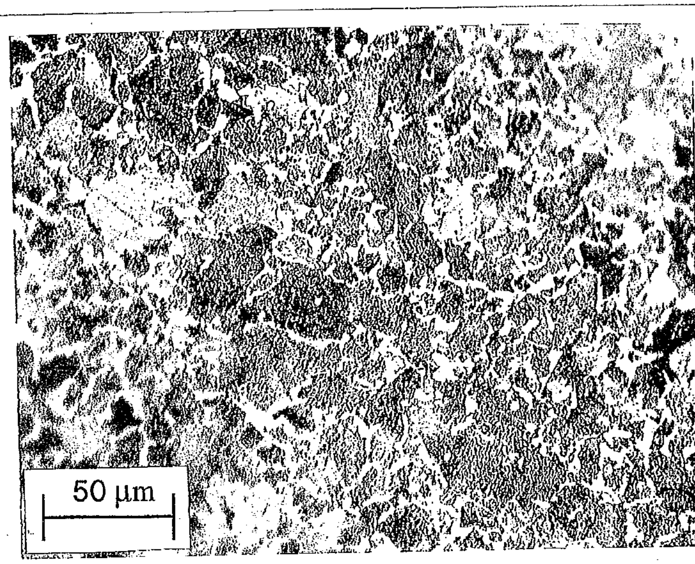

(b) Transverse direction

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