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Fatigue Behavior, Monotonic Properties

and

Microstructure Data

for

8695, Carburized H.T. Case (w/o IGO) Steel

(Iteration No. 40)

By

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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/o IGO) steel (Iteration # 40) 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/o IGO) steel. Twenty-six 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 29, 8695 Carburized H. T. Case (w/o 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, 26 fatigue data points were generated.

Test Equipment and Procedure

Two monotonic tension tests and 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 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 8695 Carburized H. T. Case (w/o IGO) steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of 8695 Carburized H. T. Case (w/o 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/o 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/o 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 σ'_f = 3054 MPa, b = -0.14, ε'_f = 0.3 and c = -0.36. 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' = 3575 MPa and n' = 0.101.

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/o 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.

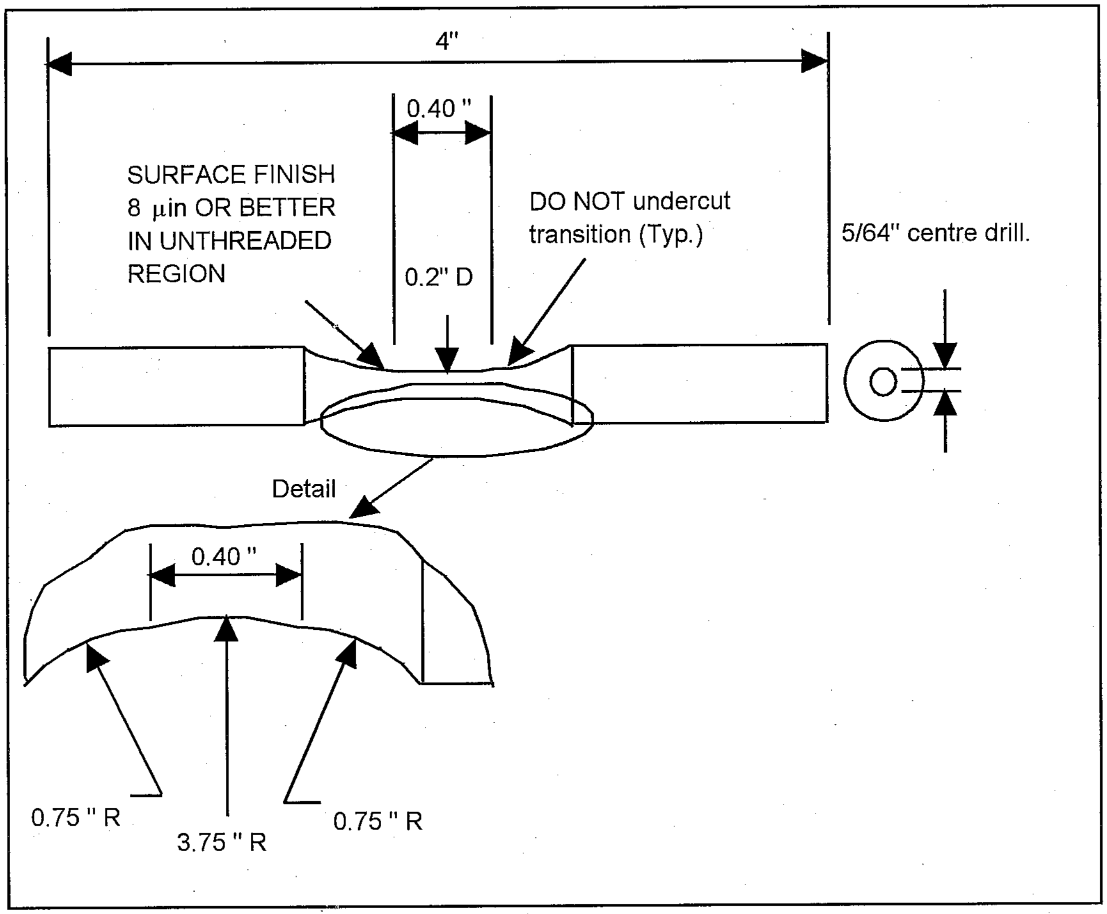
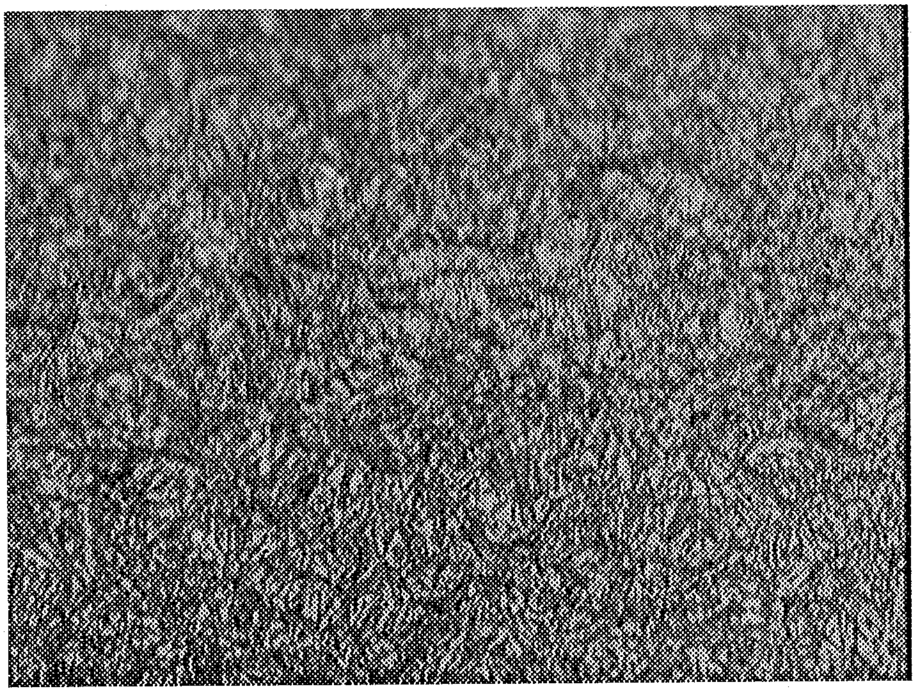
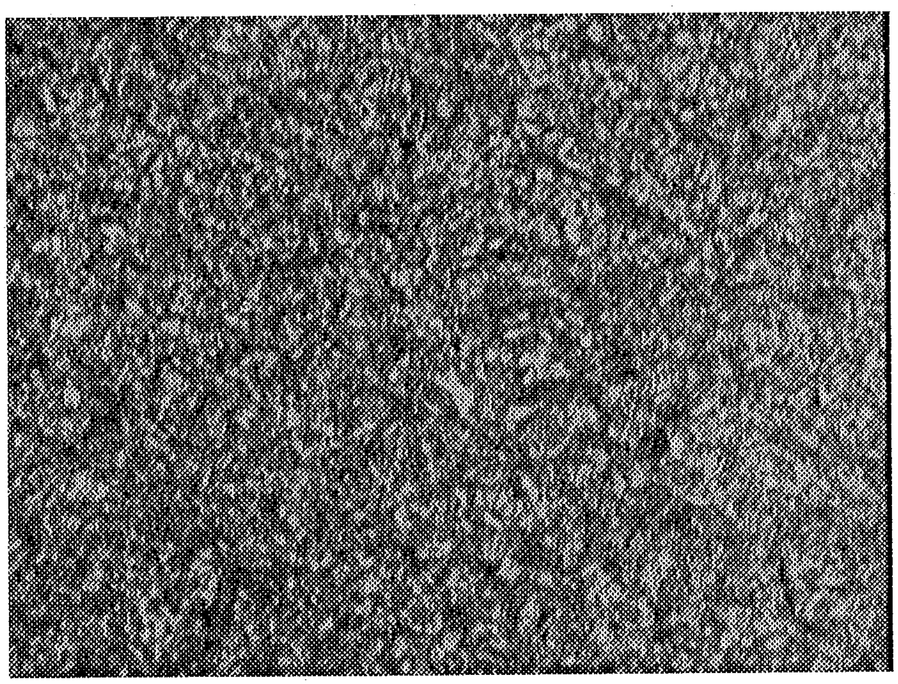


Figure 1 Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

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

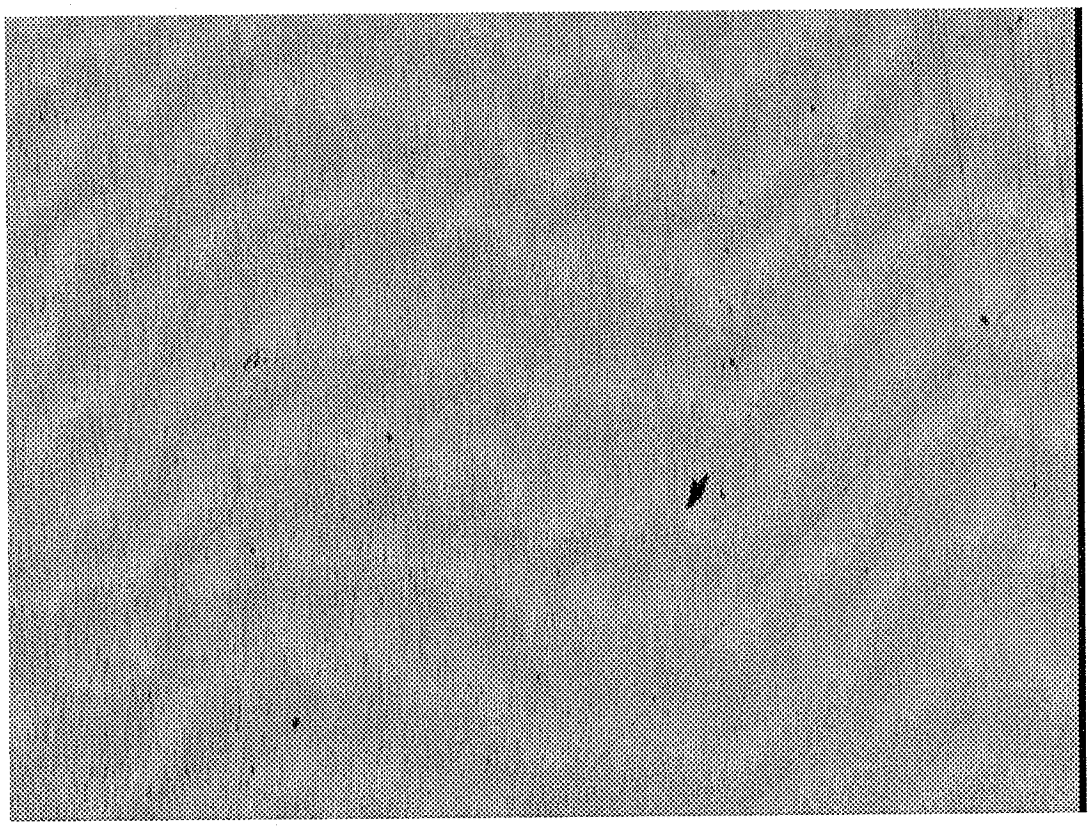


Figure 3 Inclusions photomicrograph of 8695 Carburized H. T. Case (w/o IGO) steel (X100)

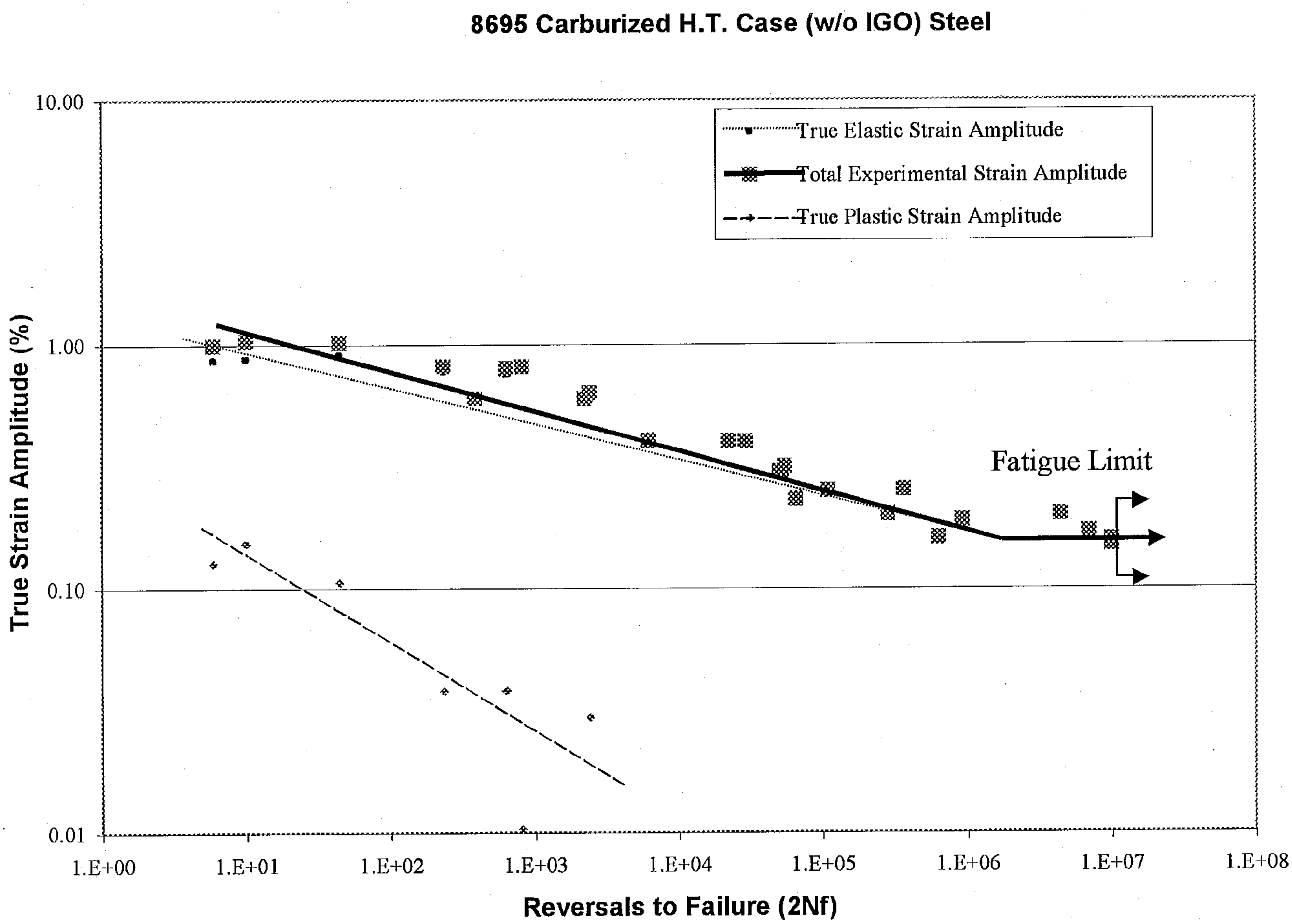


Figure 4. Constant amplitude fully reversed strain-life curve for 8695 Carburized H. T. Case (w/o IGO) steel.

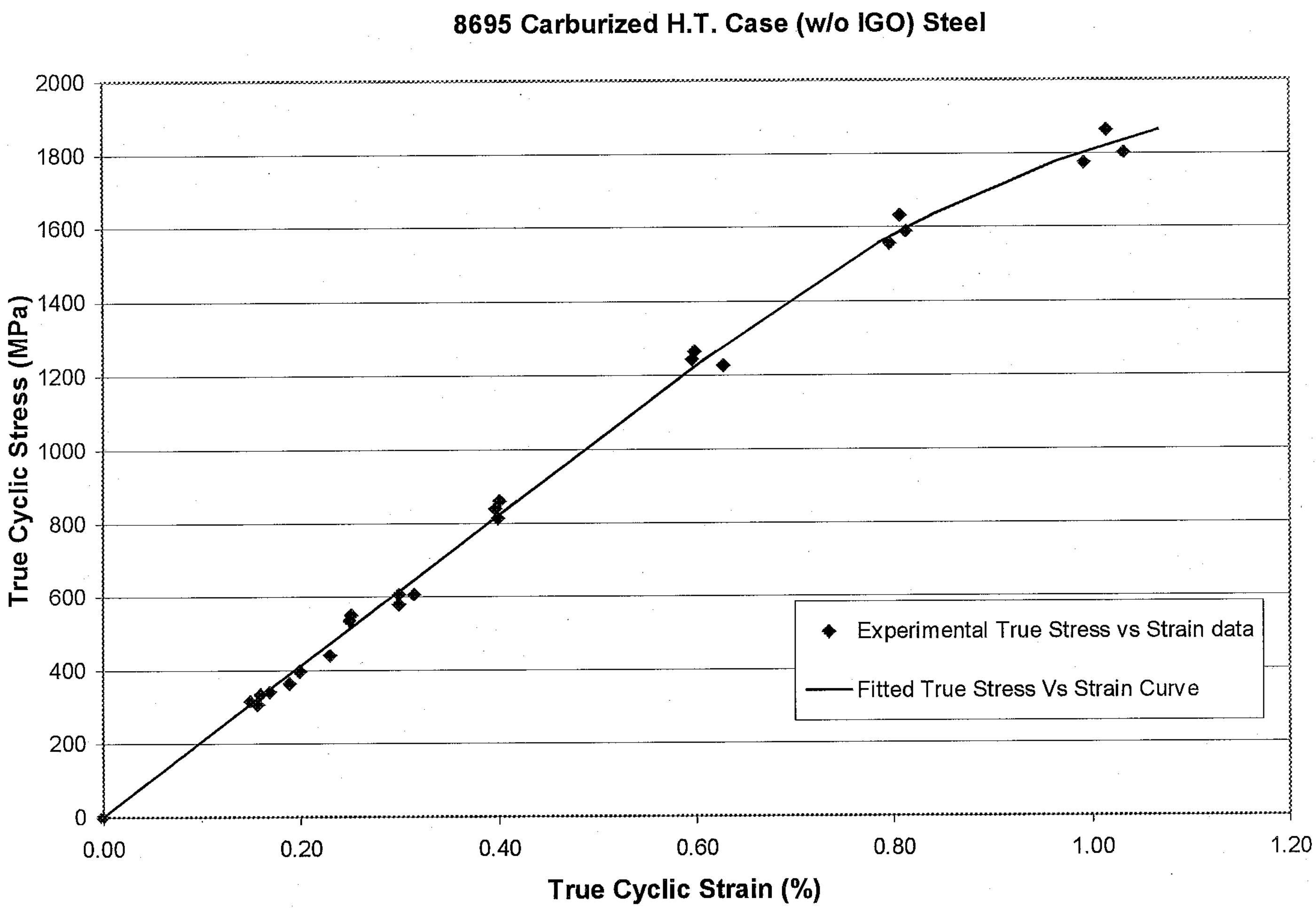


Figure 5. Cyclic stress-strain curve for 8695 Carburized H. T. Case (w/o IGO) steel.

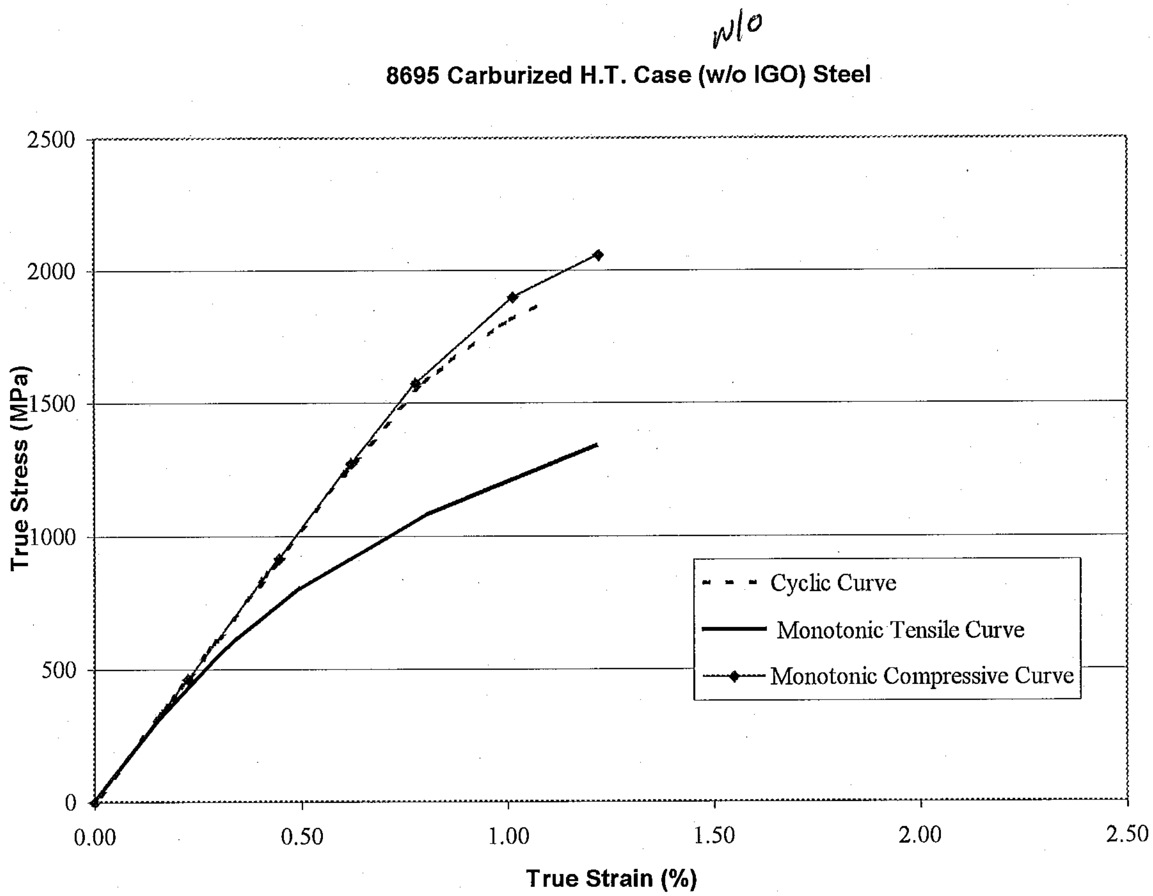


Figure 6. Monotonic and Cyclic stress-strain curves for 8695 Carburized H. T. Case (w/o IGO) steel.

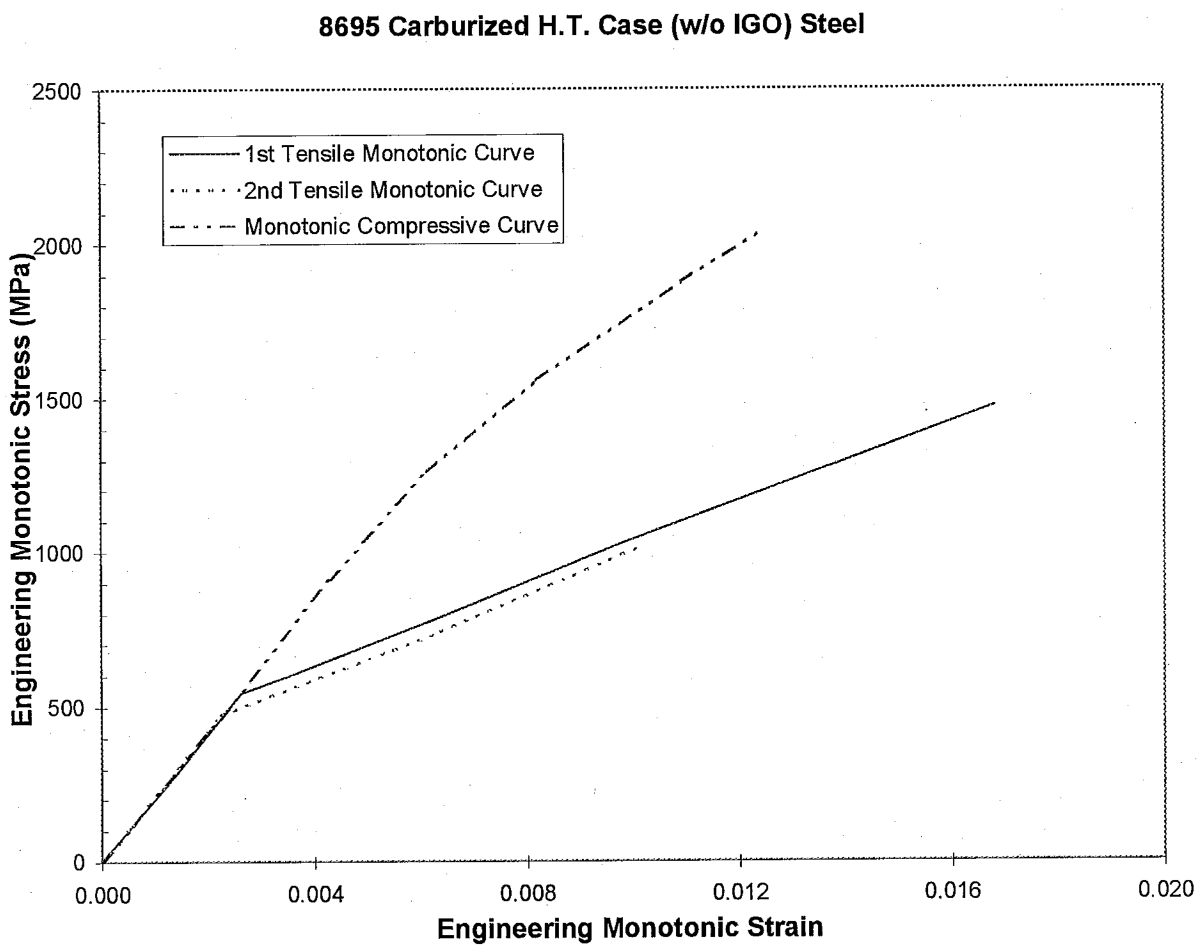


Figure 7. Tensile and compressive monotonic stress-strain curves for three 8695 Carburized H. T. Case (w/o IGO) steel specimens.

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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)
20	1.015	1863	450	0.106	0.909	44	206	54
16	1.033	1803	412	0.153	0.879	10	205	54
26	0.993	1774	439	0.127	0.865	6	206	57
5	0.807	1633	467	0.010	0.796	810	203	53
21	0.813	1588	456	0.038	0.775	234	202	55
24	0.797	1555	445	0.038	0.759	634	207	53
18	0.628	1226	395	0.030	0.598	2424	203	58
23	0.599	1265	313	0.000	0.599	384	208	56
4	0.596	1243	412	0.000	0.596	2220	205	55
22	0.399	813	96	0.000	0.399	22412	205	55
1	0.401	860	88	0.000	0.401	6270	204	52
14	0.397	838	121	0.000	0.397	29390	206	56
12	0.300	606	22	0.000	0.300	50540	205	55
2	0.315	606	30	0.000	0.315	54696	206	55
25	0.300	578	63	0.000	0.300	52148	205	52
19	0.250	536	52	0.000	0.250	108550	203	55
3	0.252	550	82	0.000	0.252	365830	208	54
6	0.230	440	36	0.000	0.230	65096	208	56
13	0.200	397	67	0.000	0.200	285374	206	56
7	0.200	399	49	0.000	0.200	4397152	205	55
8	0.190	363	33	0.000	0.190	928106	203	55
9	0.170	341	8	0.000	0.170	6945710	203	56
10	0.160	333	5	0.000	0.160	638950	205	55
17*	0.150	316	39	0.000	0.150	10000000	205	56
15*	0.157	307	5	0.000	0.157	10000000	204	55
11*	0.150	316	33	0.000	0.150	10000000	206	54

* Run out

Appendix 1

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

Average Elastic Modulus, E	=	205	GPa
Yield Strength	=	780	MPa
Compressive Yield Strength	=	2041	MPa
Ultimate tensile Strength	=	1496	MPa
% Elongation	=	1.3	%
% Reduction of Area	=	1.3	%
True fracture strain, $Ln\ (A_i / A_f)$	=	1.3	%
True fracture stress, $\sigma_f = \dfrac{P_f}{A_f}$	=	1520	MPa

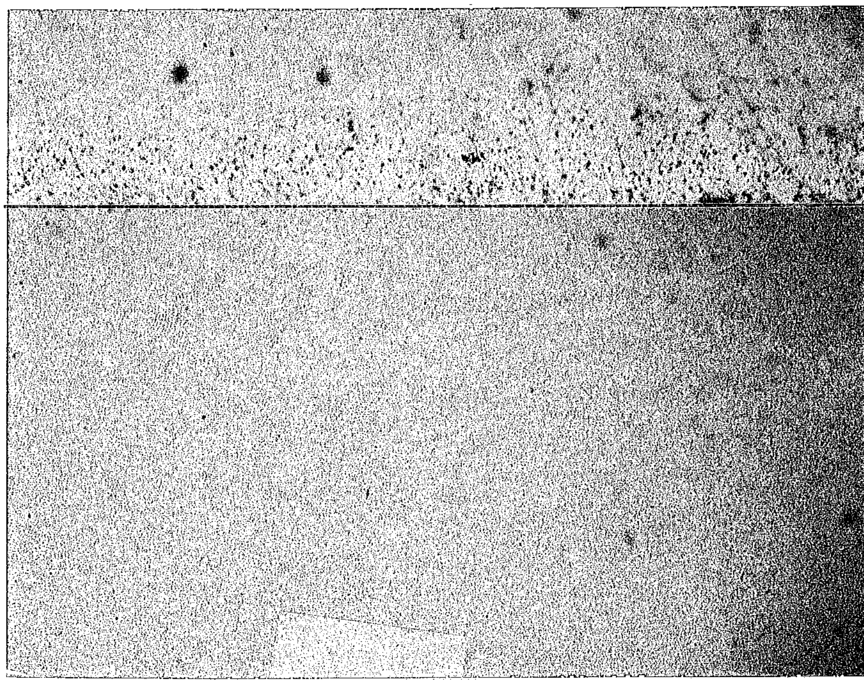
Bridgman correction, $\sigma_f = \dfrac{P_f}{A_f} \Big/ \left(1 + \dfrac{4R}{D_f}\right) Ln\left(1 + \dfrac{D_f}{4R}\right)$ =1364 MPa

Monotonic tensile strength coefficient, K	=	6500	MPa
Monotonic tensile strain hardening exponent, n	=	0.34	
Monotonic compressive strength coefficient, K	=	3512	MPa
Monotonic compressive strain hardening exponent, n	=	0.087	
Hardness, Rockwell C (HRC)	=	55	
Hardness, Brinell	=	539	

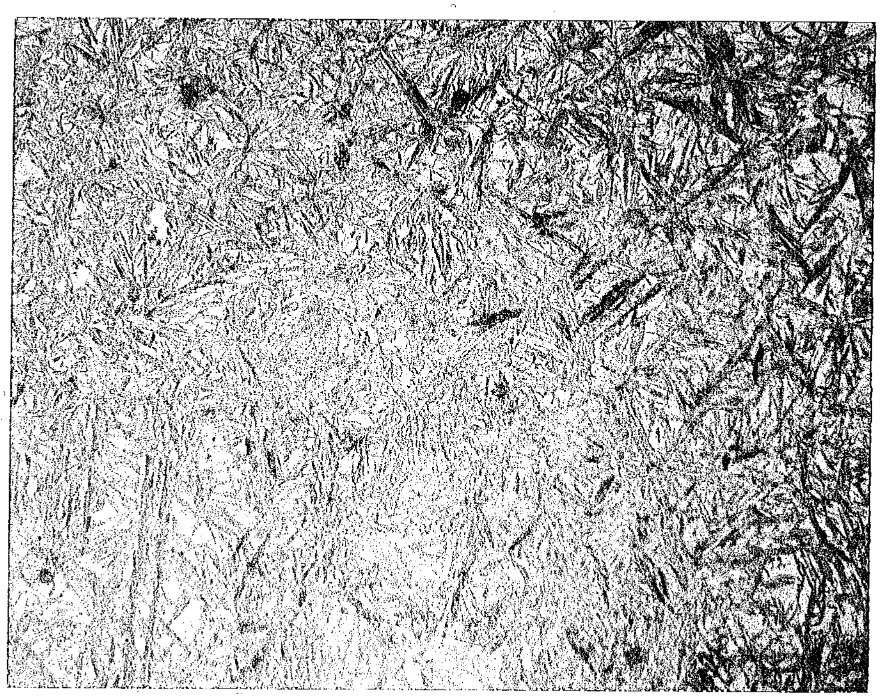
Cyclic Properties for 8695 Carburized H. T. Case (w/IGO) steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$	=	1908	MPa
Cyclic strength coefficient, K'	=	3575	MPa
Cyclic strain hardening exponent, n'	=	0.101	
Fatigue Strength Coefficient, σ'_f	=	3054	MPa
Fatigue Strength Exponent, b	=	-0.14	
Fatigue Ductility Coefficient, ε'_f	=	~~0.30~~ .003	
Fatigue Ductility Exponent, c	=	-0.361	

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 40S   8695   Surface   1000X no igo



Iter 40C   8695   Carb Core   ~~1000~~X
500