SAE 8695
Carburized H.T. Case
(w/out IGO) Steel
Iteration #41

Fatigue Behavior, Monotonic Properties
and
Microstructural Data

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TABLE OF CONTENTS

SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for 8695 Carburized H. T. Case (w/IGO) steel (Iteration # 41) have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of 1" bars. These bars were machined into smooth axial fatigue specimens. The specimens were carburized at Meritor Inc. to reach a hardness of about 55 Rc. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. A monotonic compressive test was also performed to document the difference in mechanical properties between tension and compression for 8695 Carburized H. T. Case (w/IGO) steel. Twenty-three 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 26, 8695 Carburized H. T. Case (w/IGO) 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, 23 fatigue data points were generated.

Test Equipment and Procedure

Two monotonic tension tests a monotonic compression test 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 8695 Carburized H. T. Case (w/IGO) steel. A Type D thick series inclusion severity level of 4 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 8695 Carburized H. T. Case (w/IGO) steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 8695 Carburized H. T. Case (w/IGO) steel was provided by Timken Inc. Steel Company, and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for 8695 Carburized H. T. Case (w/IGO) 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. Because the metal shows a higher yield strength in compression than in tension, there was a pronounced compressive mean stress in the fully reversed strain controlled tests. The stable mean stresses are included in the data given in Figure 4.

A fatigue strain-life curve for the 8695 Carburized H. T. Case (w/IGO) 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 $\sigma'_f = 1365$ MPa, $b = -0.068$, $\varepsilon'_f = 0.049$ and $c = -0.155$. These values of the strain-life parameters were determined from fatigue testing over the range: $0.0021 < \frac{\Delta\varepsilon}{2} < 0.007$.

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 $K' = 3897$ MPa and $n' = 0.154$.

The true monotonic and true cyclic stress-strain curves plotted together are given in Figure 6.

D) Mechanical Properties

The engineering monotonic tensile and compressive stress-strain curves are given in Figure 7. It should be noted that the compressive yield stress is much higher than the tensile yield strength. The monotonic and cyclic properties are included in Appendix 1. The Hardness of the 8695 Carburized H. T. Case (w/IGO) 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.

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.

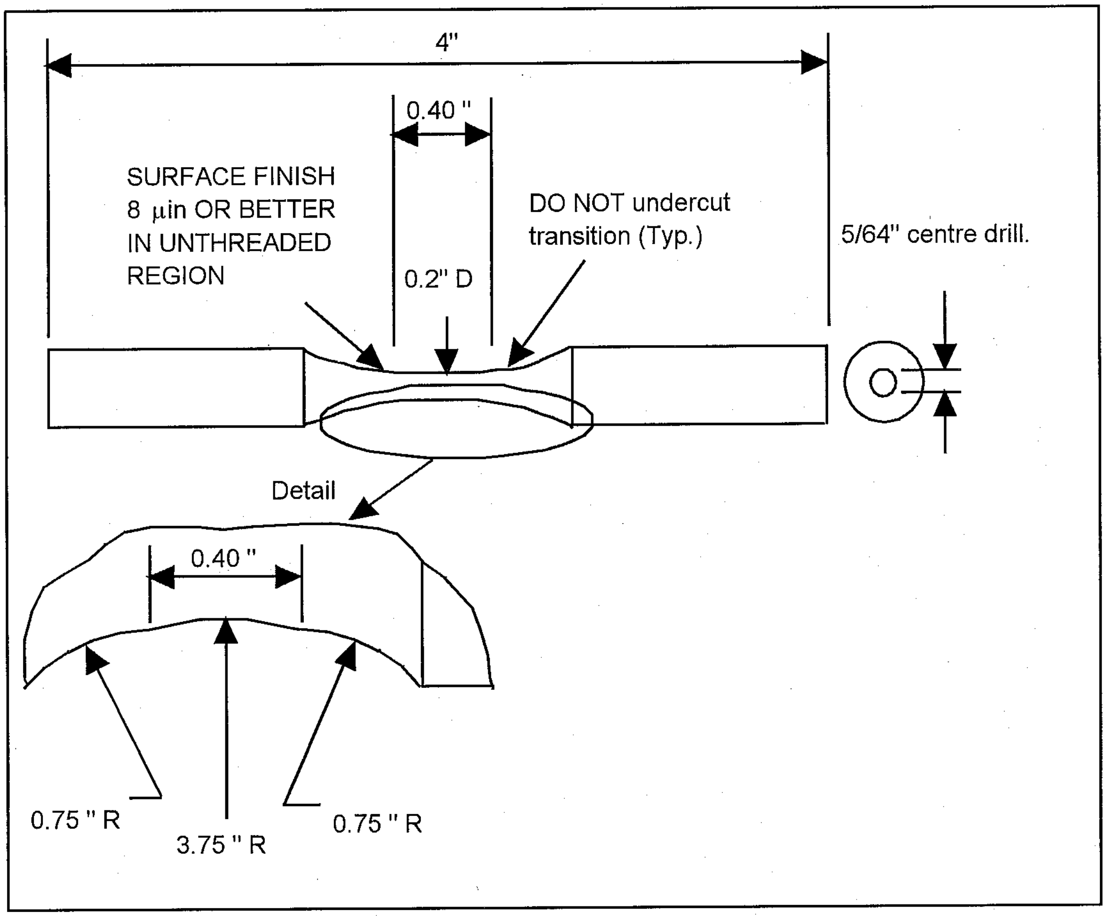
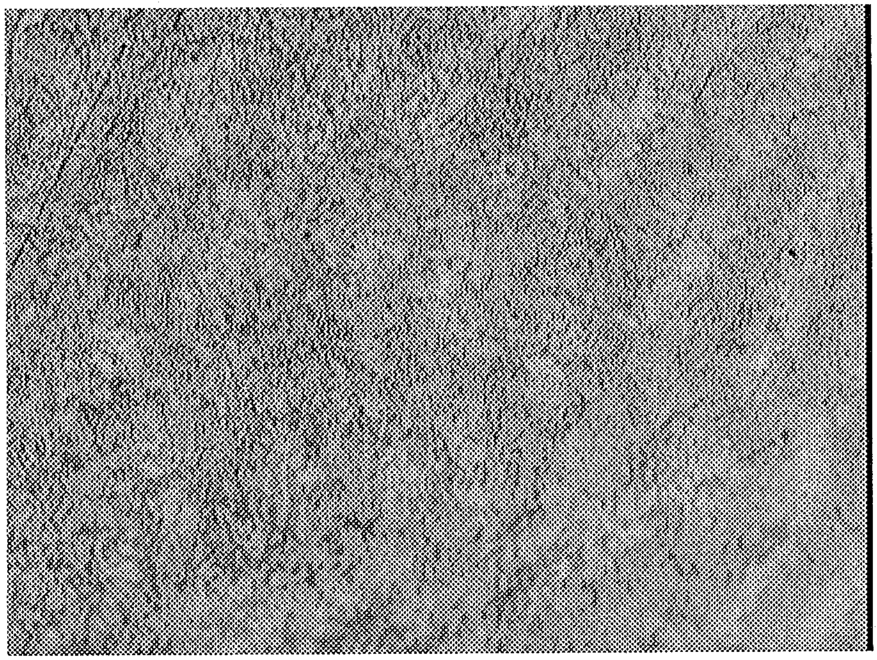
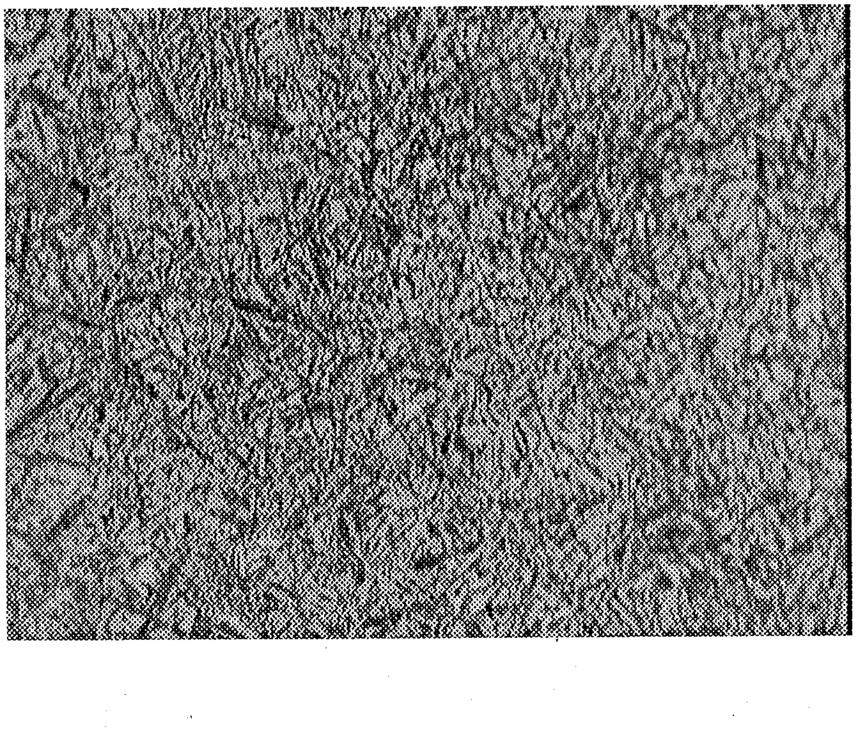


Fig. 1 Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2 Photomicrographs of 8695 Carburized H. T. Case (w/IGO) steel (X500)

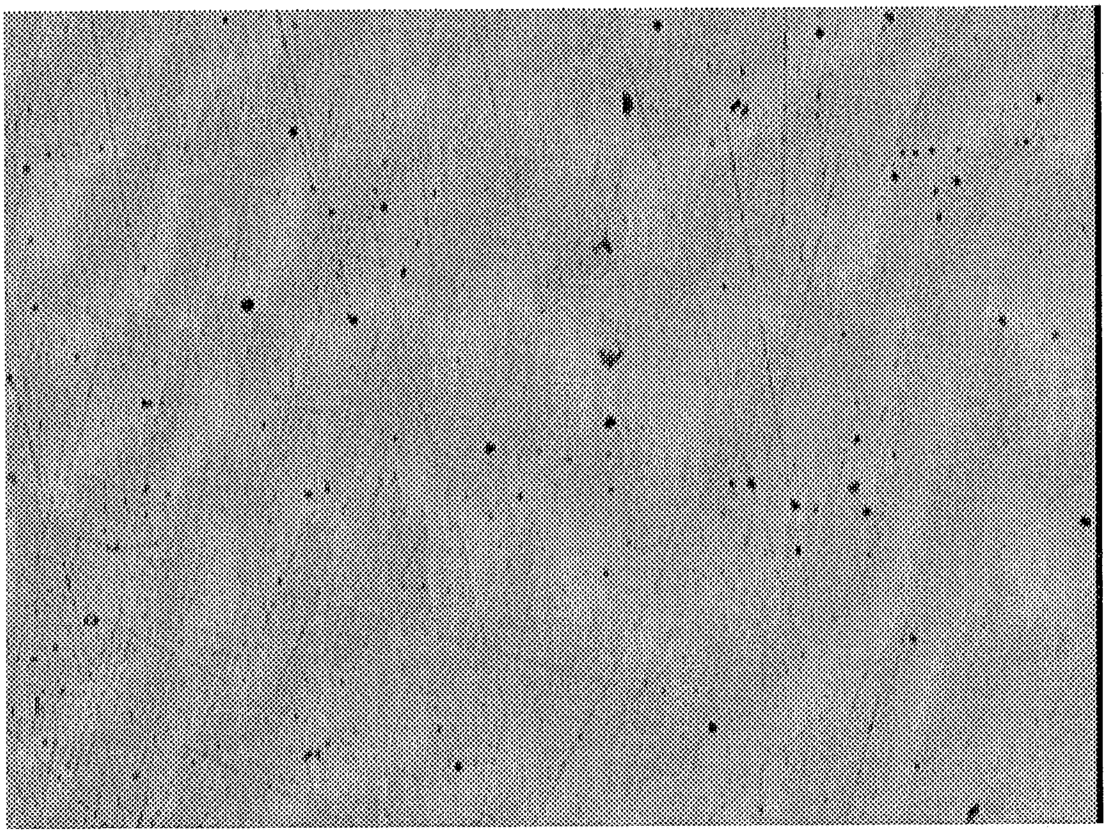


Figure 3 Inclusions photomicrograph of 8695 Carburized H. T. Case (w/IGO) steel (X100)

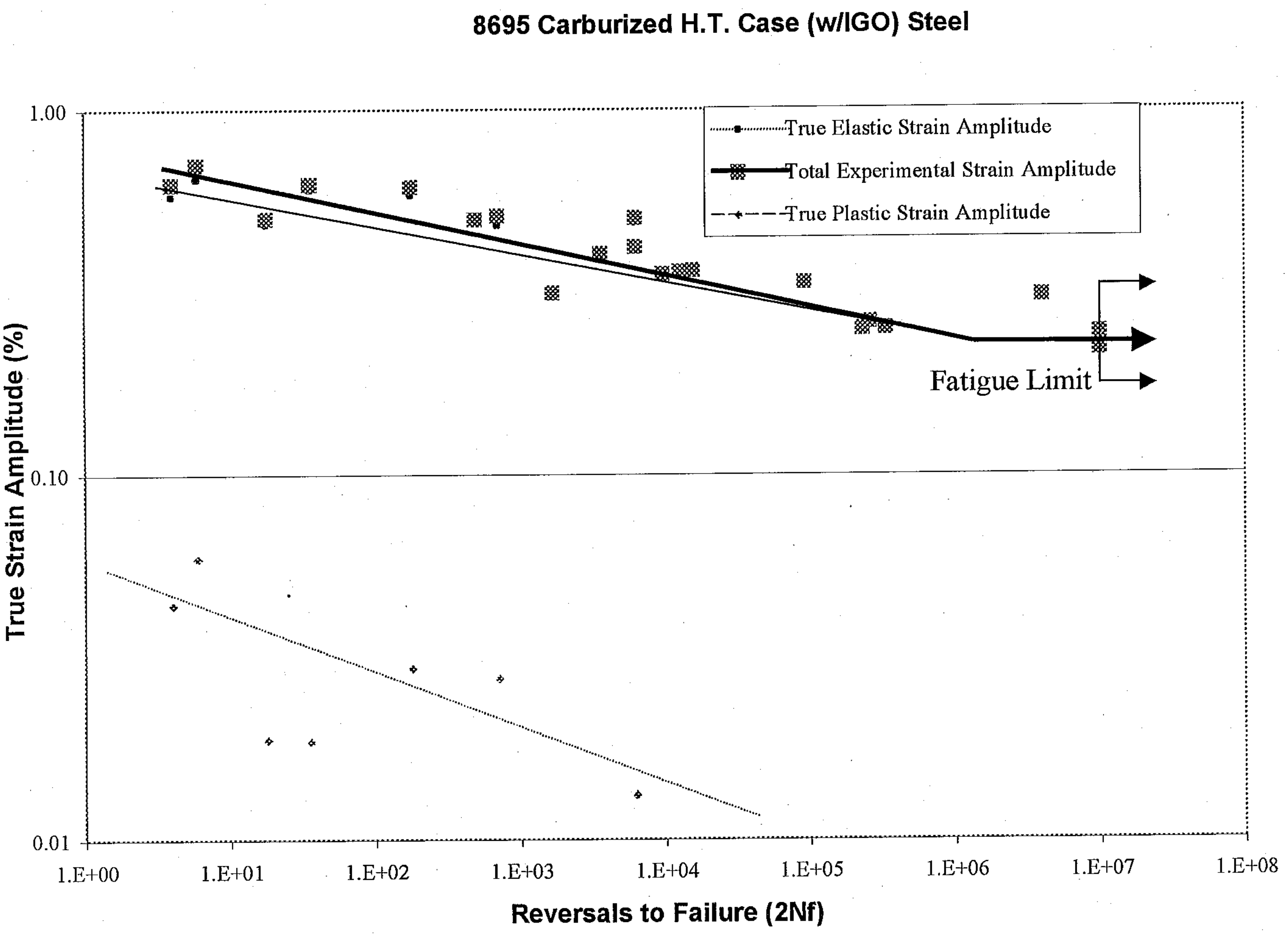


Figure 4. Constant amplitude fully reversed strain-life curve for 8695 Carburized H. T. Case (w/IGO) steel.

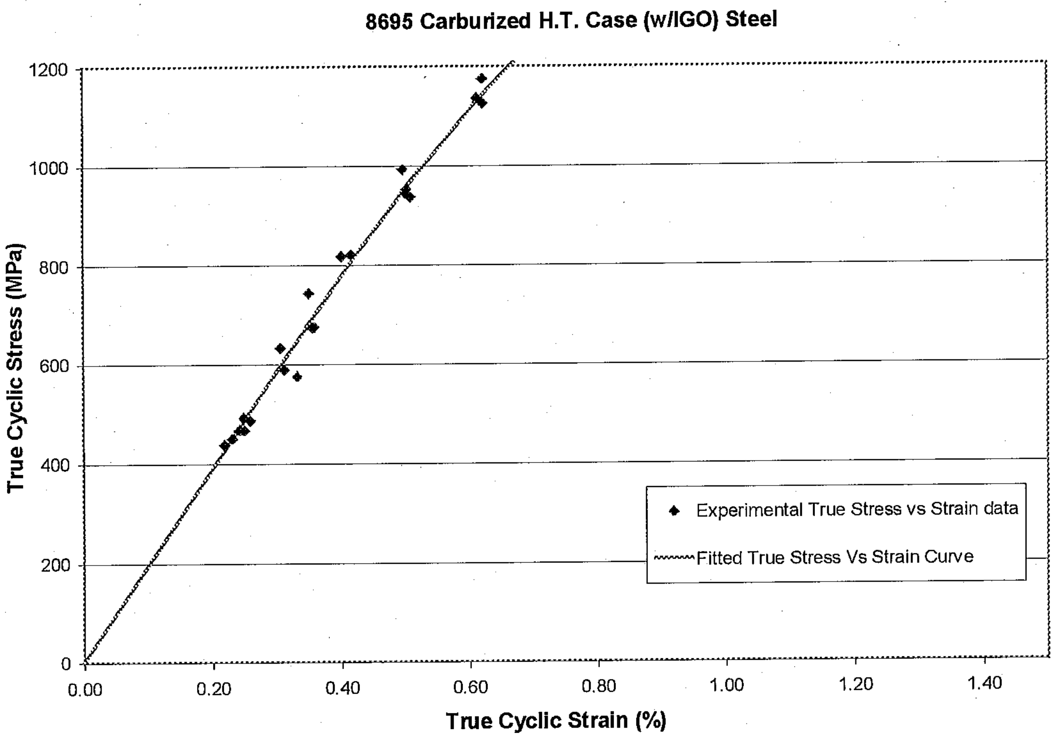


Figure 5. Cyclic stress-strain curve for 8695 Carburized H. T. Case (w/IGO) steel.

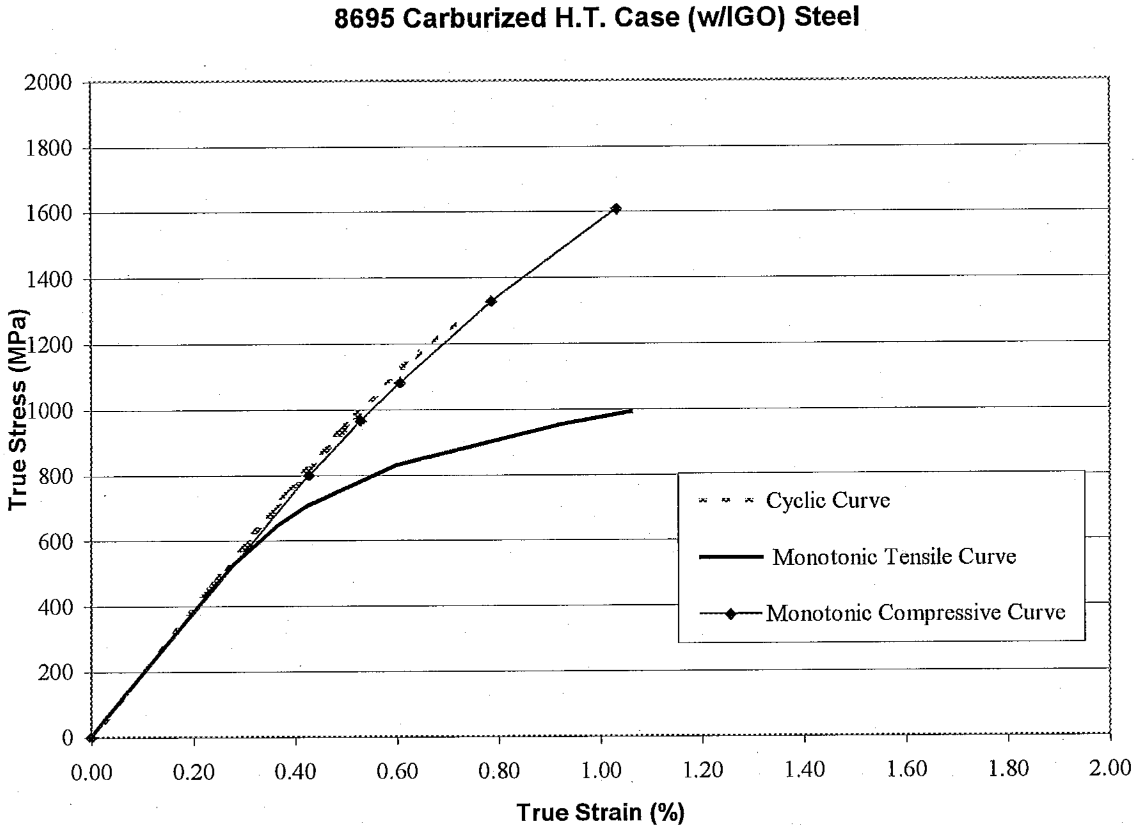


Figure 6 Monotonic and Cyclic stress-strain curves for 8695 Carburized H. T. Case (w/IGO) steel.

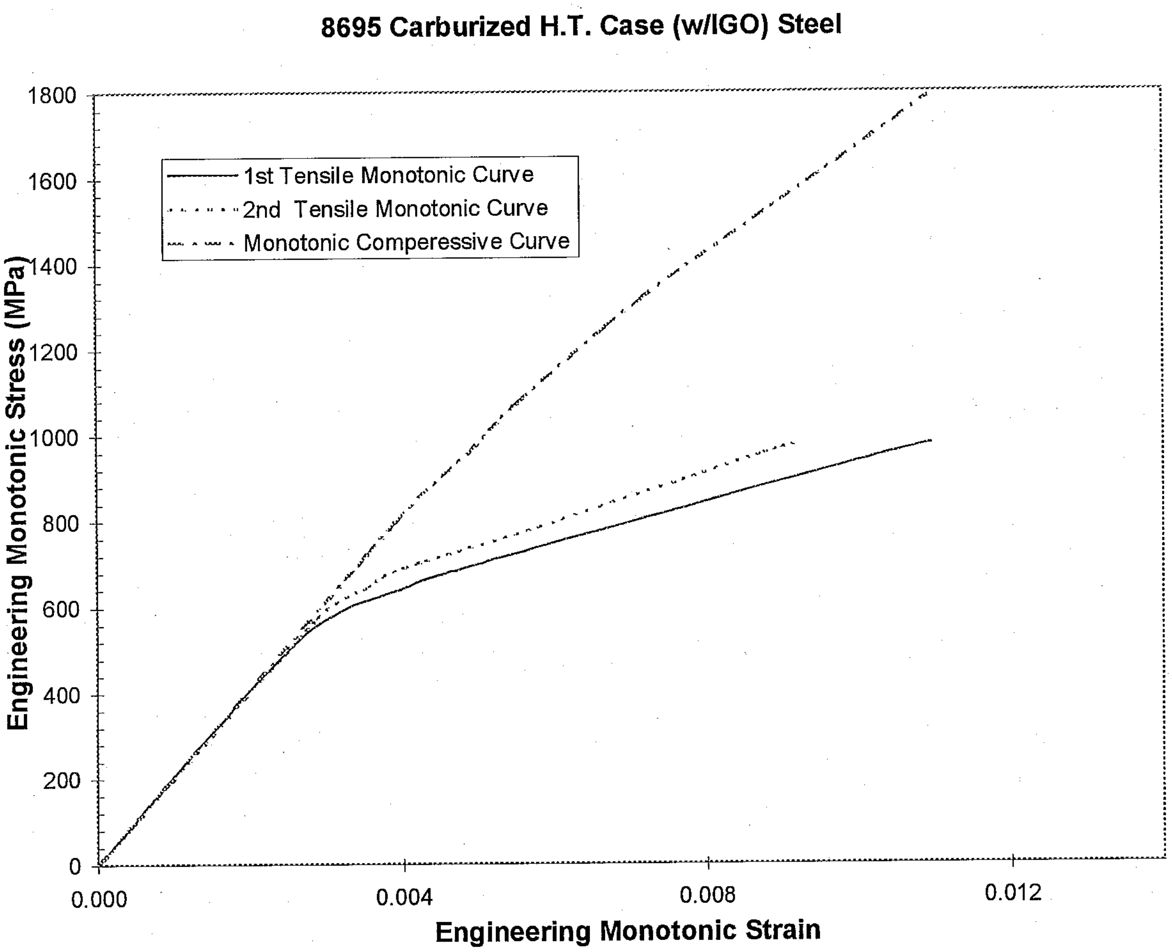


Figure 7. Tensile and compressive monotonic stress-strain curves for three 8695 Carburized H. T. Case (w/IGO) steel specimens.

Table 1 Chemical composition of 8695 Carburized H. T. Case (w/IGO) steel.

Carbon, C	0. 96%
Manganese, Mn	0.86%
Phosphorous, P	0.003%
Sulfur, S	0.028%
Silicon, Si	0.26%
Copper, Cu	0.02%
Nickel, Ni	0.48%
Chromium, Cr	0.52%
Molybdenum, Mo	0.17%
Sn	0.003%
As	0.002%
Co	0.003%
Al	0.043%
Ti	0.001%
cb	0.001%
V	0.001%
Pb	0.005%
Te	0.0009%
W	0.002%
Zr	0.001%
Ca	0.0001%

Table 2 Tensile and Fatigue Test Data for 8695 Carburized H. T. Case (w/IGO) steel.

Sp#	Total Strain Amplitude(%)	Stress Amplitude (MPa)	Compressive Mean Stress (Mpa)	Plastic Strain Amplitude(%)	Elastic Strain Amplitude(%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	MONOTONIC Young's Modulus(GPa)	Hardness (HRC)
21	0.706	1261	242	0.059	0.646	6	194	53
5	0.622	1177	280	0.019	0.603	36	189	55
4	0.622	1127	242	0.044	0.578	4	190	56
13	0.613	1138	264	0.030	0.583	178	196	54
14	0.509	938	132	0.028	0.481	708	194	55
9	0.503	954	203	0.013	0.489	452	190	53
7	0.503	943	247	0.019	0.484	18	198	58
20	0.497	993	110	0.000	0.497	492	200	56
1	0.416	821	159	0.000	0.416	6304	197	55
16	0.401	818	178	0.000	0.401	3632	204	55
10	0.359	675	41	0.000	0.359	15866	188	52
15	0.356	675	36	0.000	0.356	12770	189	54
23	0.350	744	55	0.000	0.350	9814	195	54
2	0.332	576	38	0.000	0.332	93424	173	57
17	0.312	589	19	0.000	0.312	1682	189	53
19	0.306	633	27	0.000	0.306	4002394	207	55
3	0.259	487	36	0.000	0.259	261706	188	54
22	0.249	468	27	0.000	0.249	340674	198	56
12	0.249	493	30	0.000	0.249	234276	198	56
18*	0.242	468	55	0.000	0.242	10000000	193	54
11*	0.241	468	11	0.000	0.241	10000000	194	55
8*	0.230	451	27	0.000	0.230	10000000	196	56
6*	0.218	439	26	0.000	0.218	10000000	201	55

* Run out

Appendix 1

Monotonic Properties for 8695 Carburized H. T. Case (w/IGO) steel.

Average Elastic Modulus, E = 195 GPa
Yield Strength = 847 MPa
Compressive Yield Strength = 1480 MPa
Ultimate tensile Strength = 979 MPa
% Elongation = 0.98 %
% Reduction of Area = 0.97 %
True fracture strain, $Ln\ (A_i / A_f)$ = 0.97 %

True fracture stress, $\sigma_f = \dfrac{P_f}{A_f}$ = 991 MPa

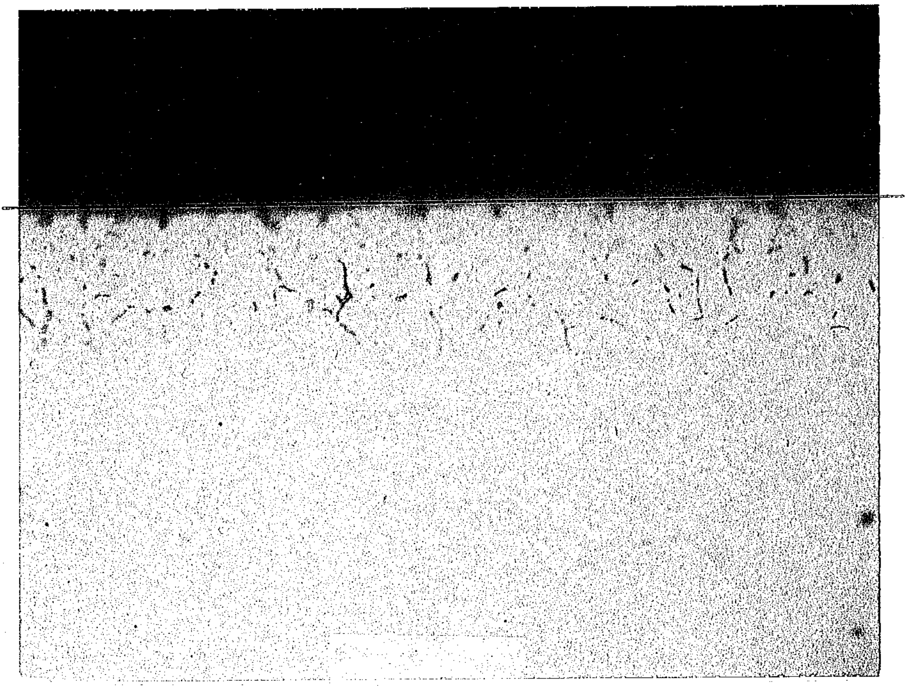
Bridgman correction, $\sigma_f = \dfrac{P_f}{A_f} \Big/ \left(1 + \dfrac{4R}{D_f}\right) Ln\left(1 + \dfrac{D_f}{4R}\right)$ =888 MPa

Monotonic tensile strength coefficient, K = 2206 MPa
Monotonic tensile strain hardening exponent, n = 0.154
Monotonic compressive strength coefficient, K = 5850 MPa
Monotonic compressive strain hardening exponent, n = 0.18
Hardness, Rockwell C (HRC) = 55
Hardness, Brinell = 539

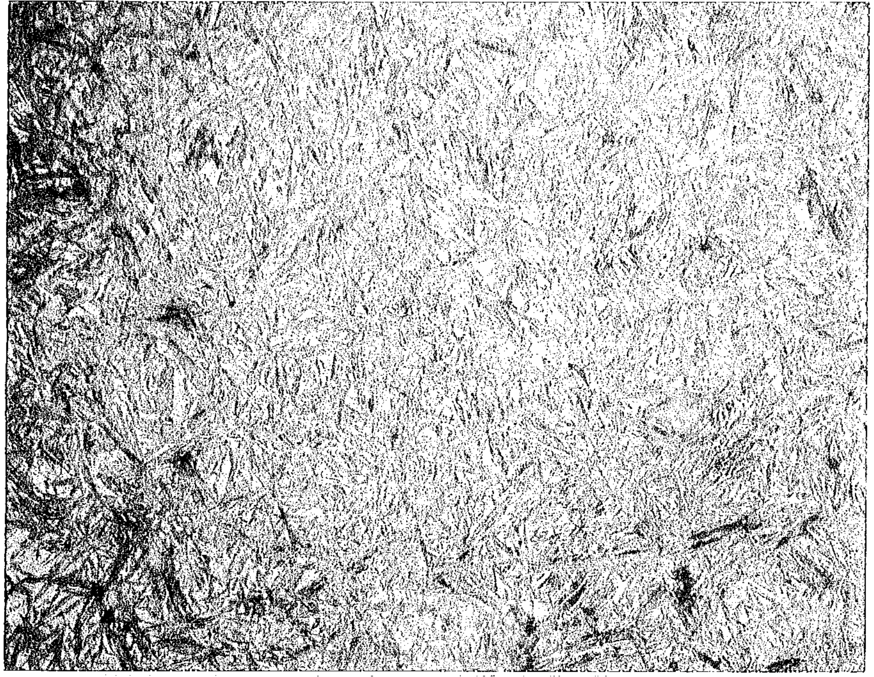
Cyclic Properties for 8695 Carburized H. T. Case (w/IGO) steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ = 1496 MPa
Cyclic strength coefficient, K' = 3897 MPa
Cyclic strain hardening exponent, n' = 0.154
Fatigue Strength Coefficient, σ'_f = 1365 MPa
Fatigue Strength Exponent, b = -0.068
Fatigue Ductility Coefficient, ε'_f = ~~0.049~~ .00049
Fatigue Ductility Exponent, c = -0.155

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.



Iter 41S 8695 Surface 1000X w/igo



Iter 41C 8695 Carb Core ~~1000~~X
500