8620 Carburized Case Steel
Iteration #89

Fatigue Behavior, Monotonic Properties and Microstructural Data

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SUMMARY

This report presents the monotonic and fatigue test results obtained for 8620 carburized case-50% Martensite, 50% Bainite (It 89) steel. The material was provided by the American Iron and Steel Institute (AISI). Monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Strain-controlled constant-amplitude fatigue tests were to obtain the strain-life curve, cyclic stress-strain curve and fatigue data for this material. Also the microstructure data was obtained.

INTRODUCTION

This report presents the results of tensile and fatigue tests performed on a group of 8620 carburized case-50% Martensite, 50% Bainite (It 89) steel sample. The material was provided by the American Iron and Steel Institute. The objectives of this investigation were to obtain the microstructure 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 1.19" round bars. Smooth cylindrical fatigue specimens, shown in Figure 1, were machined from the cylindrical bars and case carburized reaustenitized and isothermally transformed to achieve 50% martensite and 50% bainite microstructure. Then, the gauge sections of the fatigue specimens were mechanically polished in the loading direction. Before testing, the specimens had a final polish in the loading direction in the gauge sections using 600-emery paper and 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.

Test Equipment and Procedure

Monotonic tension tests were performed to determine the yield strength, the tensile strength, the percent 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 electro-hydraulic 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 voltmeter. 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 3 Hz while in stress-controlled tests the frequency used was up to 75 Hz.

RESULTS

Chemical composition and microstructure Data

The chemical composition as provided by the supplier is shown in Table 1. Daimler Chrysler did the microstructure on this material. Their report is included in Appendix 1.

Strain-Life Data

Constant amplitude test data obtained in this investigation are given in table 2. The stress amplitude corresponding to the strain amplitude was calculated from the peak load amplitude at the specimen half-life.

A fatigue strain life curve is shown in Figure 2, and is described by the following equation:

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{E}(2N_f)^b + \varepsilon'_f(2N_f)^c \qquad \text{Eq 1}$$

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

The values of the strain-life parameters were determined from the best fit curve of the fatigue testing data and presented in table 3.

Cyclic Stress-Strain Curves

Stabilized, half-life stress data obtained from strain-life fatigue tests were used to obtain the companion cyclic stress-strain curve shown in Figure 3. The cyclic stress-strain curve is described by the following equation:

$$\varepsilon = \frac{\sigma}{E_c} \qquad \text{Eq 2}$$

where ε = True total strain amplitude

σ = Cyclically stable true stress amplitude

Ec = Cyclic modulus of elasticity

The value of Ec obtained from a best fit of the above equation to the test data are given in table 3.

Mechanical Properties

The engineering monotonic tensile stress-strain curves are given in Figure 4. The true monotonic and true cyclic stress-strain curves plotted together are given in Figure 5. The monotonic properties along with the average hardness test results are included in table 3. The individual hardness measurements are 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.

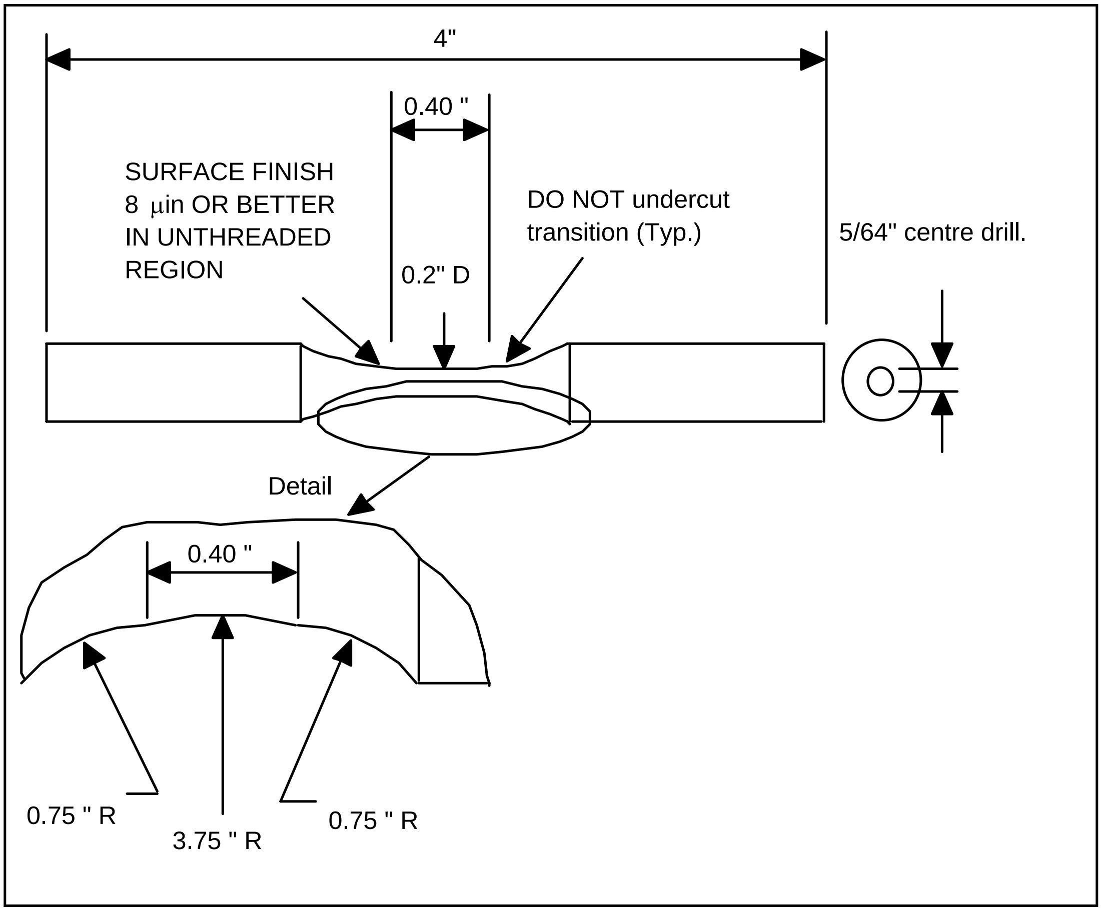

Figure 1 Smooth cylindrical fatigue specimen

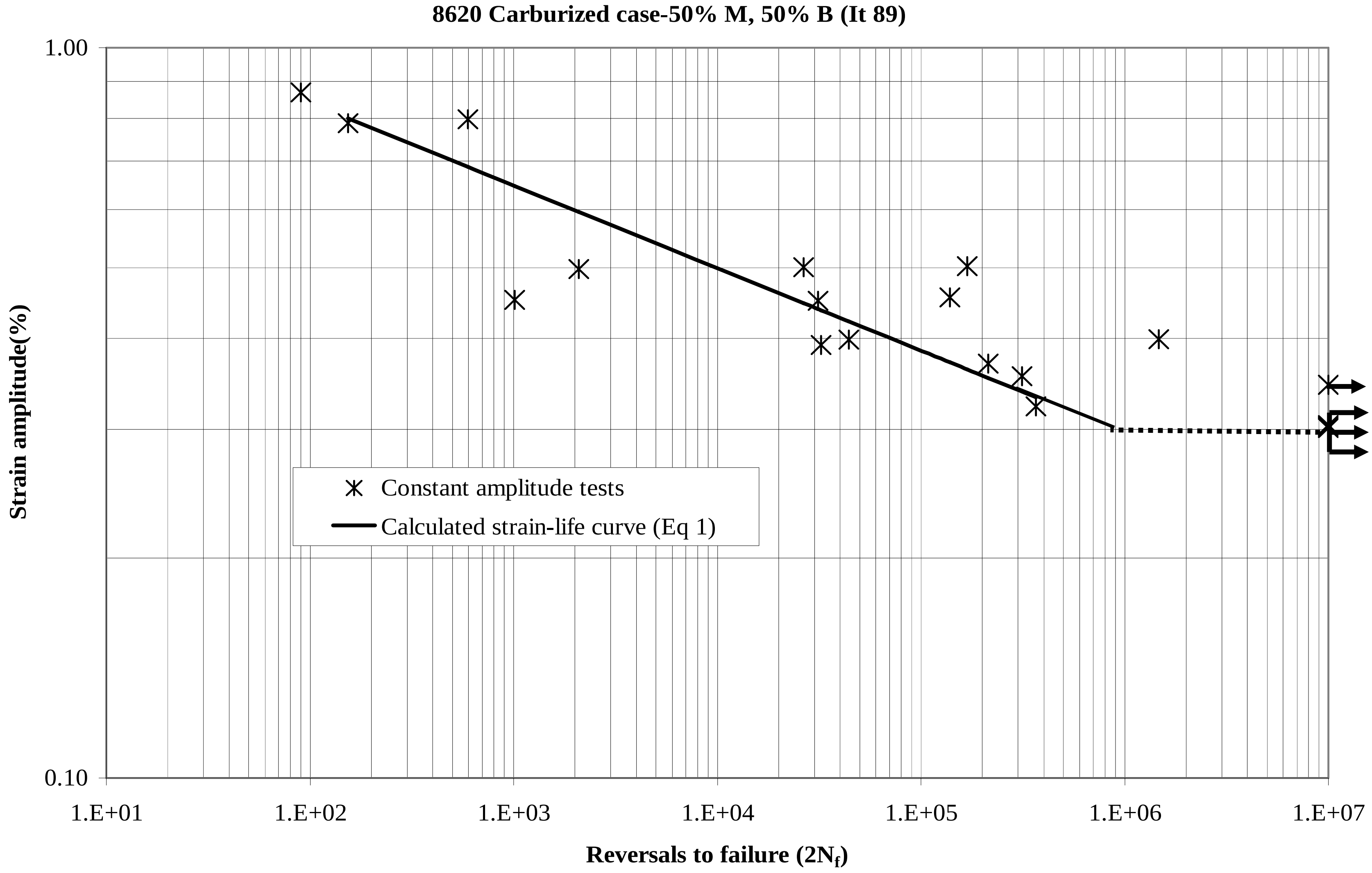

Figure 2. Constant amplitude fully reversed strain-life curve for Iteration 89

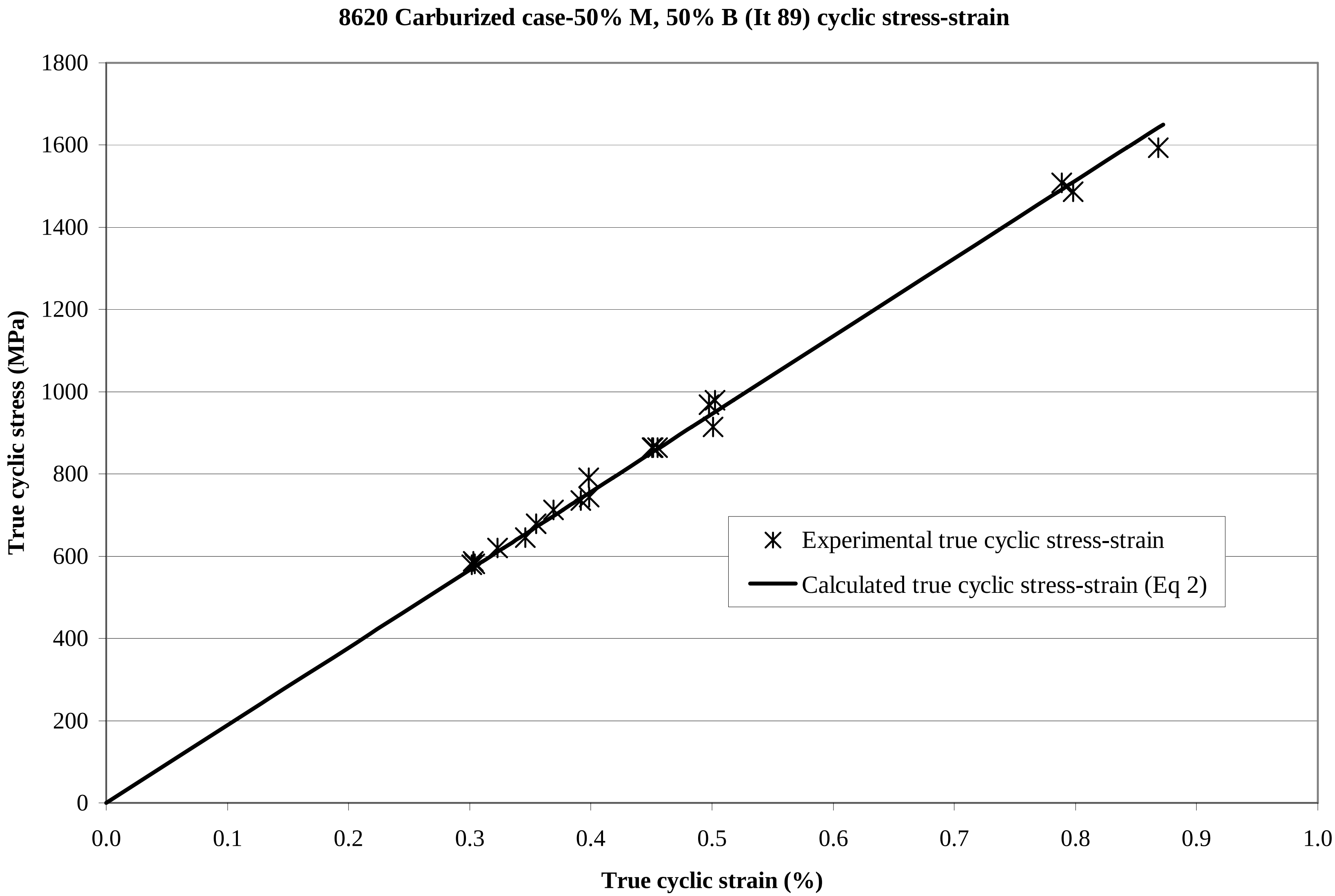

Figure 3. Cyclic true stress-strain curve for iteration 89

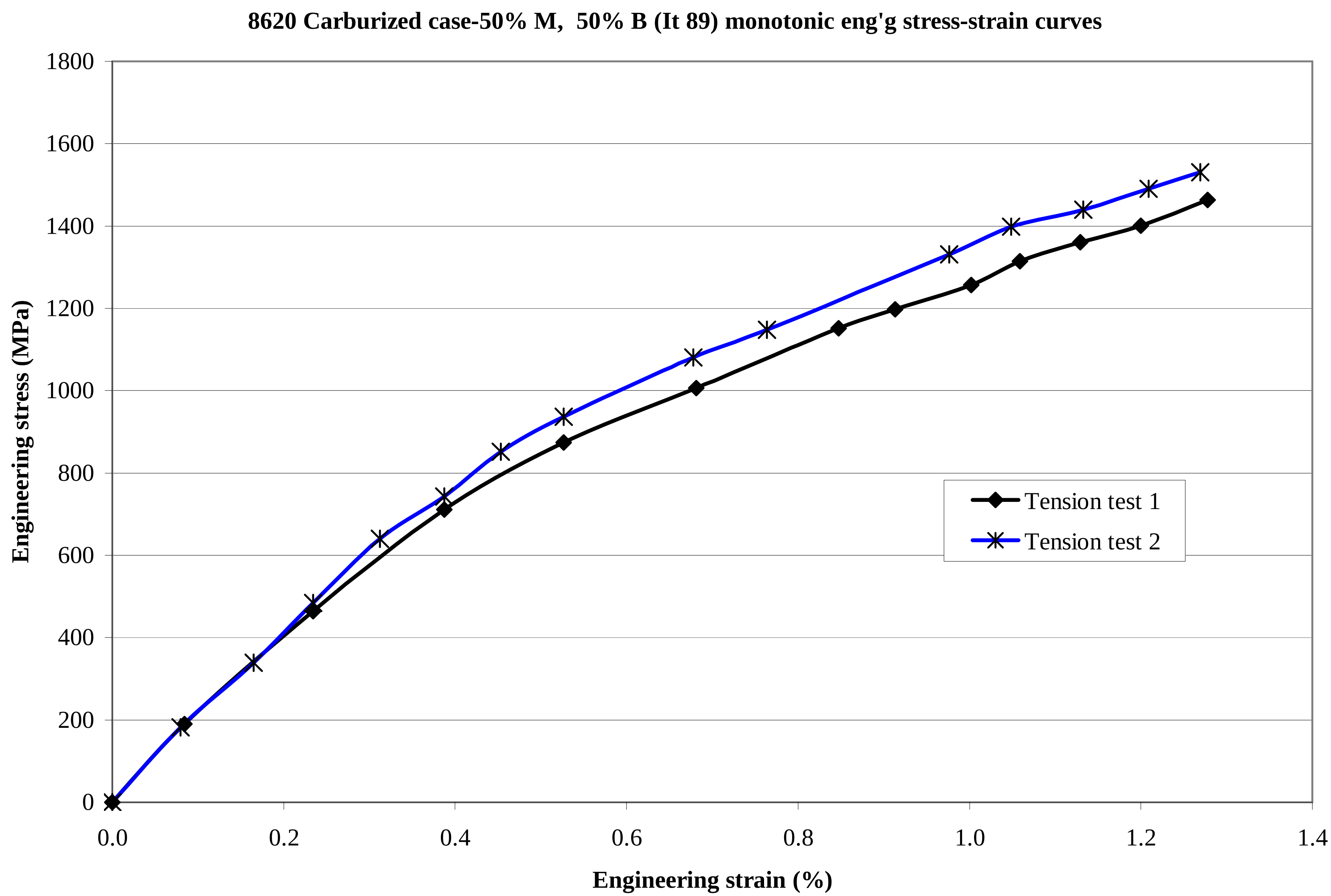

Figure 4. Tensile monotonic engineering stress-strain curves for iteration 89

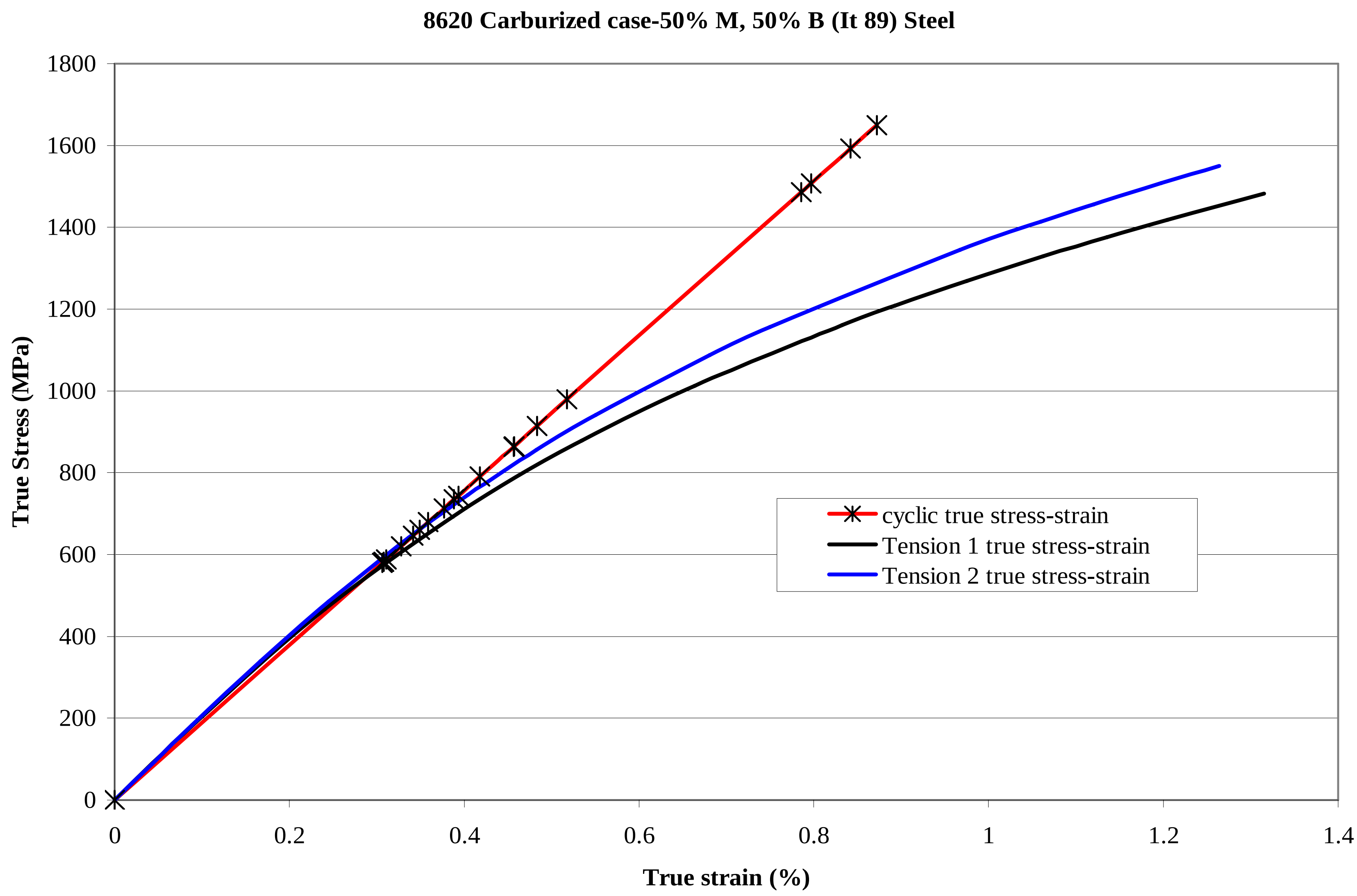

Figure 5. Monotonic and Cyclic true stress-strain curves for iteration 89

Table 1: Chemical composition for Iteration 89

Chemical element	Quantity (%)
Carbon-- C	0.21
Manganese (Mn)	0.83
Phosphorus (P)	0.009
Sulfur (S)	0.032
Silicon (Si)	0.25
Copper (Cu)	0.15
Nickel (Ni)	0.46
Chromium (Cr)	0.5
Molybdenum (Mo)	0.2
Tin (Sn)	0.006
Aluminum (Al)	0.024
Vanadium (V)	0.004
Columbium(Cb) /Niobium (Nb)	0.002
Titanium (Ti)	0.002
Boron (B)	0.0003
Calcium (Ca)	0.0005
Zirconium (Zr)	0.001
Nitrogen (ppm) (N)	0.0063
Oxygen (ppm) (O)	0.0009
Co	0.006
Zn	0.0036
Pb	0.0008
ASA	0.000

Table 2: Fatigue Data for Iteration 89

Sp#	Total Strain Amplitude (%)	Stress Amplitude (MPa)	Plastic Strain Amplitude (%)	Elastic Strain Amplitude (%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	Hardness (Rockwell C)
1	0.798	1486.4	0.000	0.798	596	
9	0.869	1593.0	0.000	0.869	90	
11	0.789	1507.5	0.000	0.789	154	
2	0.503	979.2	0.000	0.503	169,064	
13	0.498	968.7	0.000	0.498	2,084	61.7
16	0.501	914.0	0.000	0.501	26,560	
3	0.451	864.2	0.000	0.451	31,294	
20	0.455	863.5	0.000	0.455	138,462	
21	0.451	864.2	0.000	0.451	1,012	61.5
4	0.398	790.9	0.000	0.398	44,292	
18	0.399	743.7	0.000	0.399	1,473,330	
22	0.392	734.9	0.000	0.392	32,332	
5	0.369	712.9	0.000	0.369	213,964	
6	0.355	678.9	0.000	0.355	313,676	
15	0.346	645.8	0.000	0.346	10,000,000*	
7	0.323	620.3	0.000	0.323	367,060	
8	0.303	588.0	0.000	0.303	10,000,000*	62.7
10	0.304	582.1	0.000	0.304	10,000,000*	
12	0.302	579.8	0.000	0.302	10,000,000*	

* Run out

Table 3: Monotonic and cyclic properties for iteration 89

Monotonic Properties	
Average Elastic Modulus, E (GPa)	206.06
Yield Strength (MPa)	1,114
Ultimate tensile Strength (MPa)	1,497
% Elongation (%)	1.3
% Reduction of Area (%)	0.0
True fracture strain, $Ln\ (A_i / A_f)$ (%)	1.3
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$ (MPa)	1,497
Bridgman correction $= \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$ (MPa)	1,341.6
Monotonic tensile strength coefficient, K (MPa)	7,198
Monotonic tensile strain hardening exponent, n	0.30
Hardness, Rockwell C (HRC)	62
Cyclic Properties	
Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ (MPa)	N/A
Cyclic Elastic Modulus, Ec (MPa)	189140
Cyclic strength coefficient, K' (MPa)	N/A
Cyclic strain hardening exponent, n'	N/A
Fatigue Strength Coefficient, σ'_f (MPa)	2914
Fatigue Strength Exponent, b	-0.113
Fatigue Ductility Coefficient, ε'_f	N/A
Fatigue Ductility Exponent, c	N/A

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

Appendix 1

Microstructure Report

DAIMLERCHRYSLER

UAW - DaimlerChrysler
SCIENTIFIC LABS & PROVING GROUNDS

Materials Engineering Summary Report

LTR Number: 120955

From:	**Peter Bauerle**	**Phone:**	**776-7387**
Location:	**CTC**		

Lab(s):	**Mechanical Properties** **Metallography**	**Completed:**	**12/2/2004**

Subject/Part Name: Fatigue Specimen
Approver: Peter Bauerle
Originator: Peter Bauerle
Originator Phone: 248-576-7387
Number of Parts: 1
Nature of Work: Process/Materials Development
Vendor:
Plant:
P/N:
MS:
PS:

History of Part

The sample that has been submitted is a fatigue specimen that is used for the development of the AISI database. This sample has been identified as iteration 89 and is a grade 8620. The sample has first been through carburized in the gage section and then reaustenitized at 1575F for 30 minutes followed by isothermal transformation at 450F for 50 minutes. The isothermal treatment was used to generate a microstructure with 50% bainite.

Purpose

The purpose of this LTR is to evaluate hardness and microstructure of the gage section of the test specimen.

Mechanical Properties - 120955

Hardness - Rockwell (Performed By: Jim Bolton)

Direct hardness readings were taken on grip area of sample and found to be 57.3/56.9/59.4*
* note a value of 1 has been added for roundness correction

Hardness - Micro (Performed By: Jim Bolton)

120955	
DEPTH	**HARDNESS FROM O.D.**
.005	62.3
.010	62.9
.015	63.1
.020	62.9
.025	62.2
.030	63.7
.040	62.3
.050	61.2
.060	61.2
.070	57.1
.080	55.9
.090	55.5
.100	55.6
.110	55.1
.120	56.1
.130	55.6
.140	57.1
.150	57.6
.160	59.1
.170	62.3
.180	62.5
.190	63.5
.200.	62.8

Metallography - 120955

General Microstructure Description (Performed By: James Shi)

The submitted fatigue specimen was sectioned longitudinally at the grip end and prepared according to the normal procedures for microstructural evaluation. Using optical microscope Olympus PMG3, the microstructures were examined and microphotographs were taken. The results of the evaluation revealed that the part was case carburized. The typical case pattern is shown in Fig.1. The microstructure of the part consisted of some transformation product at the surface followed by bainite region, martensite region, second bainite region, and tempered martensite with a small amount of ferrite to the core. In addition, some inclusions were observed. The details of the microstructures are shown in Figs.2-5. The bainite at the subsurface (below transformation product and decarburization) was estimated to be about 40% of the volume.

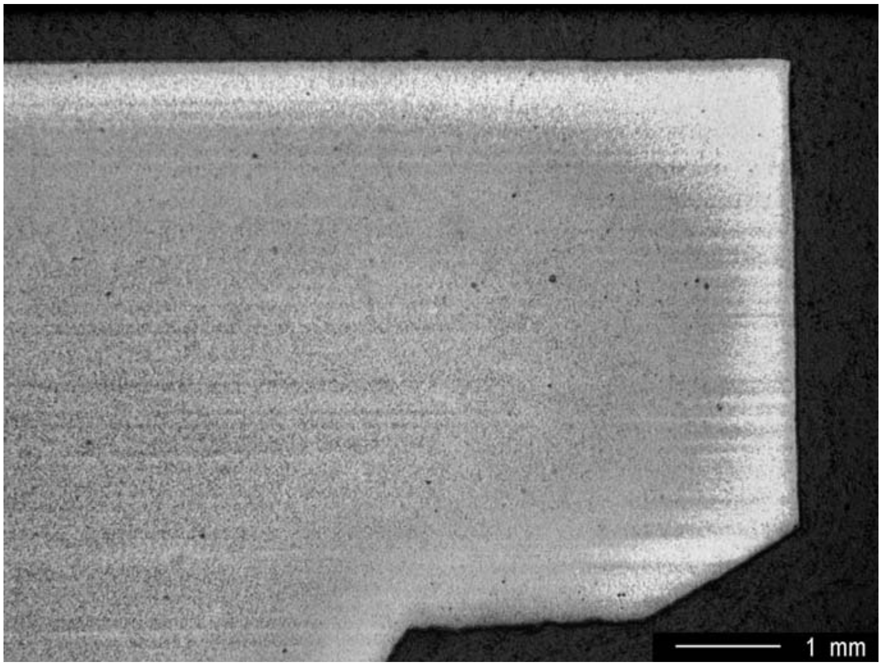

Fig.1 Case pattern inclusions at the grip end, low magnification.

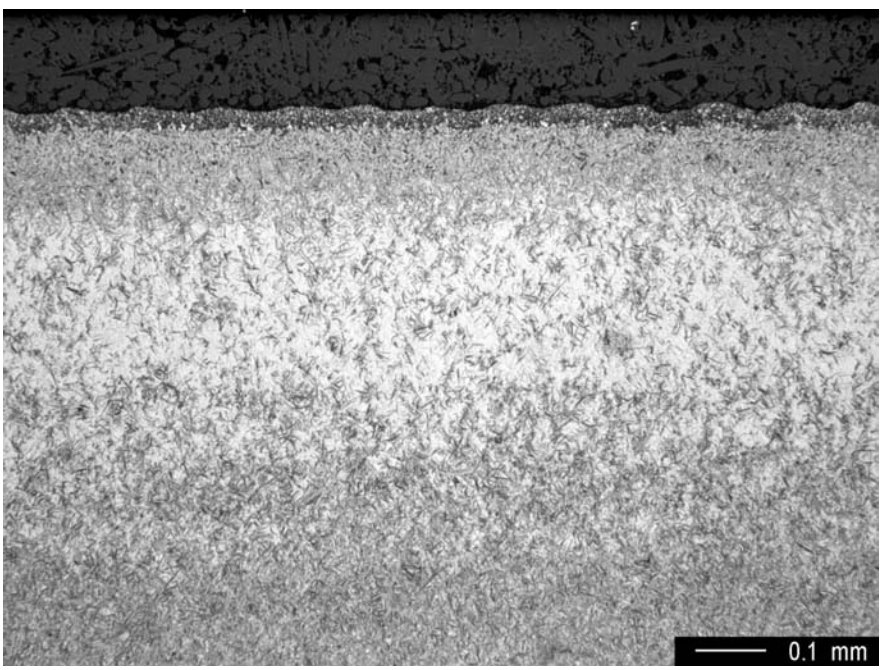

Fig.2 Microstructure at the surface showing bainite regions (darker and lighter phases at the subsurface), 40% bainite estimated, medium magnification.

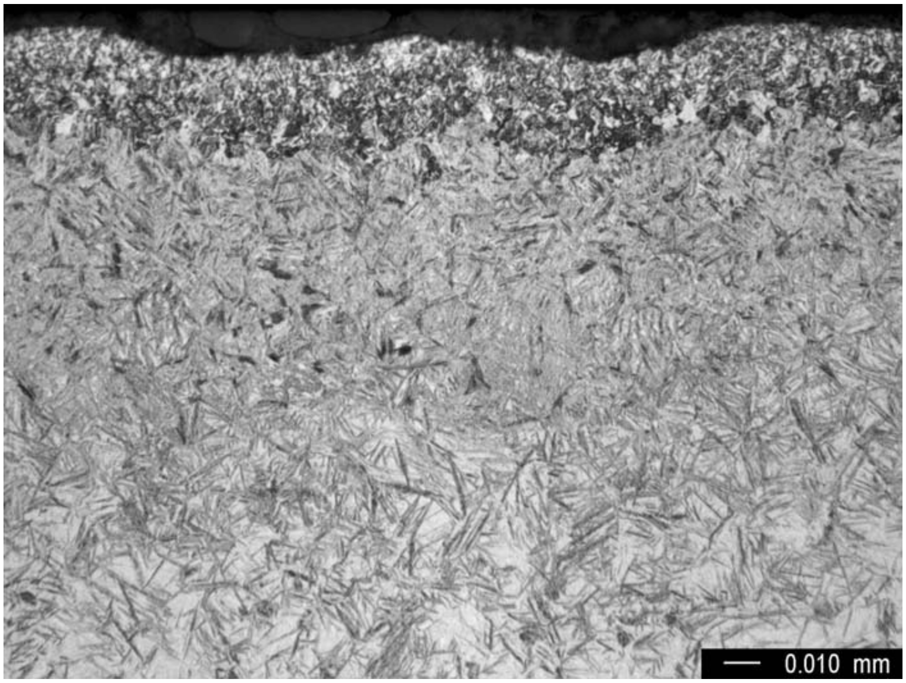

Fig.3 Microstructure at the surface showing transformation product, bainite and martensite, high magnification.

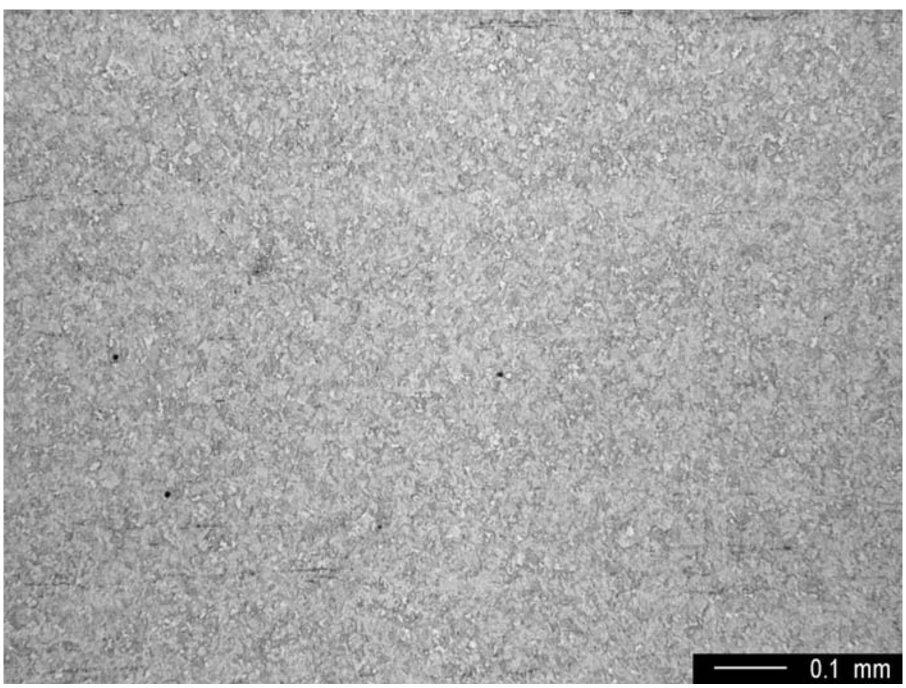

Fig.4 Core microstructure, medium magnification.

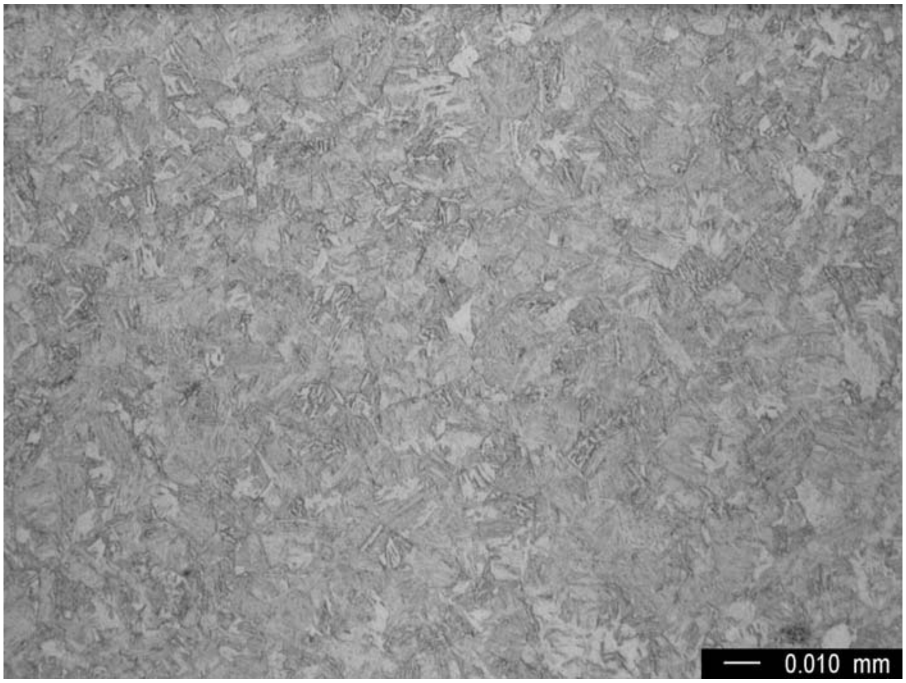

Fig.5 Core microstructure, tempered martensite with a small amount of ferrite, high magnification.

Summary/Conclusion/Recommendations

This sample represents a series of test specimens prepared for iteration 89 of the AISI fatigue properties database. The objective for this iteration was to achieve a microstructure of approximately 50% martensite and 50% bainite. The metallographic examination reveals that a 40-50% bainite content has been achieved and the objective met. The results shall be forwarded to AISI and DCX for use in the materials database.