8620 Carburized Case Steel
Iteration #87

Fatigue Behavior, Monotonic Properties and Microstructural Data

Prepared by:

A.A. Rteil
and
T.H. Topper

Department of Civil Engineering
University of Waterloo
Waterloo, Ontario Canada

Prepared for:
The AISI Bar Steel Applications Group

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American Iron and Steel Institute

American Iron and Steel Institute
2000 Town Center, Suite 320
Southfield, Michigan 48075
tel: 248-945-4777
fax: 248-352-1740
www.autosteel.org

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SUMMARY

This report presents the monotonic and fatigue test results obtained for 8620 carburized case-100% Martensite, 0% Bainite (It 87) 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-100% Martensite, 0% Bainite (It 87) 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 100% martensite and 0% 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.

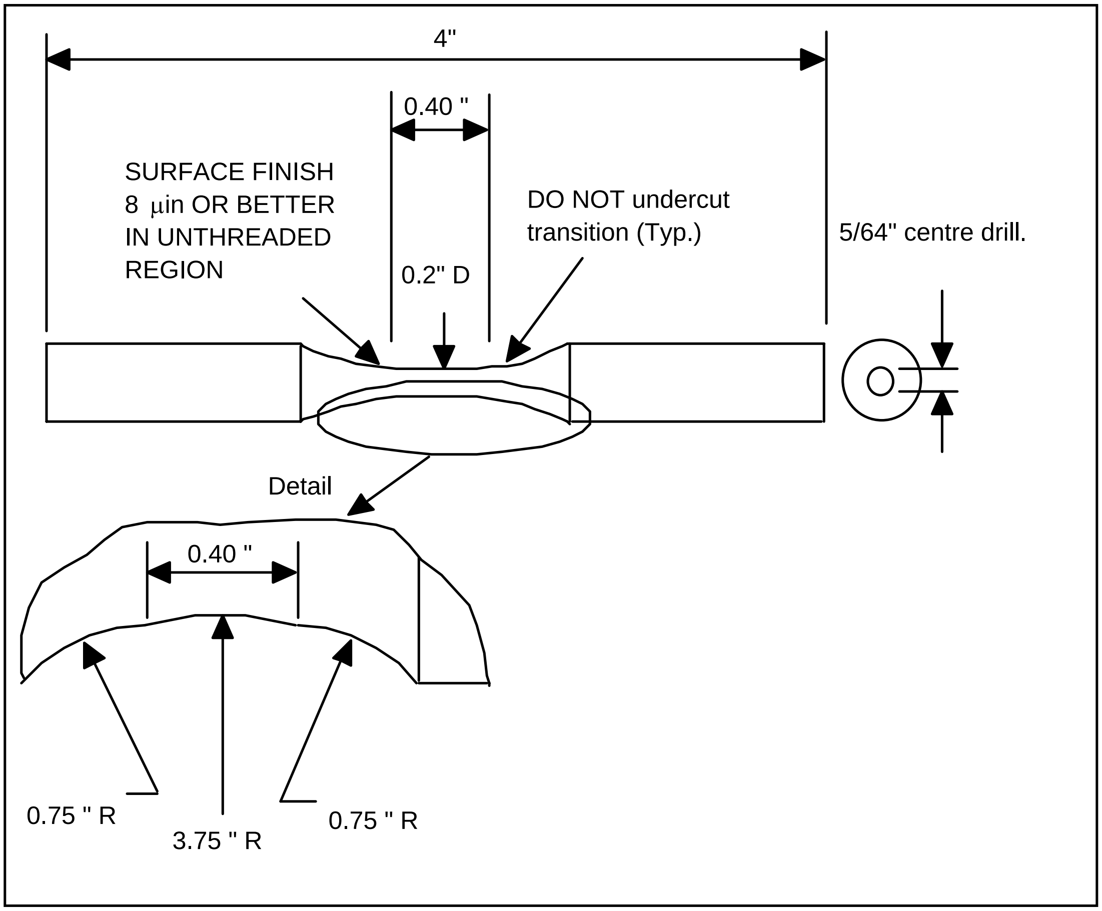

Figure 1 Smooth cylindrical fatigue specimen

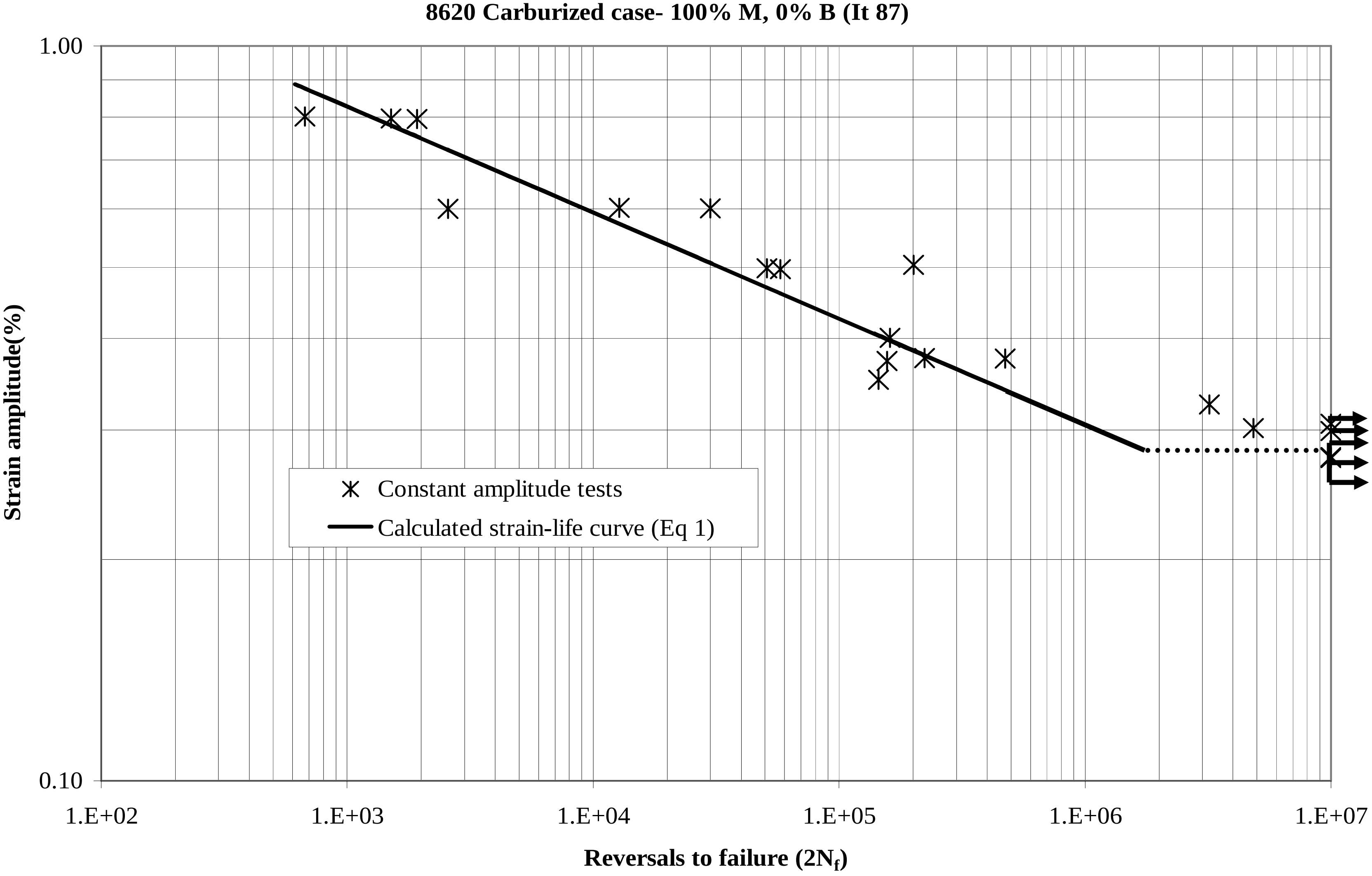

Figure 2. Constant amplitude fully reversed strain-life curve for Iteration 87

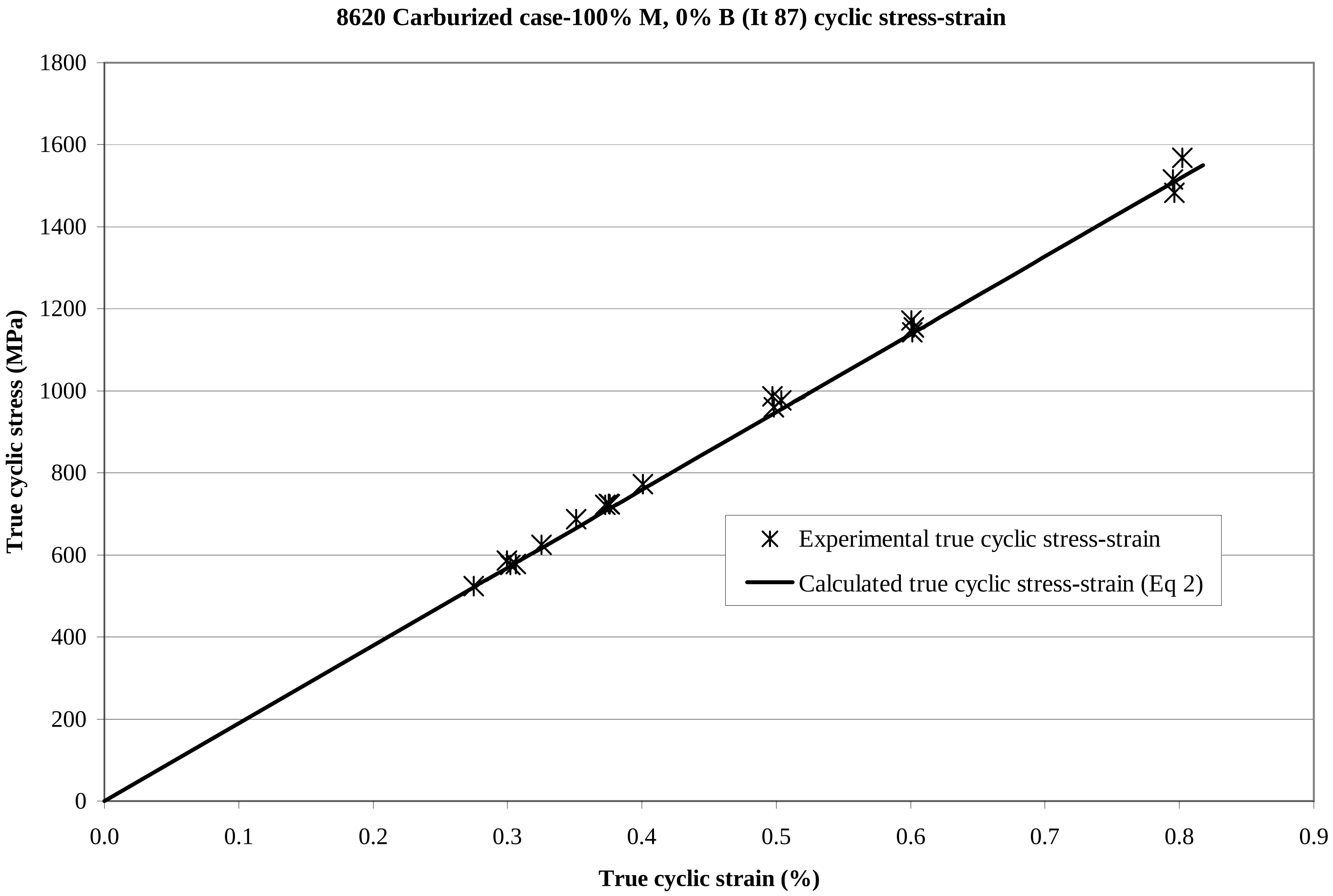

Figure 3. Cyclic true stress-strain curve for iteration 87

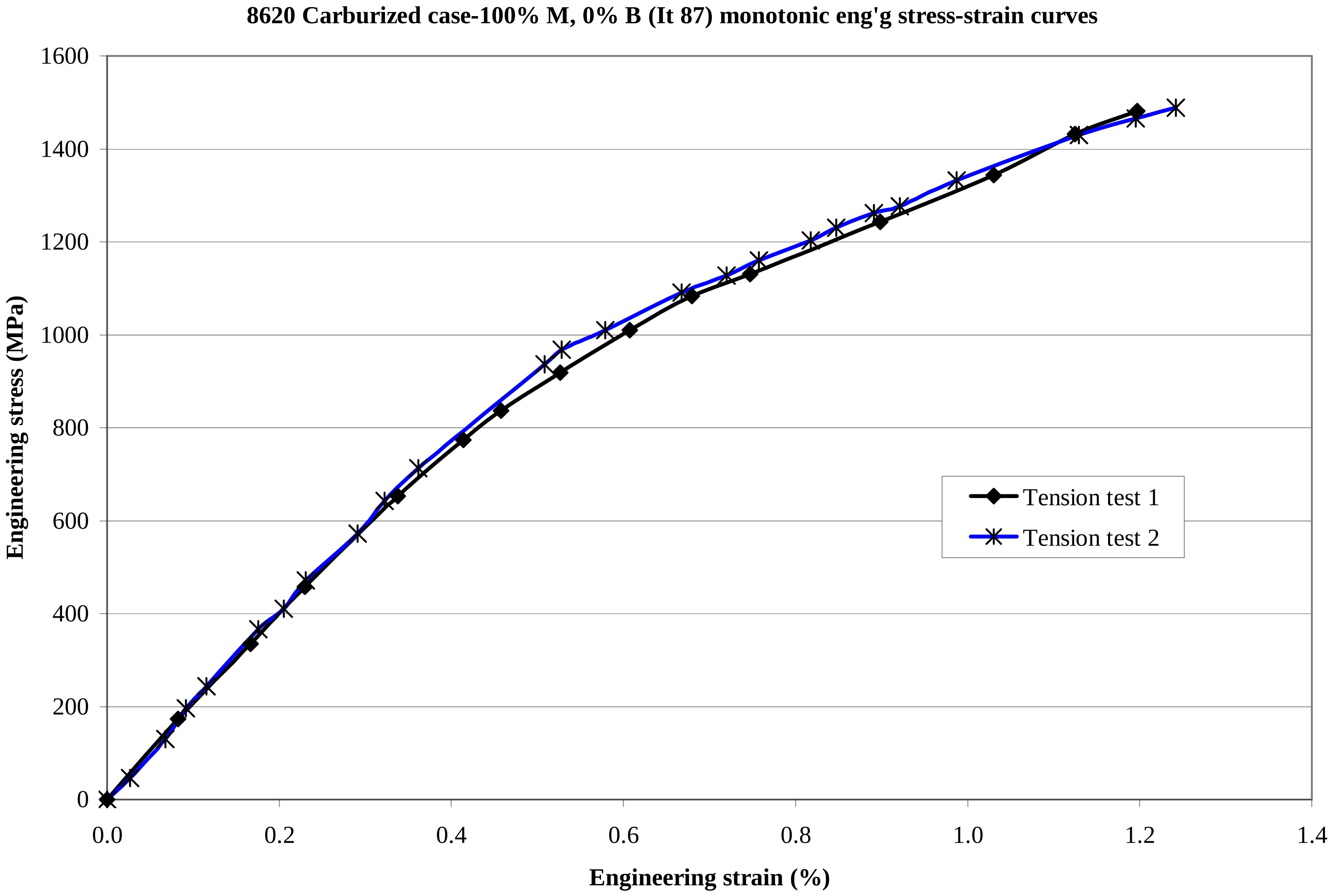

Figure 4. Tensile monotonic engineering stress-strain curves for iteration 87

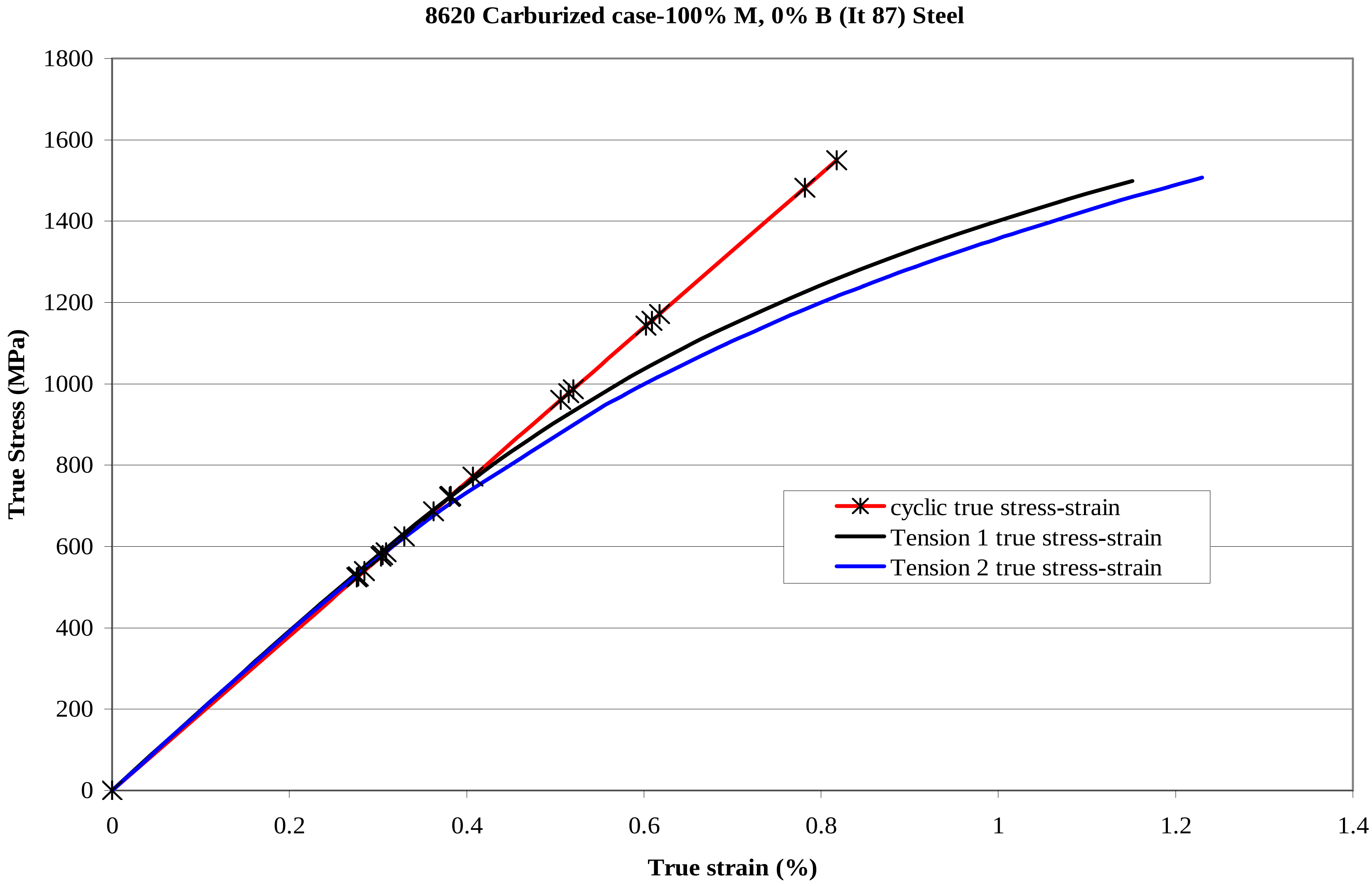

Figure 5. Monotonic and Cyclic true stress-strain curves for iteration 87

Table 1: Chemical composition for Iteration 87

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 87

Sp#	Total Strain Amplitude (%)	Stress Amplitude (MPa)	Plastic Strain Amplitude (%)	Elastic Strain Amplitude (%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	Hardness (Rockwell C)
1	0.796	1482.2	0.000	0.796	1,510	
12	0.795	1515.4	0.000	0.795	1,920	
14	0.802	1568.4	0.000	0.802	674	
9	0.601	1142.6	0.000	0.601	29,990	
16	0.601	1171.0	0.000	0.601	2,568	
21	0.602	1155.0	0.000	0.602	12,792	61
2	0.498	960.0	0.000	0.498	50,768	
17	0.497	986.9	0.000	0.497	57,772	61
18	0.504	976.6	0.000	0.504	201,014	
3	0.401	772.3	0.000	0.401	161,296	
4	0.375	724.8	0.000	0.375	473,490	
19	0.373	722.1	0.000	0.373	156,542	
20	0.376	723.0	0.000	0.376	222,456	61
6	0.325	624.8	0.000	0.325	3,199,592	
5	0.351	687.1	0.000	0.351	144,448	
7	0.306	578.4	0.000	0.306	10,000,000*	
8	0.299	586.1	0.000	0.299	10,000,000*	
10	0.302	575.6	0.000	0.302	4,826,110	
11	0.275	523.8	0.000	0.275	10,000,000*	
13	0.276	537.9	0.000	0.276	10,000,000*	
15	0.276	539.6	0.000	0.276	10,000,000*	

* Run out

Table 3: Monotonic and cyclic properties for iteration 87

Monotonic Properties	
Average Elastic Modulus, E (GPa)	197.18
Yield Strength (MPa)	1,252
Ultimate tensile Strength (MPa)	1,485
% Elongation (%)	1.2
% Reduction of Area (%)	0.0
True fracture strain, $Ln\ (A_i / A_f)$ (%)	1.2
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$ (MPa)	1,485
Bridgman correction $= \frac{P_f}{A_f} \bigg/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$ (MPa)	1,330
Monotonic tensile strength coefficient, K (MPa)	5,575
Monotonic tensile strain hardening exponent, n	0.24
Hardness, Rockwell C (HRC)	61
Cyclic Properties	
Cyclic Yield Strength, (0.2% offset)$= K'(0.002)^{n'}$ (MPa)	N/A
Cyclic Elastic Modulus, Ec (MPa)	189,600
Cyclic strength coefficient, K' (MPa)	N/A
Cyclic strain hardening exponent, n'	N/A
Fatigue Strength Coefficient, σ'_f (MPa)	4458
Fatigue Strength Exponent, b	-0.145
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: 120728

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

Lab(s):	**Mechanical Properties** **Metallography**	**Completed:**	**10/6/2004**

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 87 and is a grade 8620 that has been through carburized.

Purpose

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

Mechanical Properties - 120728

Hardness - Micro (Performed By: Jim Bolton)

Atraverse was done as per customer request

120728	
DEPTH	HARDNESS
.005	62.0
.010	62.9
.015	62.7
.020	62.8
.025	62.5
.030	61.6
.040	61.1
.050	61.2
.060	59.8
.070	58.7
.080	58.7
.090	58.3
.100	57.0
SURFACE	
60.7/60.8/61.4*	

Metallography - 120728

General Microstructure Description (Performed By: James Shi)

The submitted fatigue specimen was sectioned longitudinally at the grip end through the center line 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 tempered martensite from surface to core. In addition, some retained austenite was observed at the sub-surface and it was estimated to be 20% by comparing the retained austenite rating chart. No apparent banding structures were noted. The details of the microstructures are shown in Figs.1-6.

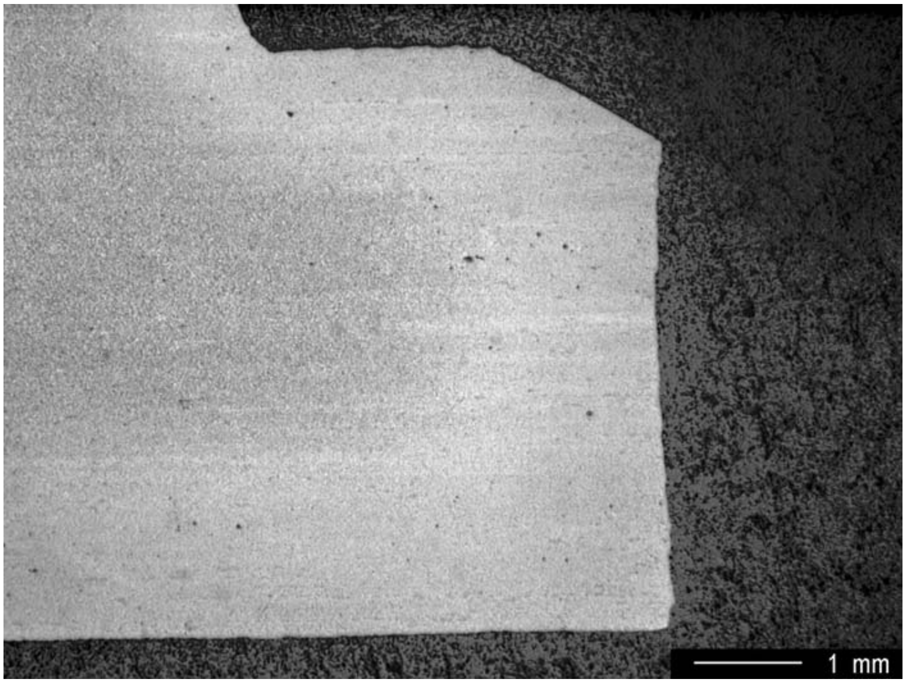

Fig.1 Case pattern at the grip end, low magnification.

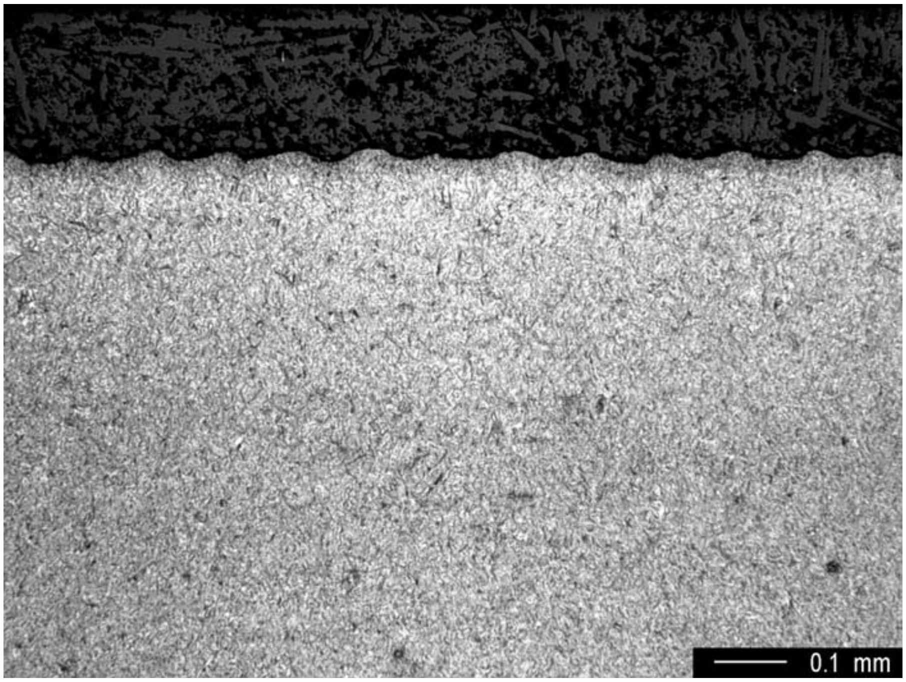

Fig.2 Microstructure at the surface, medium magnification.

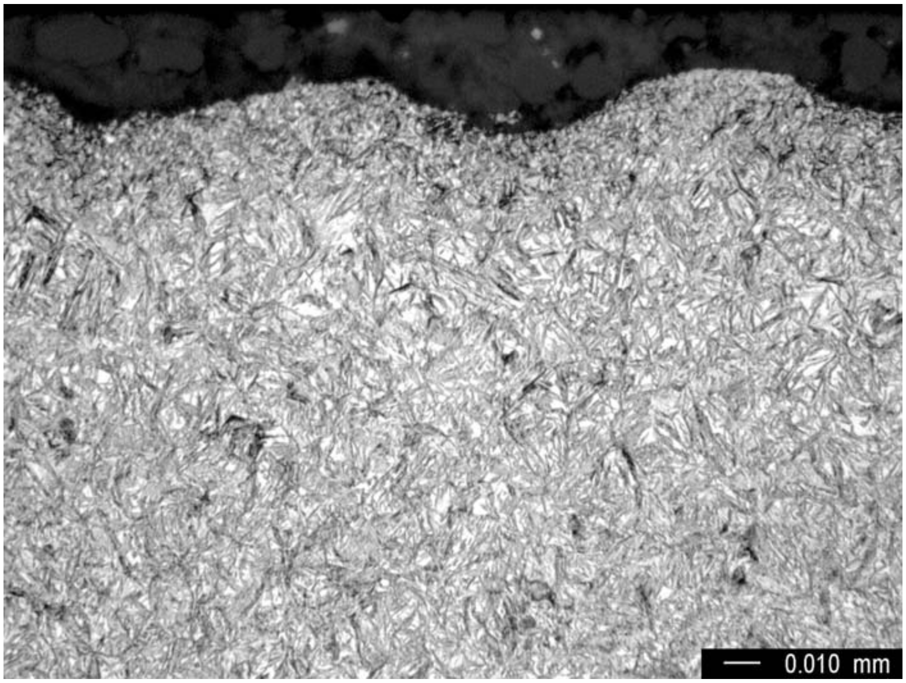

Fig.3 Microstructure at the surface, high magnification.

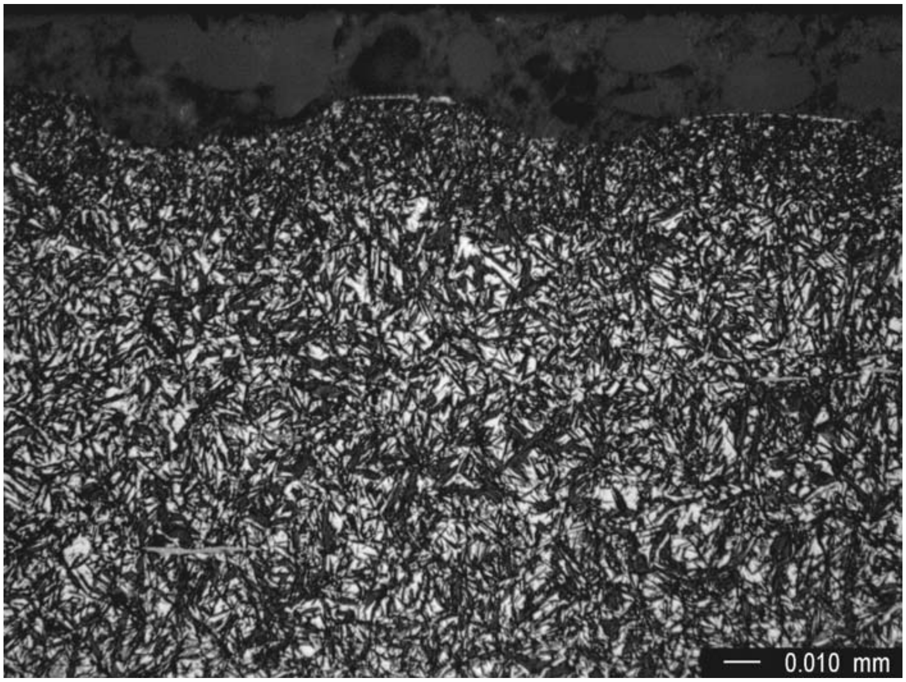

Fig.4 Microstructure at the surface showing retained austenite (white phase), high magnification.

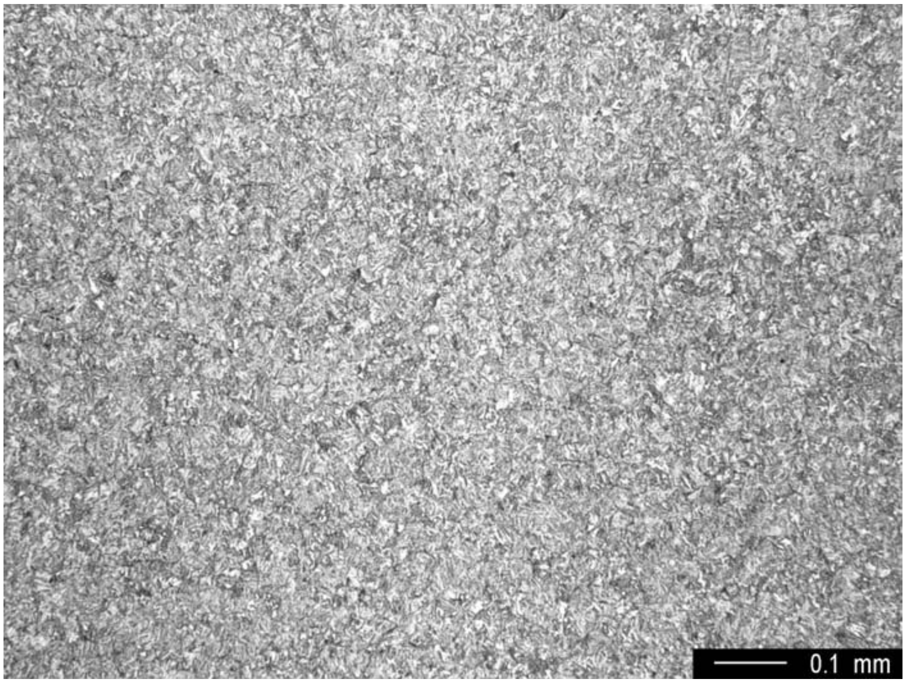

Fig.5 Core microstructure, medium magnification.

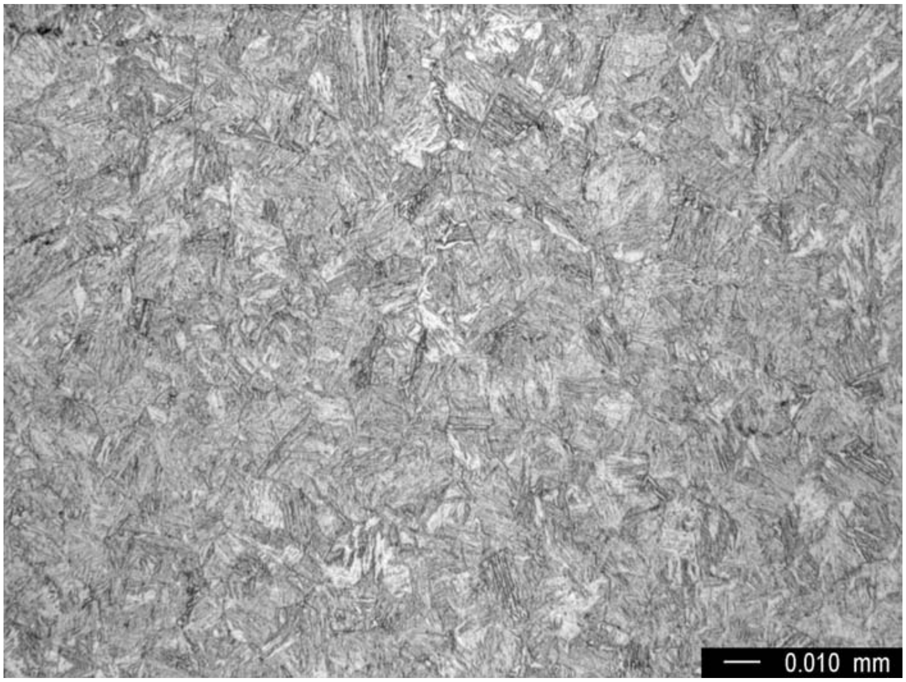

Fig.6 Core microstructure, high magnification.

Summary/Conclusion/Recommendations

The results meet the requirement of a 58-62 HRC range and the microstructure is representative of test specimens that have been through hardened.