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Fatigue Behavior, Monotonic Properties
and
Microstructure Data
for
8620, Carburized H.T. (Core) Steel
(Iteration No. 39)

By

M. Khalil,

T. H. Topper

Department of Civil Engineering,

University of Waterloo

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SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for 8620 Carburized H. T. (Core) steel (Iteration # 39) have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of 3.26" bars. These bars were machined into smooth axial fatigue specimens. The specimens were carburized at Meritor Inc. after had been copper plated to reach a hardness of about 45 Rc. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Twenty-two 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 24, 8620 Carburized H. T. (Core) 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, 22 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 martensite microstructure of the 8620 Carburized H. T. (Core) steel. A Type D thick series inclusion severity level of 3 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 8620 Carburized H. T. (Core) steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 8620 Carburized H. T. (Core) steel was provided by the Inland Steel Company, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for 8620 Carburized H. T. (Core) 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 8620 Carburized H. T. (Core) 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 $\sigma'_f = 3875$ MPa, $b = -0.14$, $\varepsilon'_f = 4.8$ and $c = -0.962$. These values of the strain-life parameters were determined from fatigue testing over the range: $0.0026 < \frac{\Delta\varepsilon}{2} < 0.013$.

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 $K' = 2881$ MPa and $n' = 0.127$.

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 8620 Carburized H. T. (Core) 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.

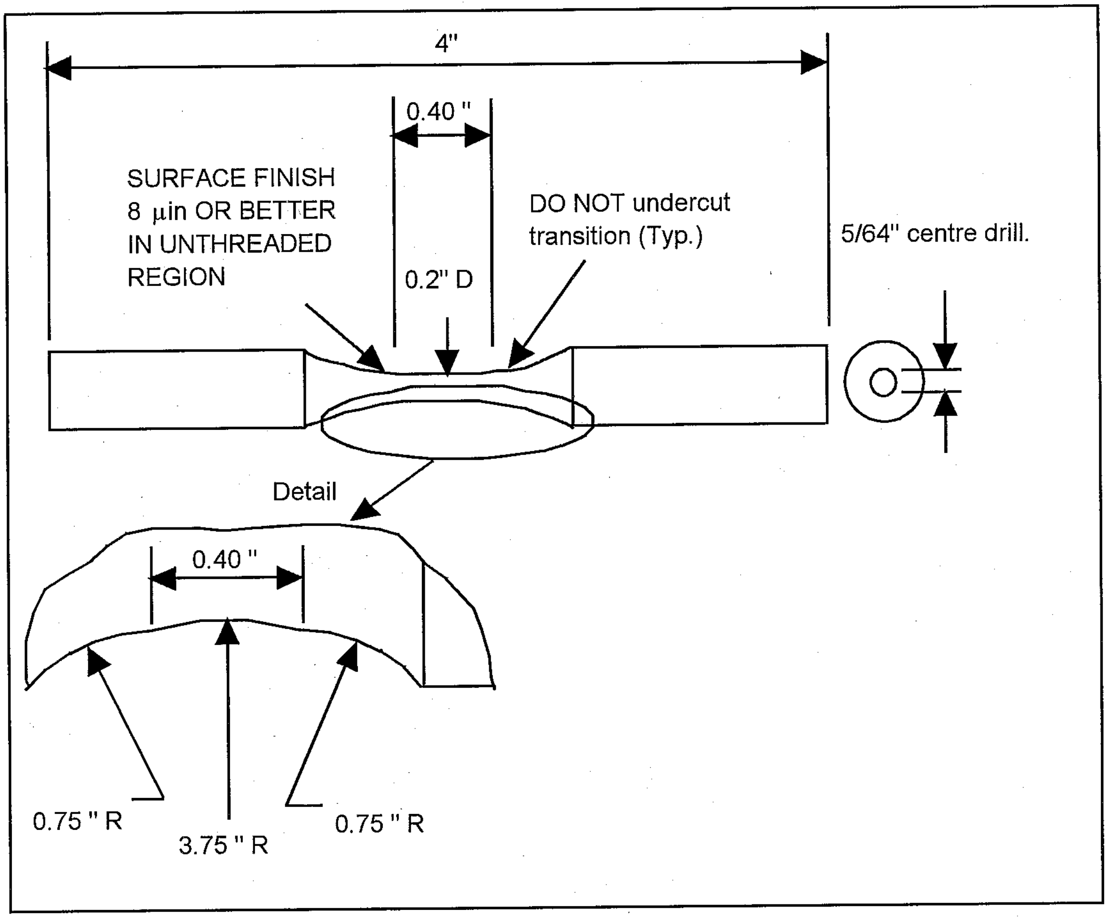
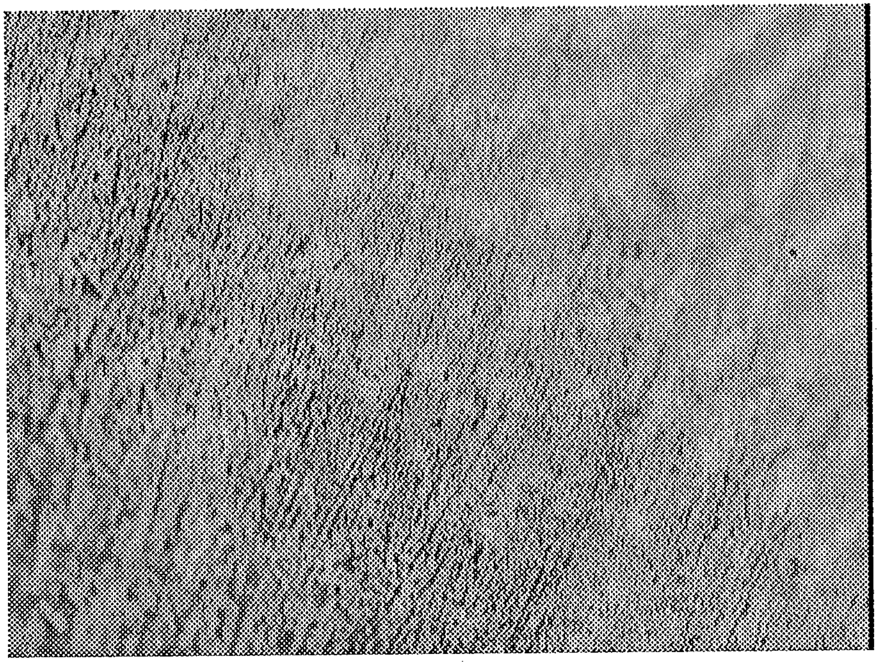
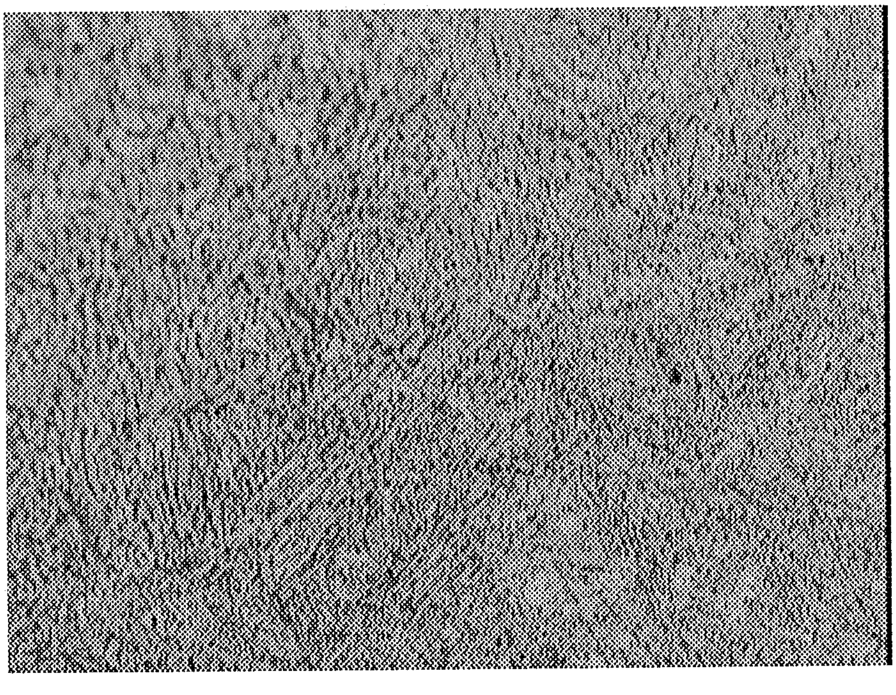


Fig. 1 Smooth cylindrical fatigue specimen

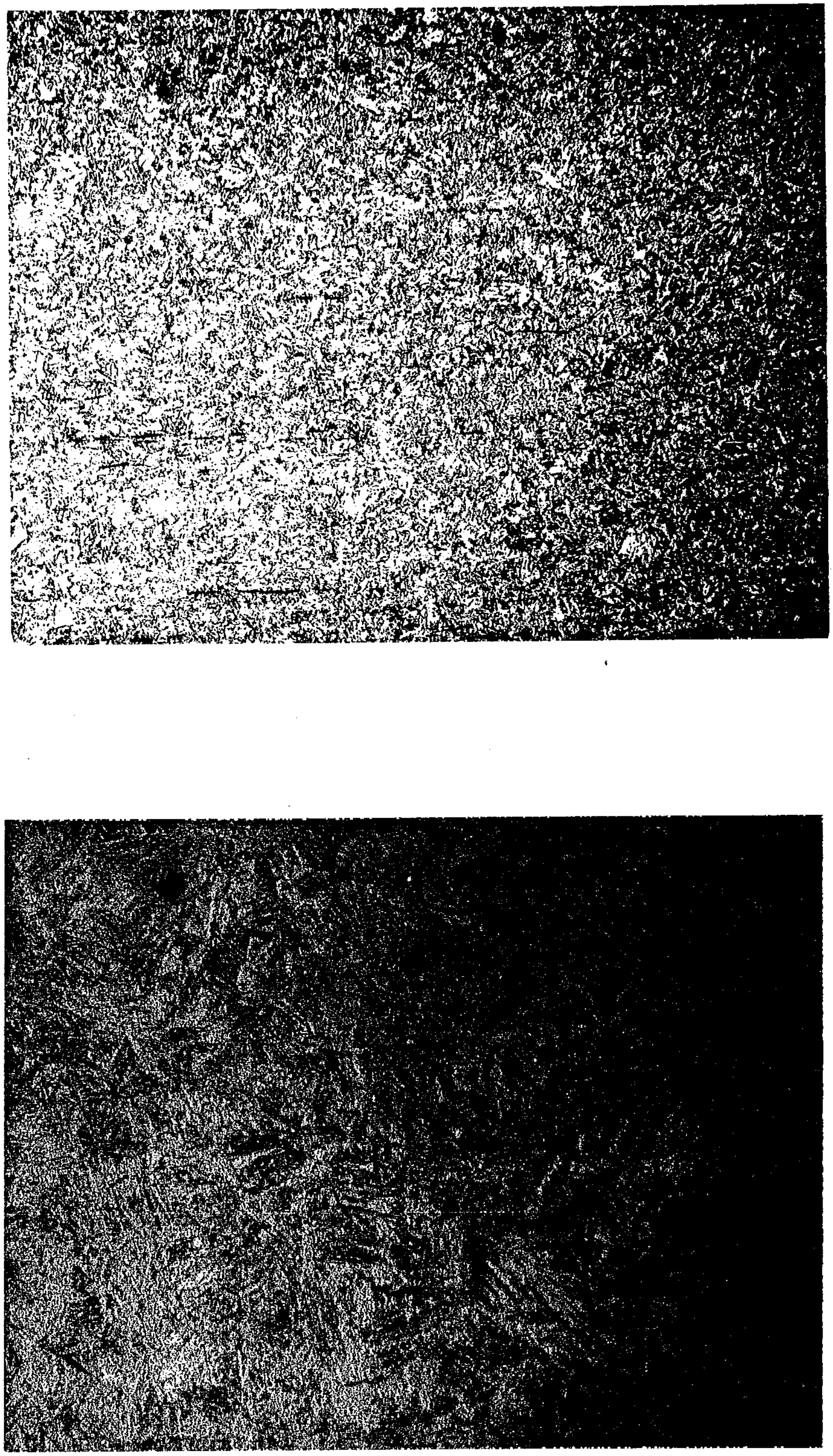


(a) Longitudinal Direction



(b) Transverse Direction

Fig. 2 Photomicrographs of 8620 Carburized H. T. (Core) steel (X500)



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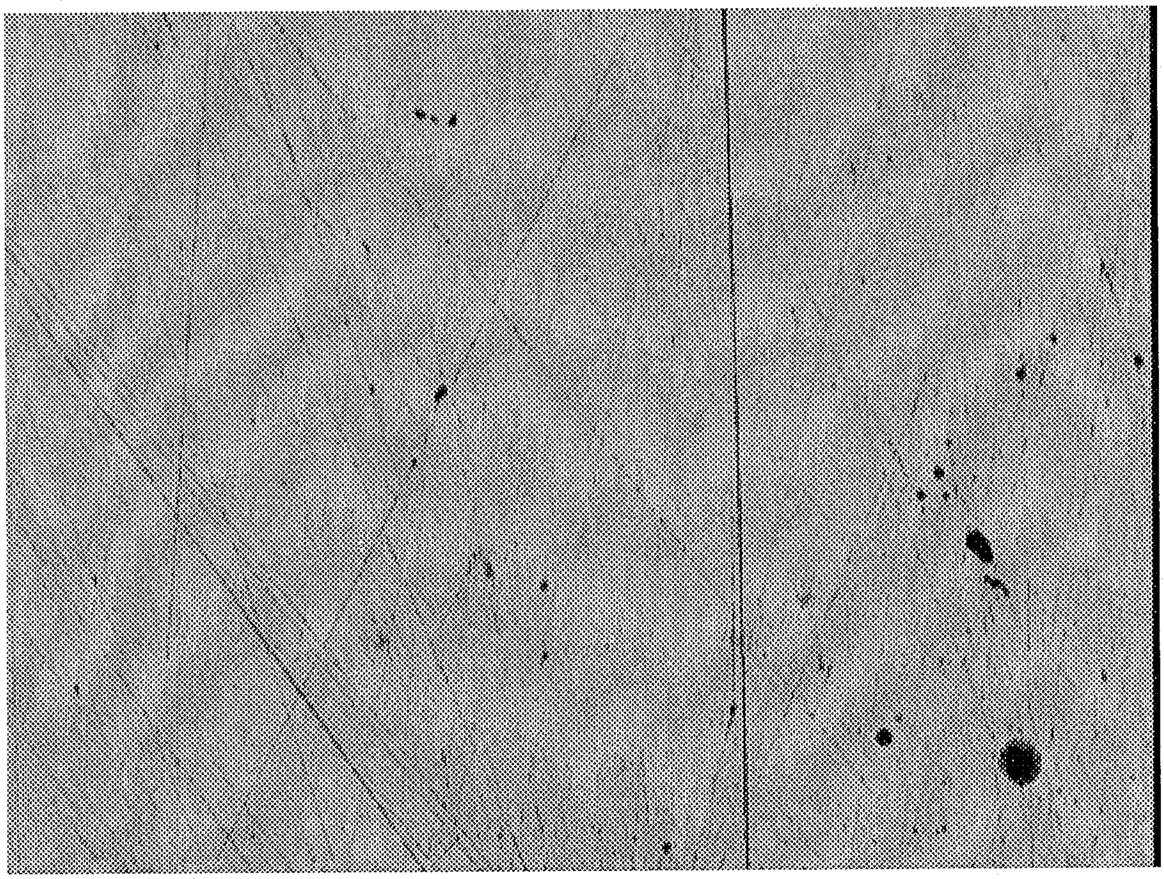


Fig. 3 Inclusions photomicrograph of 8620 Carburized H. T. (Core) steel (X100)

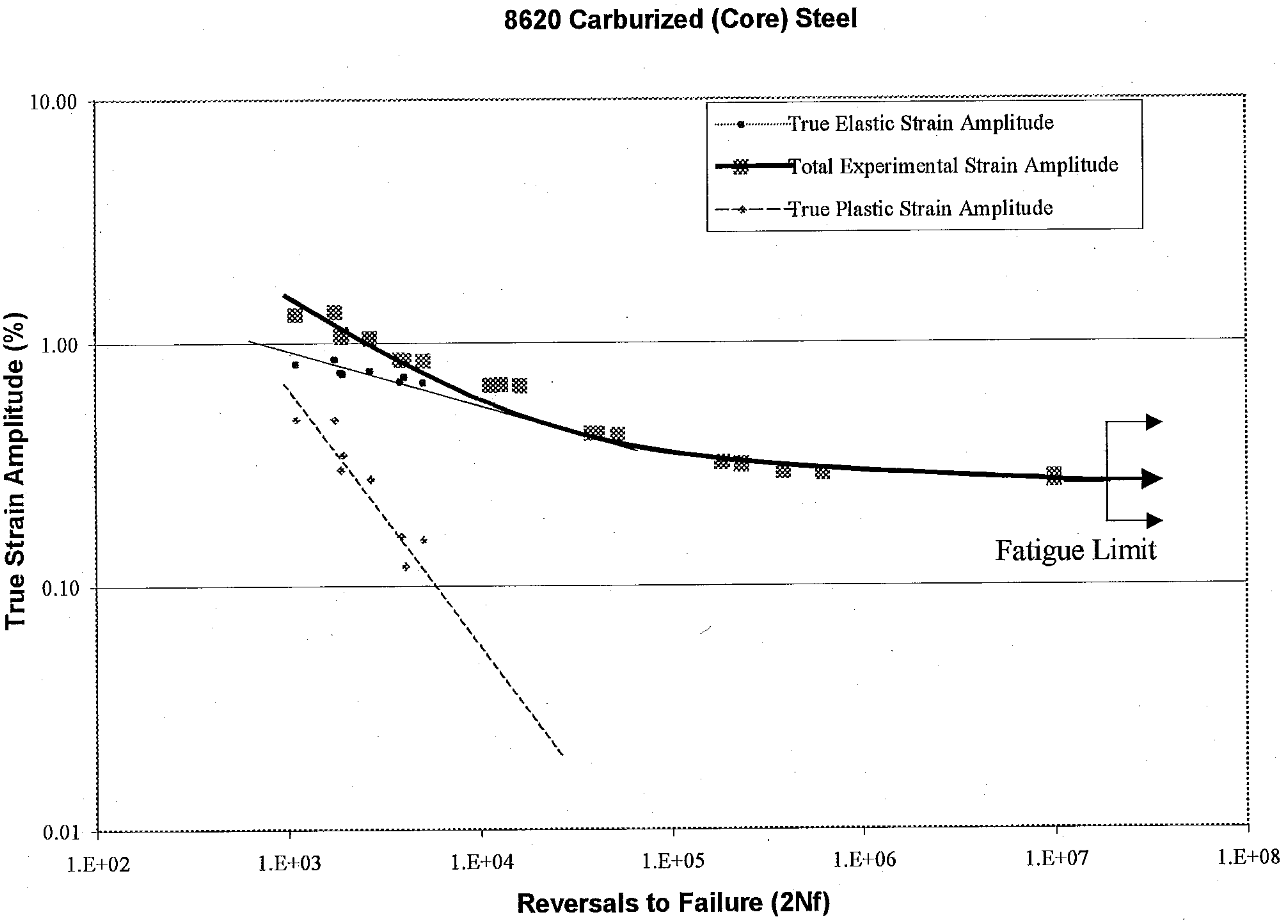


Figure 4. Constant amplitude fully reversed strain-life curve for 8620 Carburized H. T. (Core) steel.

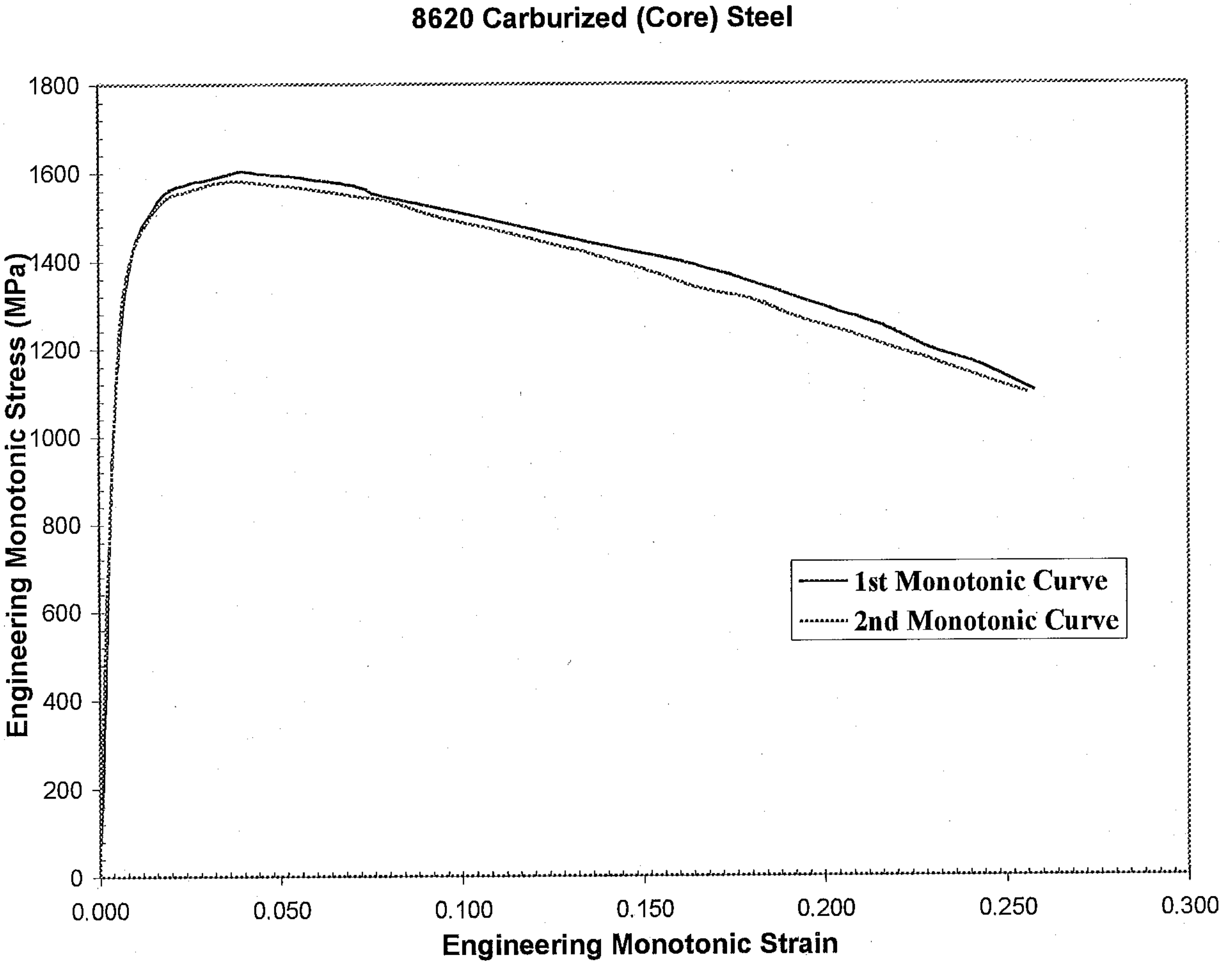


Figure 5. Monotonic stress-strain curves for two 8620 Carburized H. T. (Core) steel specimens.

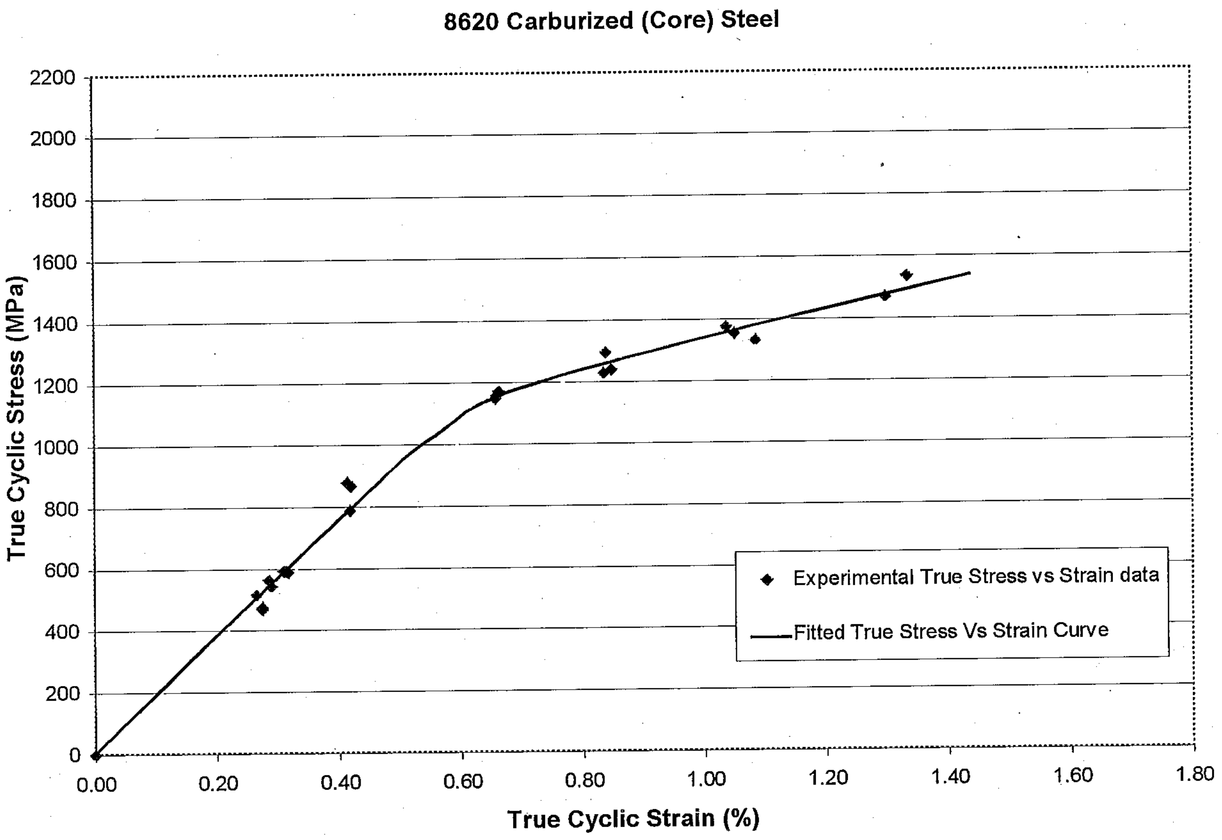


Figure 6. Cyclic stress-strain curve for 8620 Carburized H. T. (Core) steel.

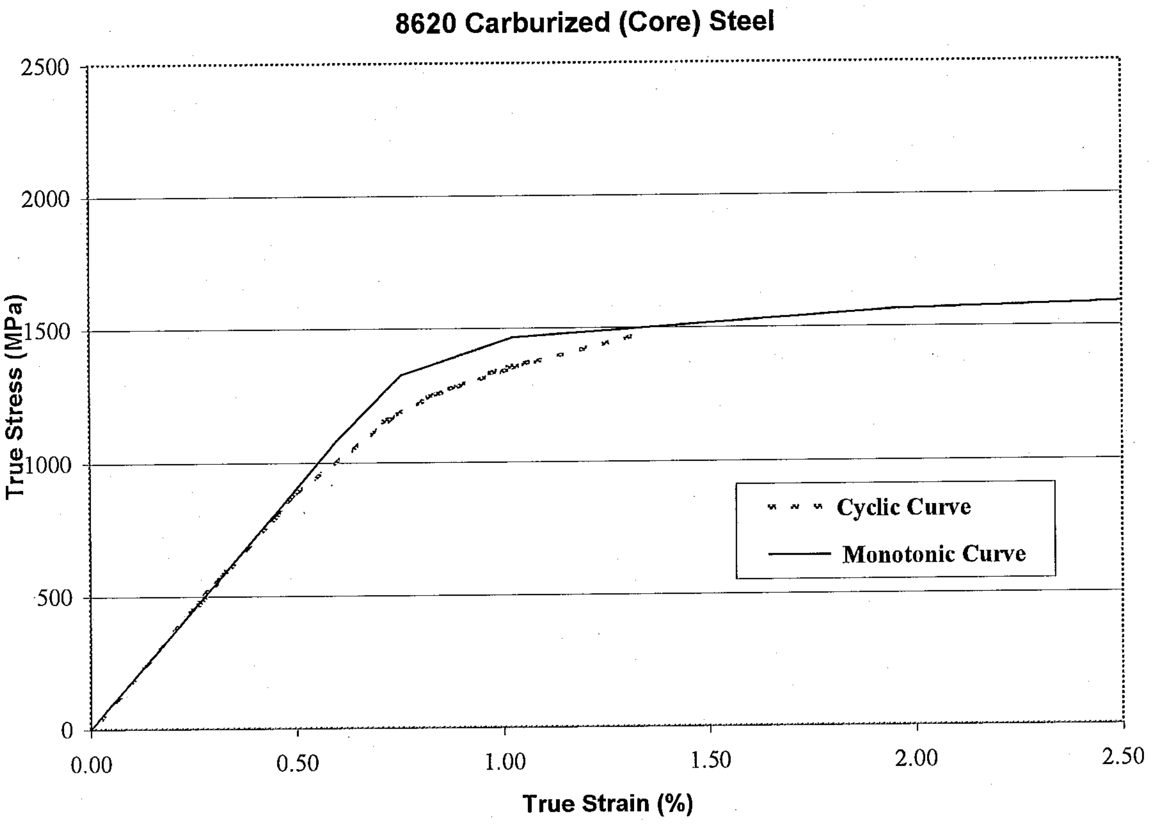


Fig. 7 Monotonic and Cyclic stress-strain curves for 8620 Carburized H. T. (Core) steel.

Table 1 Chemical composition of 8620 Carburized H. T. (Core) steel.

Carbon, C	0. 23%
Manganese, Mn	0.82%
Phosphorous, P	0.011%
Sulfur, S	0.027%
Silicon, Si	0.25%
Copper, Cu	0.016%
Nickel, Ni	0.48%
Chromium, Cr	0.5%
Molybdenum, Mo	0.18%
Sn	0.003%
As	0.002%
Vanadium, Va	
N	0.004%
Ti	0.003%
Nb	0.002%
V	0.005%
Pb	0.001%
Te	0.0009%

Table 2 Tensile and Fatigue Test Data for 8620 Carburized H. T. (Core) 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)
8	1.335	1536	0.482	0.853	1780	182	42
10	1.300	1468	0.484	0.816	1112	175	45
11	1.086	1332	0.346	0.740	1940	183	43
18	1.052	1354	0.300	0.752	1906	179	45
3	1.039	1376	0.274	0.764	2700	180	44
17	0.848	1240	0.159	0.689	3878	180	42
22	0.840	1295	0.120	0.720	4080	186	44
2	0.836	1229	0.154	0.683	5100	181	48
16	0.661	1160	0.016	0.645	11388	181	45
6	0.658	1149	0.019	0.639	16340	178	45
21	0.664	1172	0.013	0.651	12920	178	45
13	0.420	868	0.000	0.420	38488	185	44
20	0.419	787	0.000	0.419	41428	177	43
1	0.414	879	0.000	0.414	53124	180	45
4	0.317	588	0.000	0.317	185944	176	45
14	0.314	591	0.000	0.314	234044	180	44
19	0.310	593	0.000	0.310	232756	179	45
15	0.291	545	0.000	0.291	389116	182	44
7	0.286	564	0.000	0.286	619038	188	43
9*	0.276	477	0.000	0.276	10000000	182	45
12*	0.276	468	0.000	0.276	10000000	176	45
5*	0.266	516	0.000	0.266	10000000	177	43

* Run out

Appendix 1

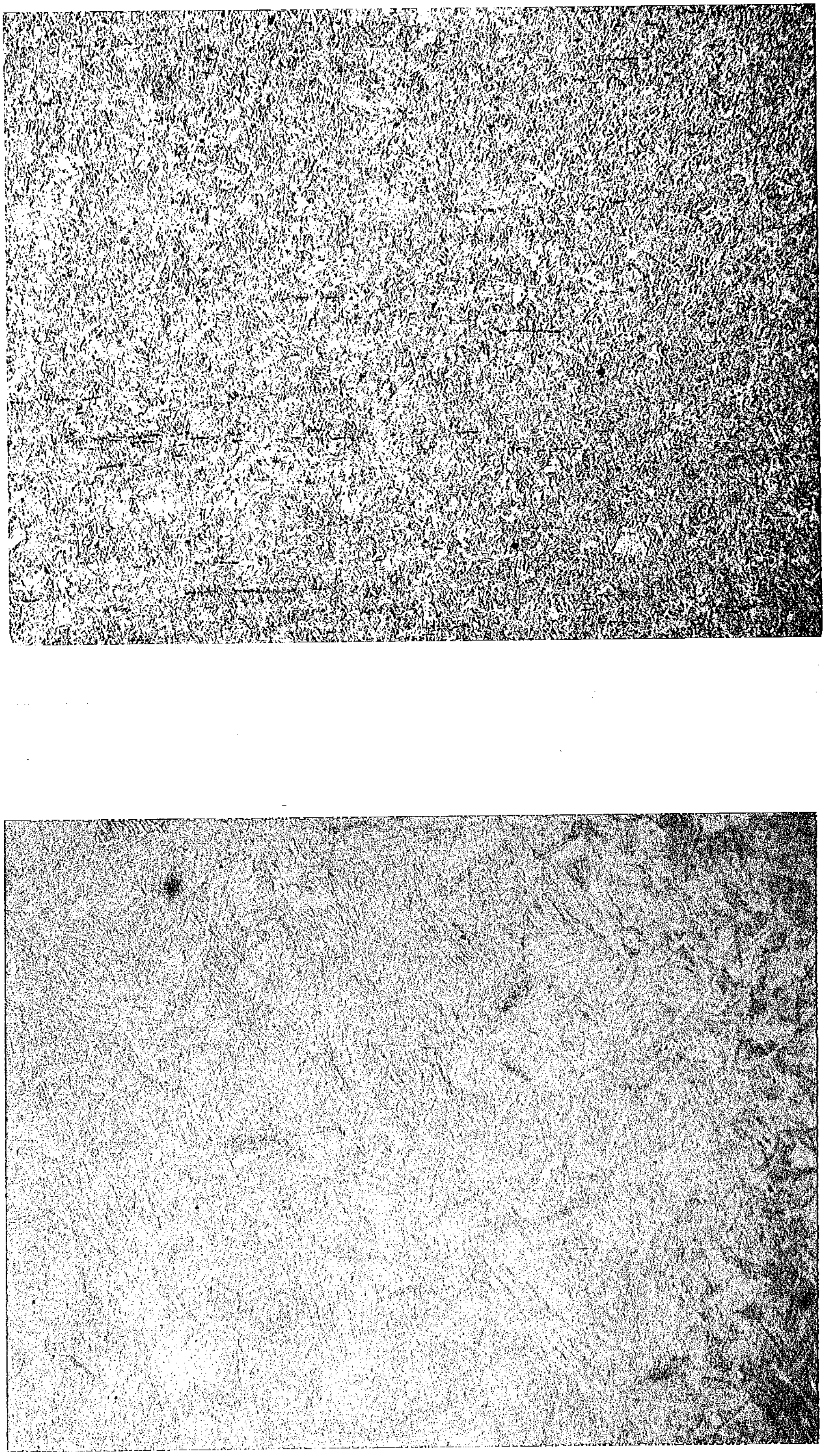
Monotonic Properties for 8620 Carburized H. T. (Core) steel.

Average Elastic Modulus, E = 180 GPa
Yield Strength = 1420 MPa
Ultimate tensile Strength = 1683 MPa
% Elongation = 47.7 %
% Reduction of Area = 36.2 %
True fracture strain, $Ln\ (A_i / A_f)$ = 78.1 %
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$ = 2999 MPa
Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$ =2601 MPa
Monotonic strength coefficient, K = 1876 MPa
Monotonic strain hardening exponent, n = 0.04
Hardness, Rockwell C (HRC) = 45
Hardness, Brinell = 430

Cyclic Properties for 8620 Carburized H. T. (Core) steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ = 1308 MPa
Cyclic strength coefficient, K' = 2881 MPa
Cyclic strain hardening exponent, n' = 0.127
Fatigue Strength Coefficient, σ'_f = 3875 MPa
Fatigue Strength Exponent, b = -0.14
Fatigue Ductility Coefficient, ε'_f = $\boxed{4.8}$ — ?
Fatigue Ductility Exponent, c = -0.962

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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