Fatigue Behavior, Monotonic Properties
and
Microstructure Data
for
8620, Through Carburized (Case) Steel
(Iteration No. 38)

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 Through Carburized (Case) steel (Iteration # 38) 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 Daimler Chrysler Inc. to reach a hardness of about 59 Rc. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the 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 21, 8620 Through Carburized (Case) 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, 19 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 °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 Through Carburized (Case) steel. A Type D thin series inclusion severity level of 1.5 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 Through Carburized (Case) steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 8620 Through Carburized (Case) steel was provided by the Inland Steel Company, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for 8620 Through Carburized (Case) 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 Through Carburized (Case) 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 $\sigma'_f = 1283$ MPa, $b = -0.0711$, $\varepsilon'_f = 0.142$ and $c = -0.11$. These values of the strain-life parameters were determined from fatigue testing over the range: $0.00175 < \frac{\Delta\varepsilon}{2} < 0.00658$.

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 $K' = 3493$ MPa and $n' = 0.196$.

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 Through Carburized (Case) 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.

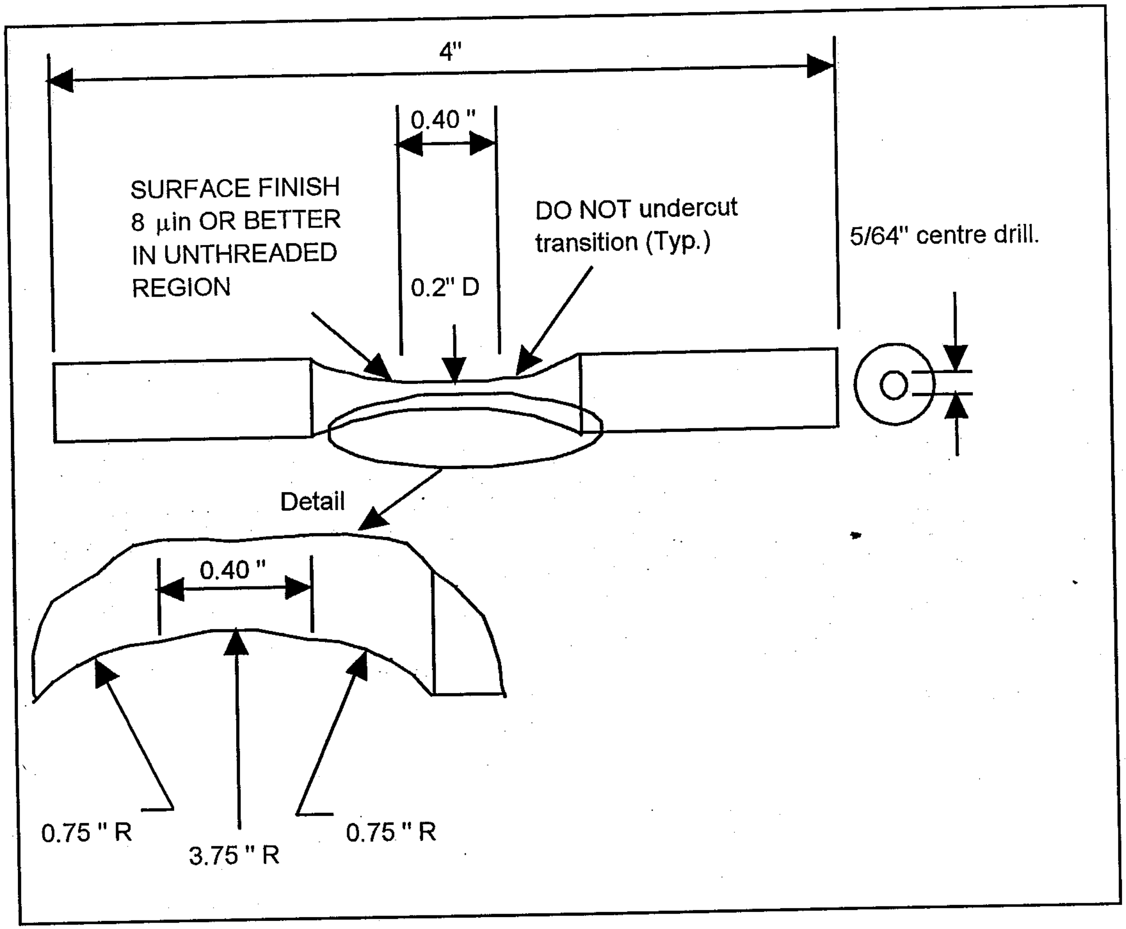
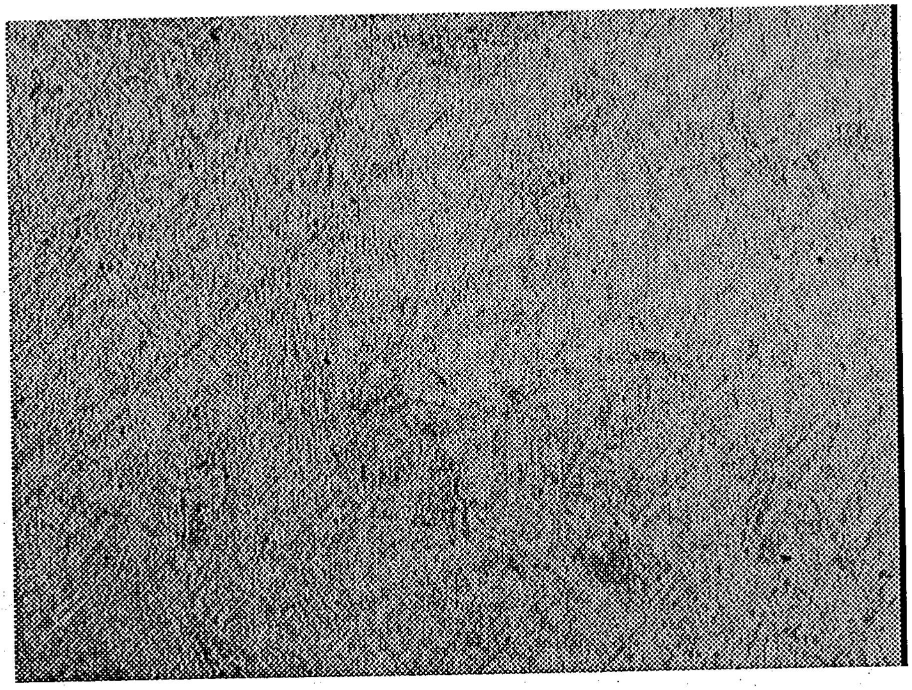
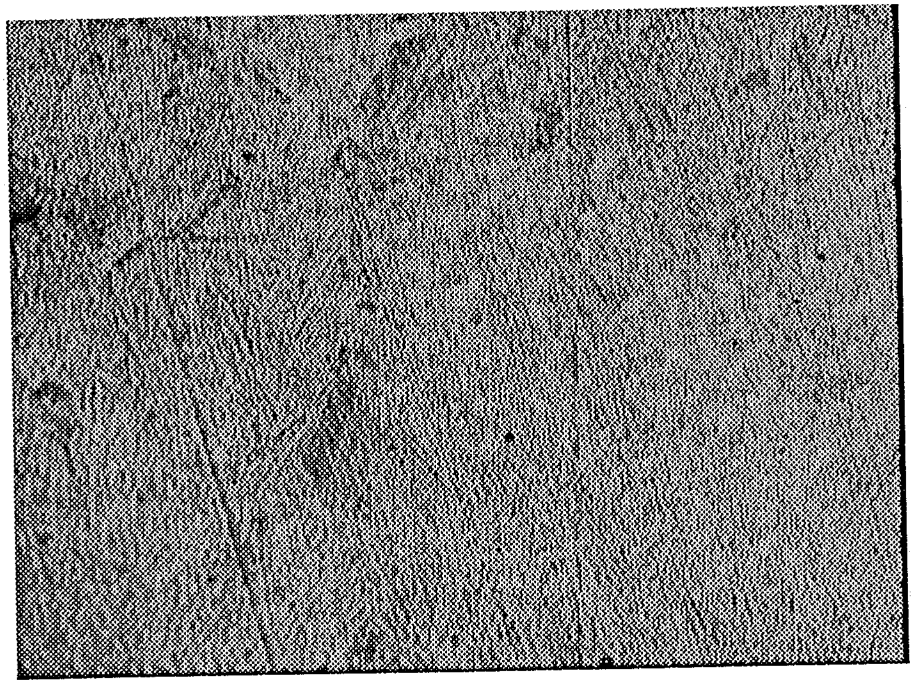


Figure 1. Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2. Photomicrographs of 8620 Through Carburized (Case) steel (X500)

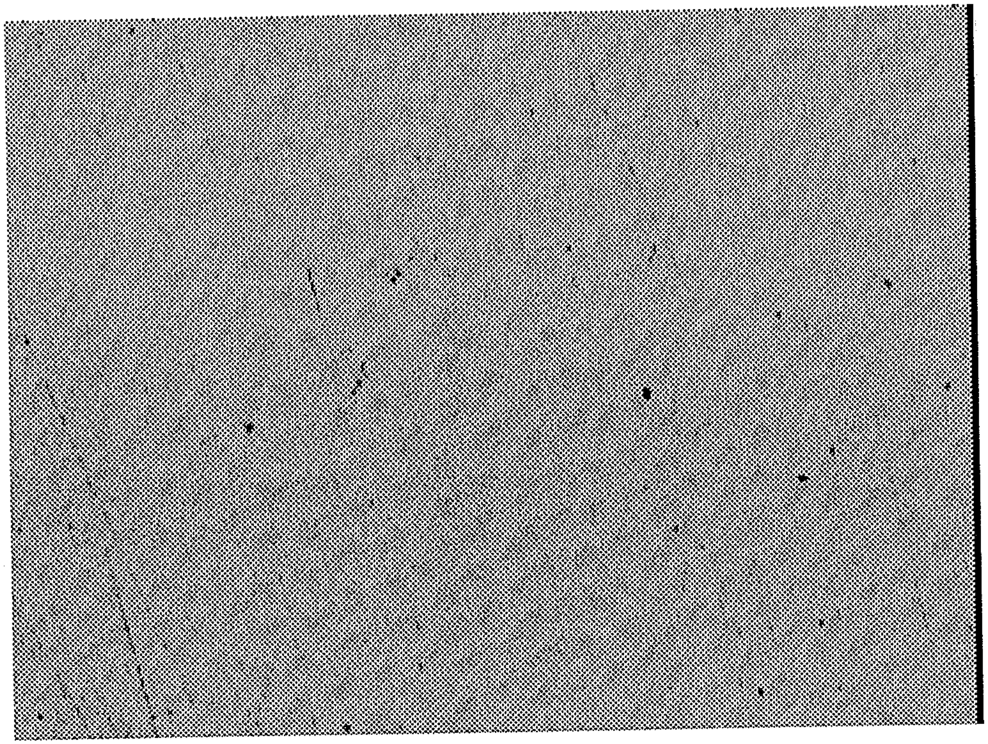


Figure 3. Inclusions photomicrograph of 8620 Through Carburized (Case) steel (X100)

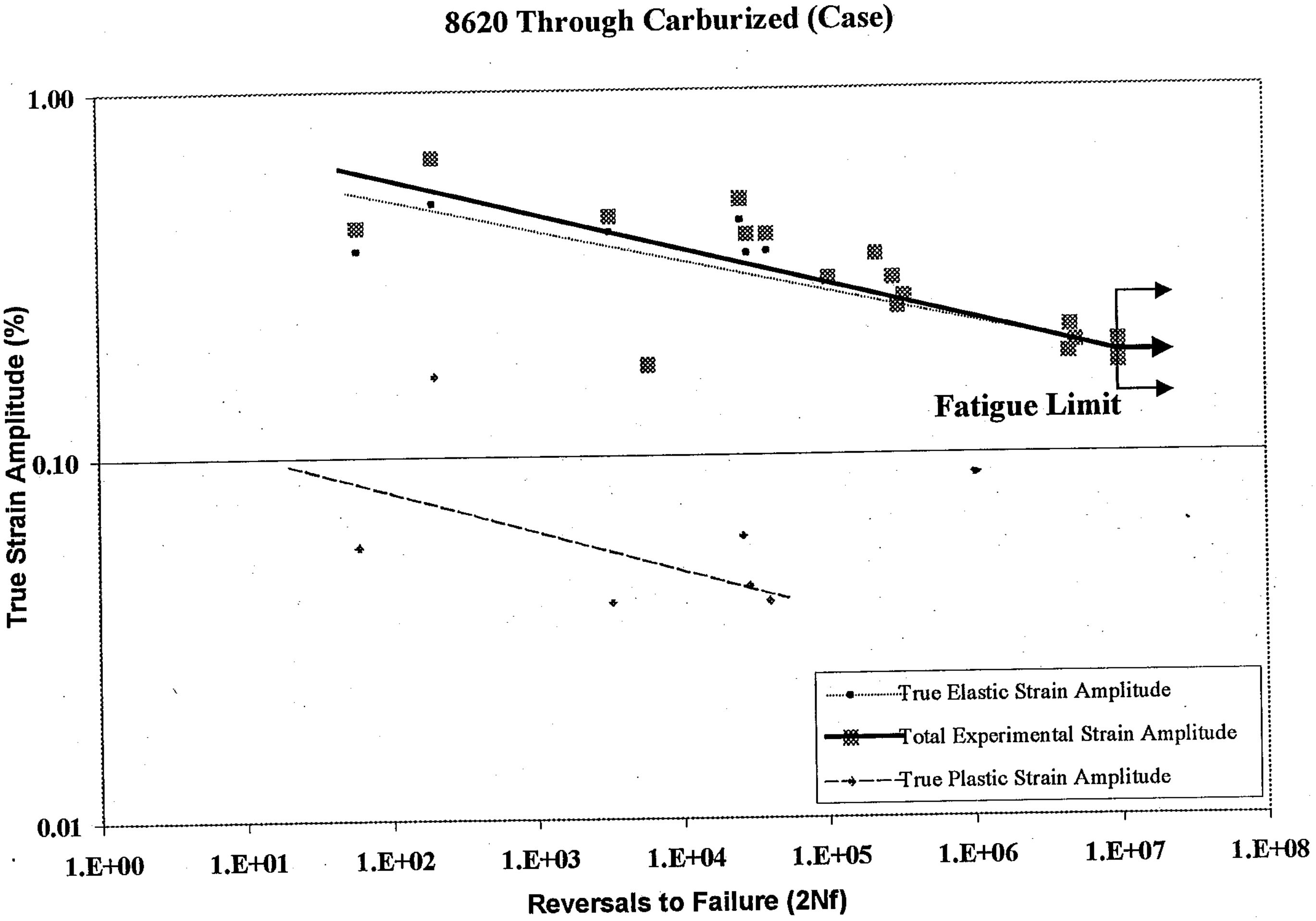


Figure 4. Constant amplitude fully reversed strain-life curve for 8620 Through Carburized (Case) steel.

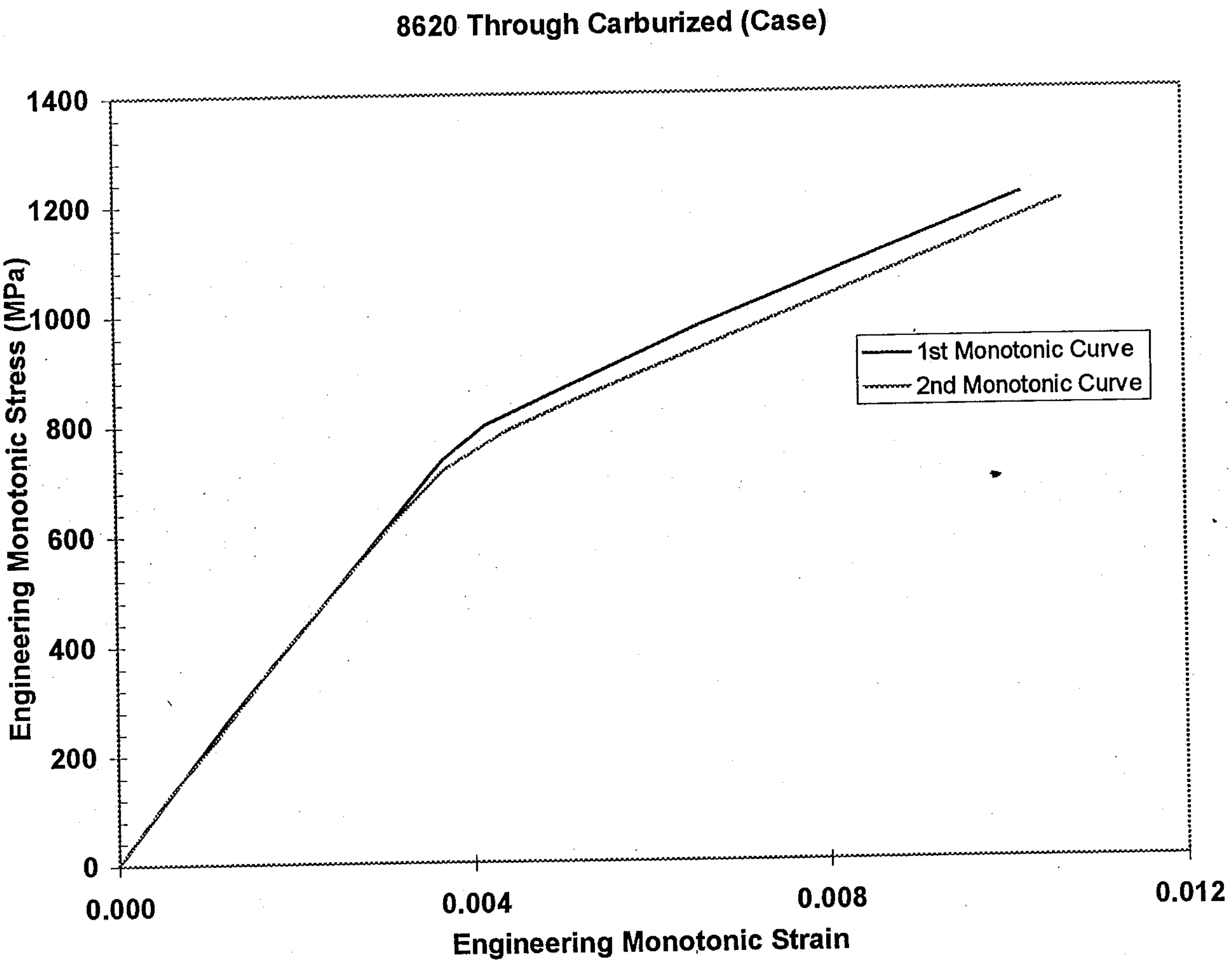


Figure 5. Monotonic stress-strain curves for two 8620 Through Carburized (Case) steel specimens.

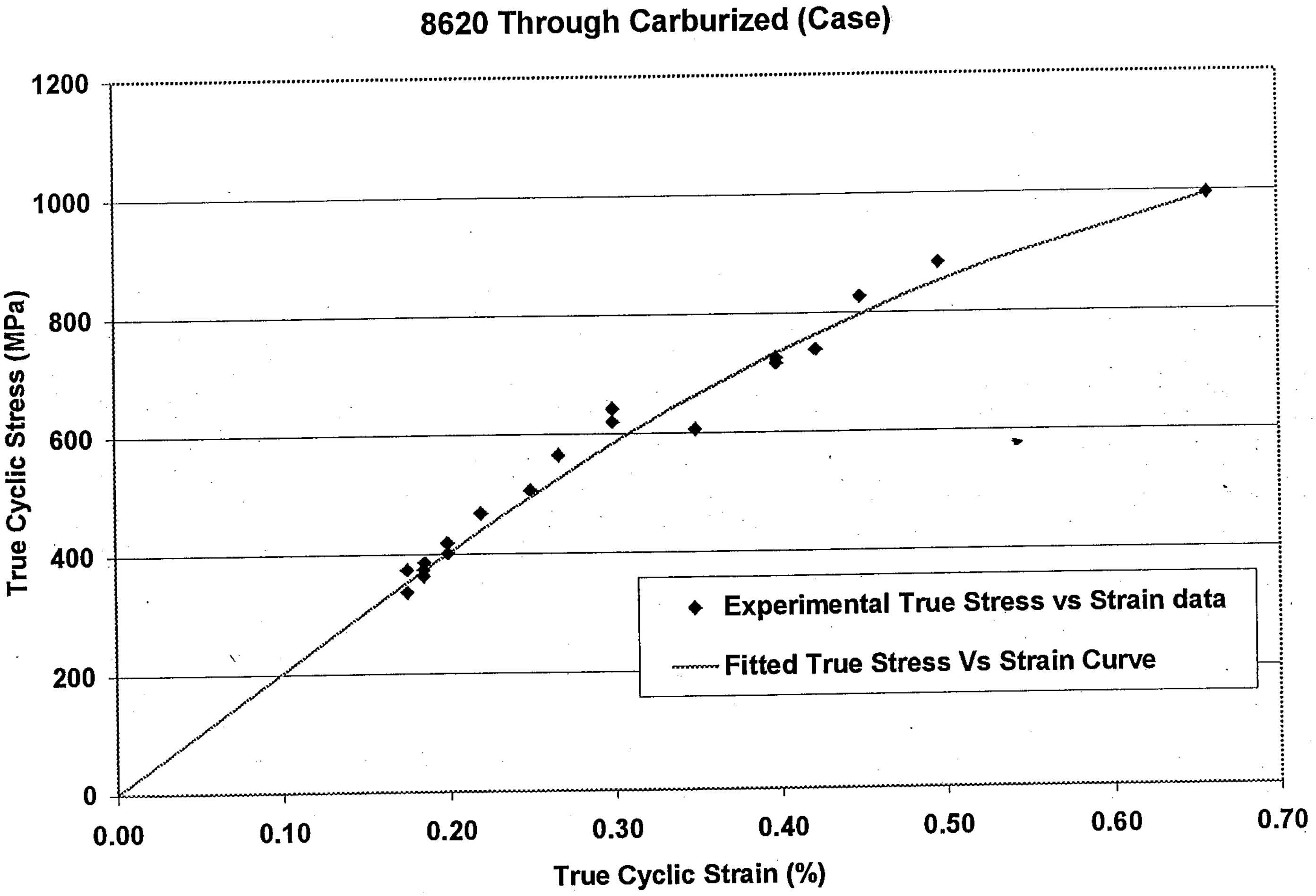


Figure 6. Cyclic stress-strain curve for Through Carburized (Case) steel.

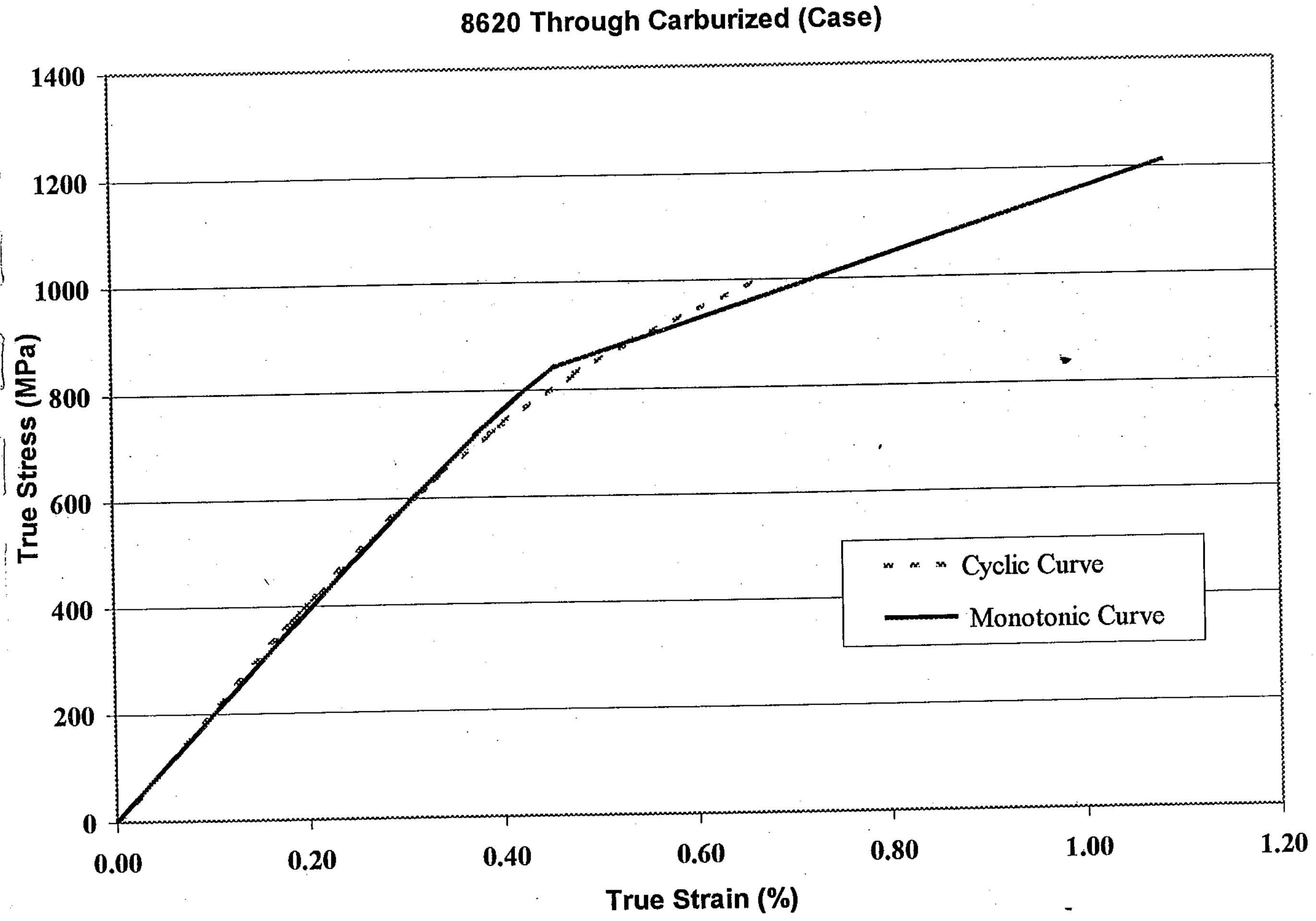


Figure 7. Monotonic and Cyclic stress-strain curves for Through Carburized (Case) steel.

Table 1 Chemical composition of 8620 Through Carburized (Case) 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	NA
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 Through Carburized (Case) 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)
4	0.658	995	0.166	0.492	200	202	62
17	0.497	883	0.060	0.437	26272	198	55
22	0.449	827	0.040	0.409	3284	203	56
10	0.422	739	0.056	0.366	60	201	61
1	0.398	725	0.039	0.359	40000	199	58
18	0.399	717	0.044	0.355	29060	200	60
13	0.300	641	0.000	0.300	105578	201	57
2	0.300	619	0.000	0.300	291834	203	58
14	0.349	606	0.000	0.349	222640	202	60
11	0.267	564	0.000	0.267	346658	195	61
3	0.250	506	0.000	0.250	312856	203	59
6	0.220	468	0.000	0.220	4710310	213	54
12	0.200	418	0.000	0.200	5109802	209	58
8	0.200	402	0.000	0.200	10000000	201	59
19	0.186	385	0.000	0.186	4597712	207	62
16*	0.185	374	0.000	0.185	10000000	202	58
21	0.175	374	0.000	0.175	6010	214	64
15*	0.185	363	0.000	0.185	10000000	196	59
20*	0.175	335	0.000	0.175	10000000	192	60

* Run out

Appendix 1

Monotonic Properties for 8620 Through Carburized (Case)steel.

Average Elastic Modulus, E = 202 GPa
Yield Strength = 920 MPa
Ultimate tensile Strength = 1202 MPa
% Elongation = 1.0 %
% Reduction of Area = 1.0 %
True fracture strain, $Ln\ (A_i / A_f)$ = 1.0 %

True fracture stress, $\sigma_f = \dfrac{P_f}{A_f}$ = 1215 MPa

Bridgman correction, $\sigma_f = \dfrac{P_f}{A_f} \Bigg/ \left(1 + \dfrac{4R}{D_f}\right) Ln\left(1 + \dfrac{D_f}{4R}\right)$ =1150 MPa

Monotonic strength coefficient, K = 2335 MPa
Monotonic strain hardening exponent, n = 0.122
Hardness, Rockwell C (HRC) = 59
Hardness, Brinell = 583

Cyclic Properties for 8620 Through Carburized (Case) steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ = 1033 MPa
Cyclic strength coefficient, K' = 3493 MPa
Cyclic strain hardening exponent, n' = 0.196
Fatigue Strength Coefficient, σ'_f = 1283 MPa
Fatigue Strength Exponent, b = -0,071
Fatigue Ductility Coefficient, ε'_f = ~~0.142~~ .0014
Fatigue Ductility Exponent, c = -0.111

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.