8620 Carburized Case Steel
Iteration #95

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-0% M, 100% B (It 95) 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-0%M, 100% B (It 95) 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 0% martensite and 100% 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:

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K'}\right)^{\frac{1}{n'}} \qquad \text{Eq 2}$$

where ε = True total strain amplitude

σ = Cyclically stable true stress amplitude

K' = Cyclic strength coefficient

n' = Cyclic strain hardening exponent

The constants K’ and n' 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.

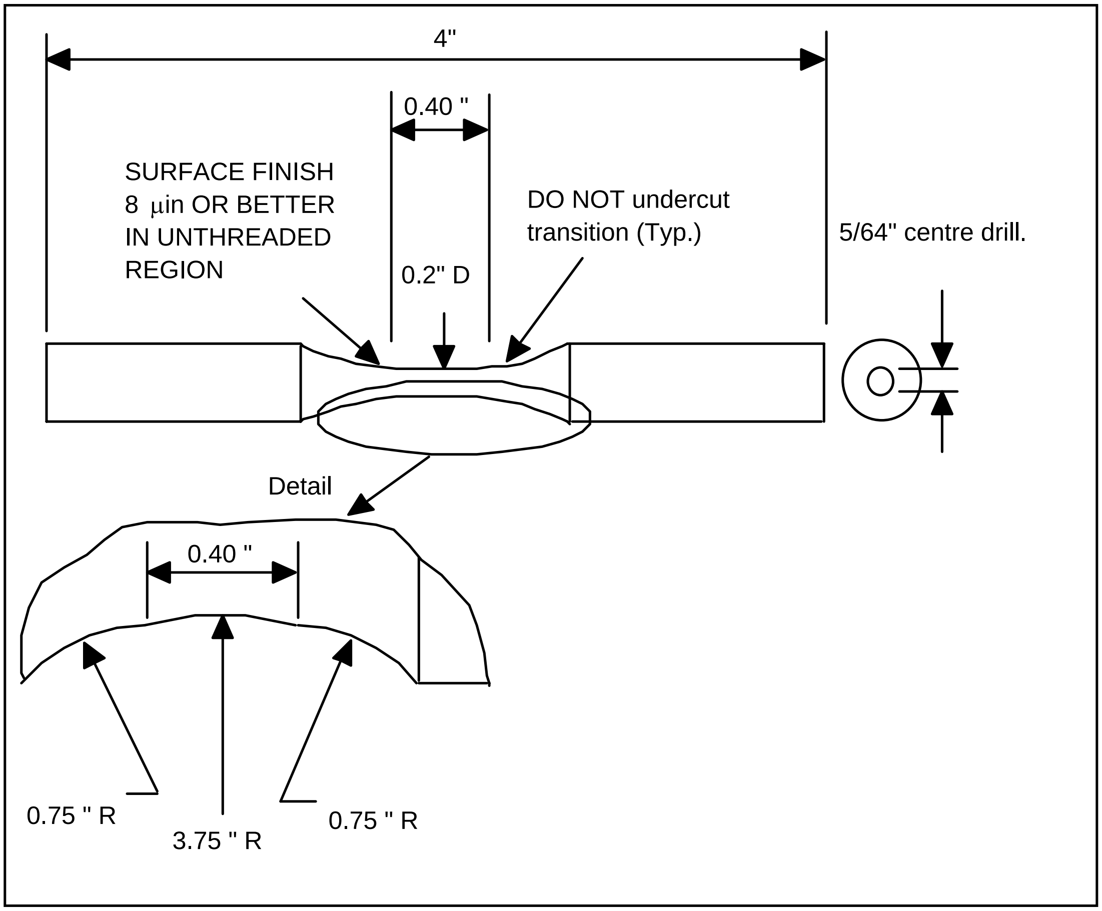


Figure 1 Smooth cylindrical fatigue specimen

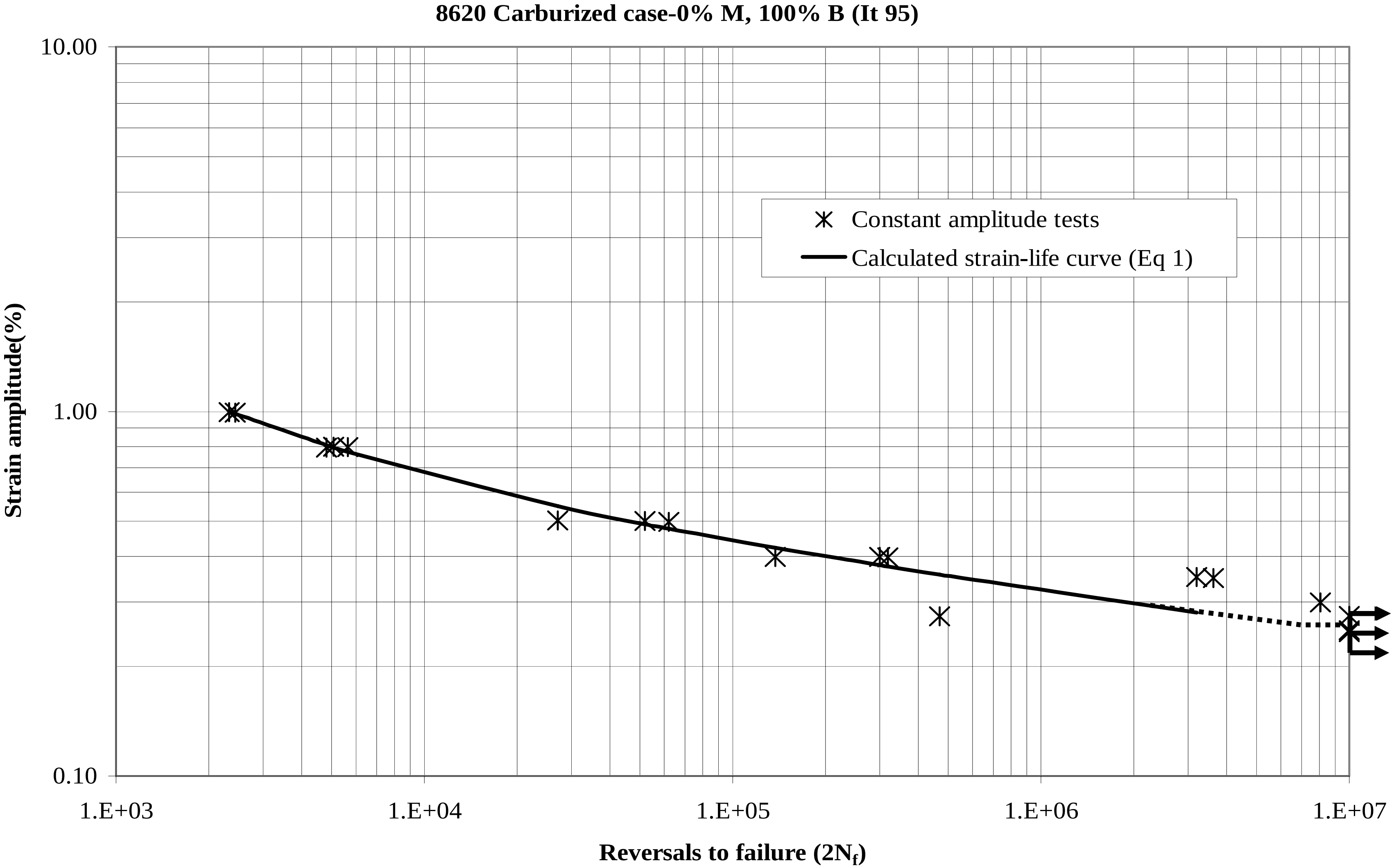


Figure 2. Constant amplitude fully reversed strain-life curve for Iteration 95

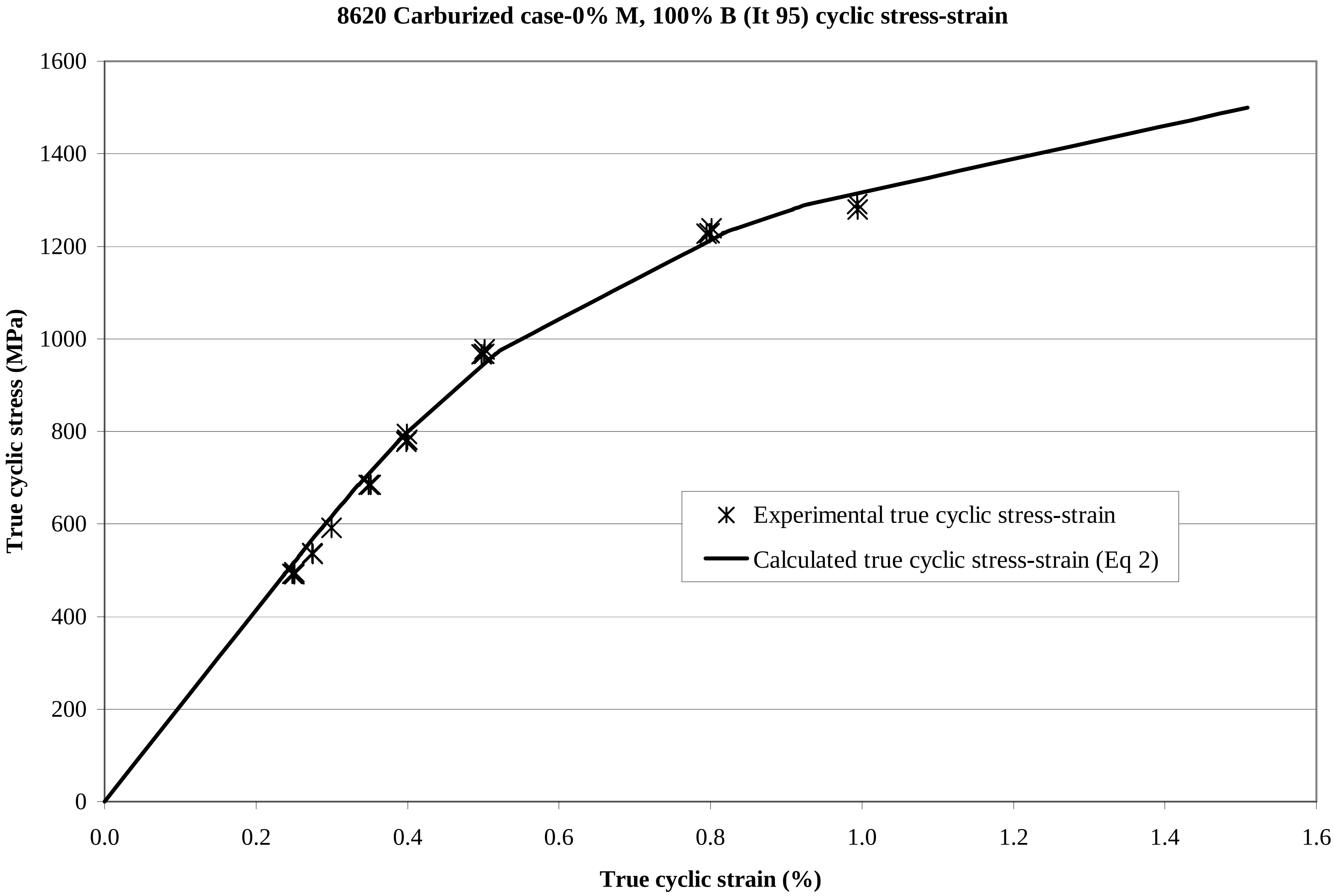


Figure 3. Cyclic true stress-strain curve for iteration 95

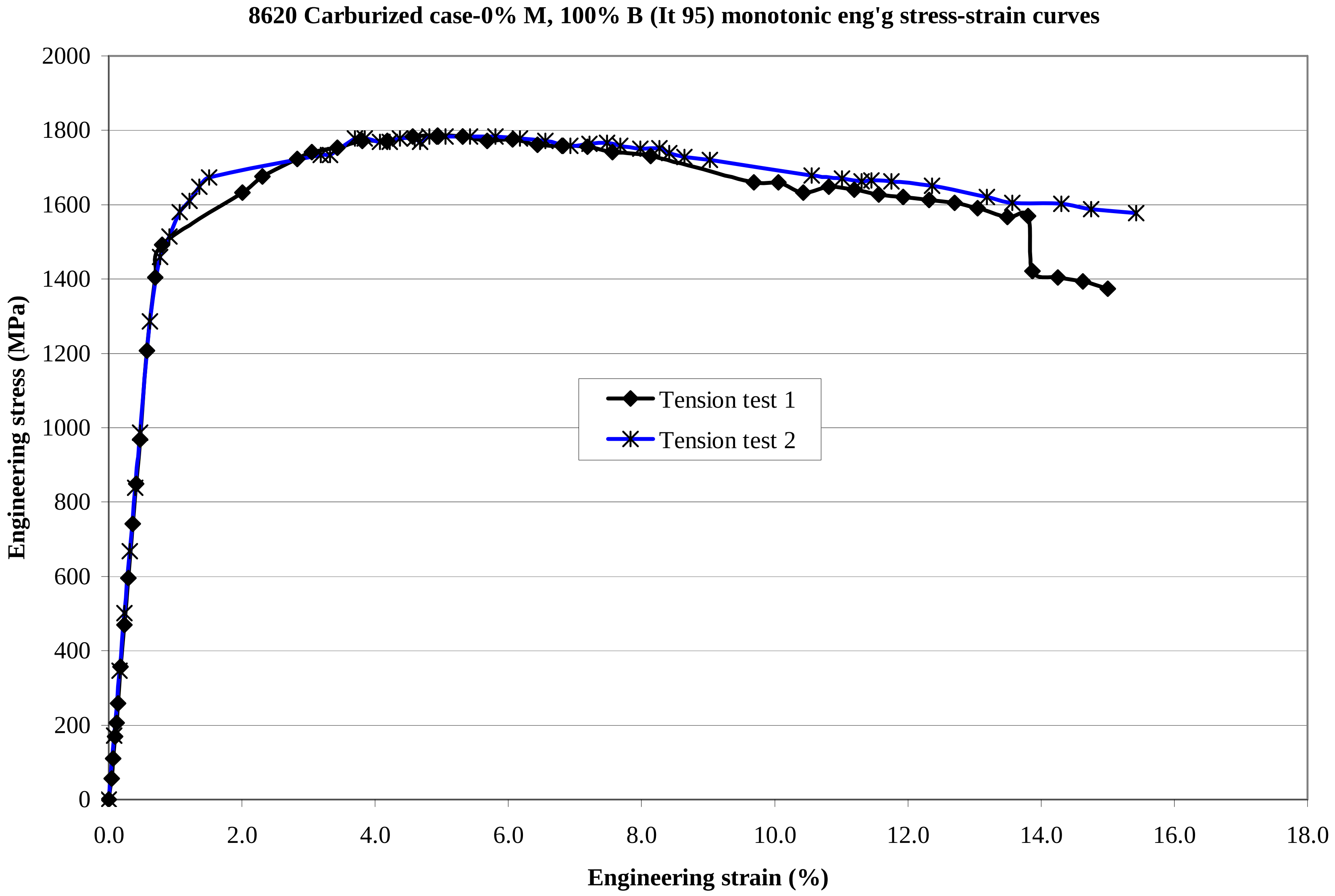


Figure 4. Tensile monotonic engineering stress-strain curves for iteration 95

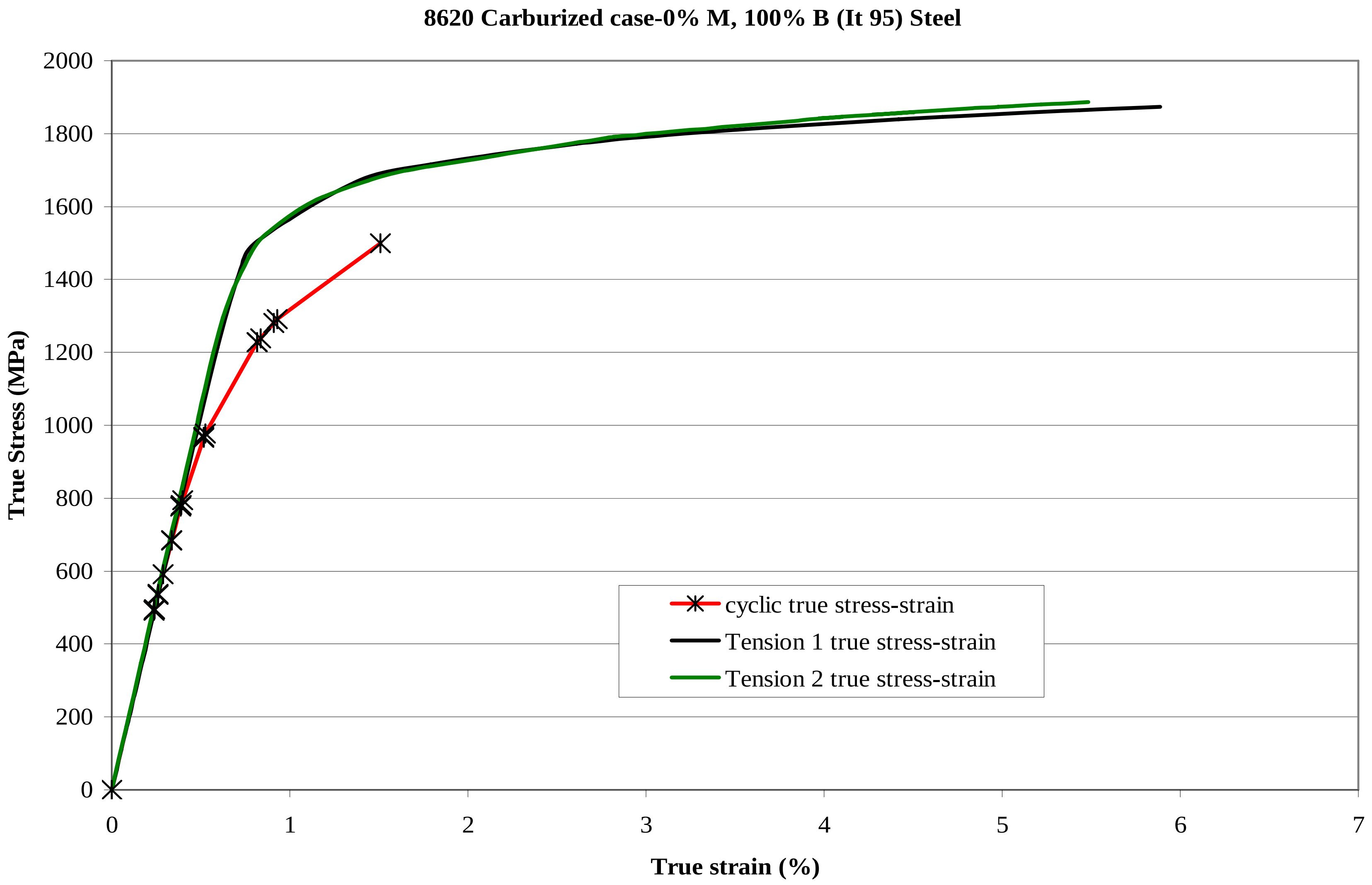


Figure 5. Monotonic and Cyclic true stress-strain curves for iteration 95

Table 1: Chemical composition for Iteration 95

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 95

Sp#	Total Strain Amplitude (%)	Stress Amplitude (MPa)	Plastic Strain Amplitude (%)	Elastic Strain Amplitude (%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	Hardness (Rockwell C)
7	0.994	1280.1	0.378	0.616	2,326	
8	0.993	1291.2	0.372	0.621	2,436	49
4	0.802	1238.9	0.205	0.596	5,072	
5	0.795	1227.8	0.204	0.591	4,822	
6	0.799	1227.8	0.208	0.591	5,654	49
1	0.501	968.0	0.035	0.466	51,950	
2	0.502	977.1	0.032	0.470	27,048	
3	0.498	966.3	0.033	0.465	61,980	
9	0.399	794.6	0.017	0.382	137,242	
10	0.398	777.8	0.024	0.374	319,090	49
11	0.400	781.4	0.024	0.376	300,360	
12	0.349	684.7	0.019	0.329	3,620,610	
13	0.351	684.1	0.022	0.329	3,202,590	
14	0.300	591.6	0.015	0.285	8,063,888	
15	0.275	535.0	0.000	0.275	10,000,000*	
16	0.274	537.0	0.016	0.258	468,500	
17	0.248	492.3	0.011	0.237	10,000,000*	
18	0.251	491.7	0.014	0.237	10,000,000*	
19	0.251	495.6	0.012	0.238	10,000,000*	

* Run out

Table 3: Monotonic and cyclic properties for iteration 95

Monotonic Properties	
Average Elastic Modulus, E (GPa)	207.8
Yield Strength (MPa)	1566
Ultimate tensile Strength (MPa)	1785
% Elongation (%)	15
% Reduction of Area (%)	39
True fracture strain, $Ln\ (A_i / A_f)$ (%)	49
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$ (MPa)	2409
Bridgman correction $= \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$ (MPa)	2206.4
Monotonic tensile strength coefficient, K (MPa)	2242
Monotonic tensile strain hardening exponent, n	0.058
Hardness, Rockwell C (HRC)	49
Cyclic Properties	
Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$ (MPa)	1204.2
Cyclic strength coefficient, K' (MPa)	3260.9
Cyclic strain hardening exponent, n'	0.1603
Fatigue Strength Coefficient, σ'_f (MPa)	3260
Fatigue Strength Exponent, b	-0.115
Fatigue Ductility Coefficient, ε'_f	0.74
Fatigue Ductility Exponent, c	-0.687

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
SLPG
SCIENTIFIC LABS & PROVING GROUNDS

Materials Engineering Lab Report

LTR Number: 123907

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

From:	**Mechanical Properties** **Metallography**	**Completed:**	**10/4/2005**

Subject/Part Name: Fatigue Test Specimen
Report Status: Complete
Originator: Peter Bauerle
Originator Phone: 248-576-7387
Number of Parts: 1
Nature of Work: Pilot, Mule, Program Development Issue
Vendor:
Plant:
P/N:
MS:
PS:

History of Part

The sample that has been submitted is a fatigue specimen that will be used for the development of the AISI database. The sample has been identified as iteration 95 and is a grade 8620. The sample has been, initially, through carburized in the gage section and then reaustenitized at 1575F for 30 minutes followed by isothermal transformation at 600F for 240 minutes. The isothermal treatment was used to generate a microstructure with a 100% bainite.

Test Results

Mechanical Properties - 123907

Hardness - Rockwell (Performed By: Jim Bolton)

Direct hardness readings were taken on grip end of sampleand are 51.5*/50.9*/50.8*

* a value of 1.5 has been added for roundness correction

Hardness - Micro (Performed By: Jim Bolton)

A microhardness traverse was also performed on the gage area

Newage Testing Instruments C.A.M.S. Hardness Testing System

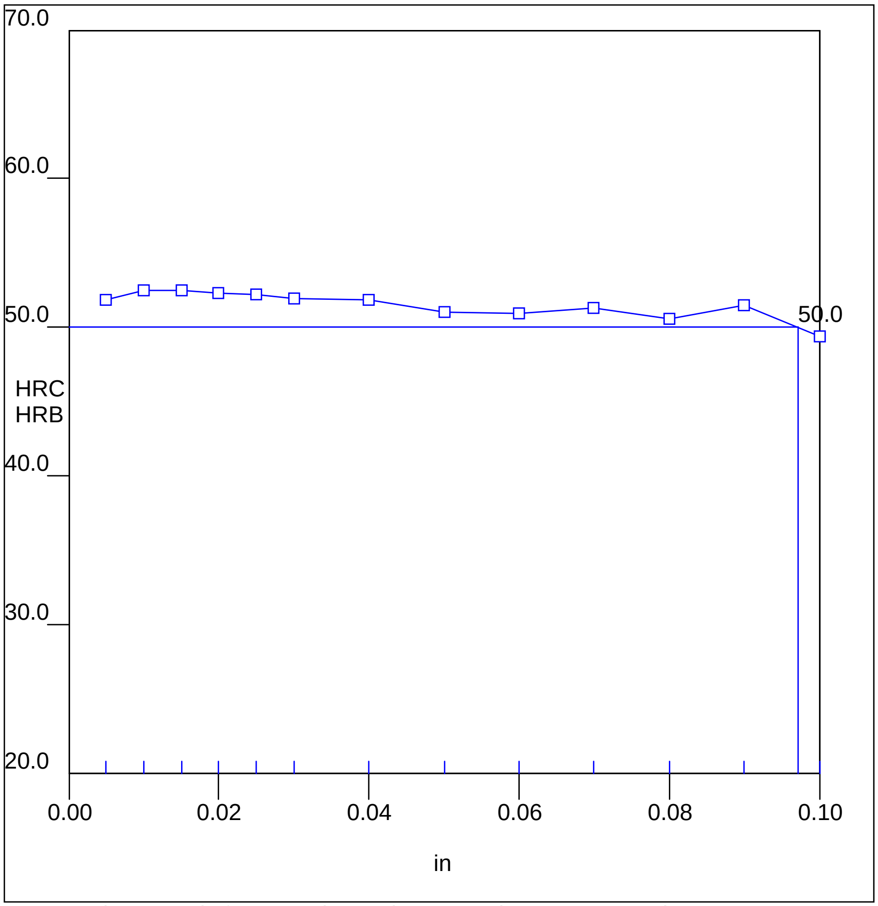
Test Facility

NAME: 123907 Rec#1 DATE: Sep 23 2005 TIME: 10:30:15
COMM: TEST SPECIMAN

LTR #	123907	FURNACE NUMBER	
PART NAME	TEST SPECIMAN	LAB NUMBER	661
MOUNT #	NO.1	COMMENT1	
VENDOR		OPERATOR	
CUSTOMER		COMMENT3	

Load: 1000 gf Scale: HRC TRAVERSE # 1
Description: TRAVERSE FROM O.D.
Comment:

D(in)	HRC	HRB
0.0050	51.8	NC
0.0100	52.5	NC
0.0150	52.5	NC
0.0200	52.3	NC
0.0250	52.2	NC
0.0300	51.9	NC
0.0400	51.8	NC
0.0500	51.0	NC
0.0600	50.9	NC
0.0700	51.3	NC
0.0800	50.6	NC
0.0900	51.5	NC
0.1000	49.4	NC



50.0HRC(NCHRB) @ 0.0971 in min: 0.0000 in max: 0.0000 in
40.0HRC NOT FOUND
30.0HRC NOT FOUND

* = out of tolerance

Metallography - 123907

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 microstructure of the part consisted, primarily, of bainite from surface to core. No banded structure and no apparent retained austenite were observed. The details of the microstructures are shown in Figs.1-5.

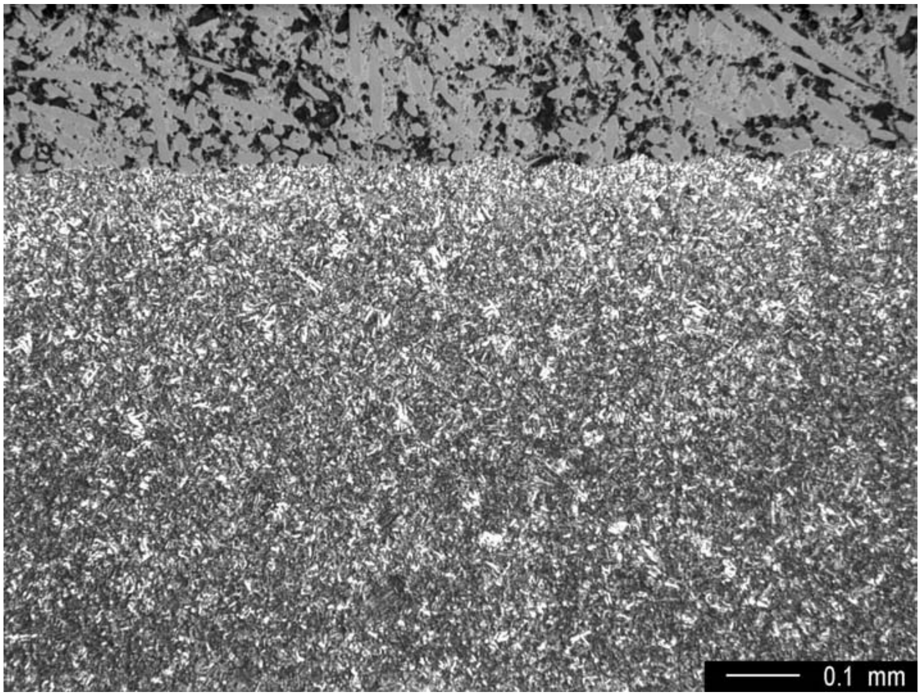


Fig.2 Microstructure at the surface, medium magnification.

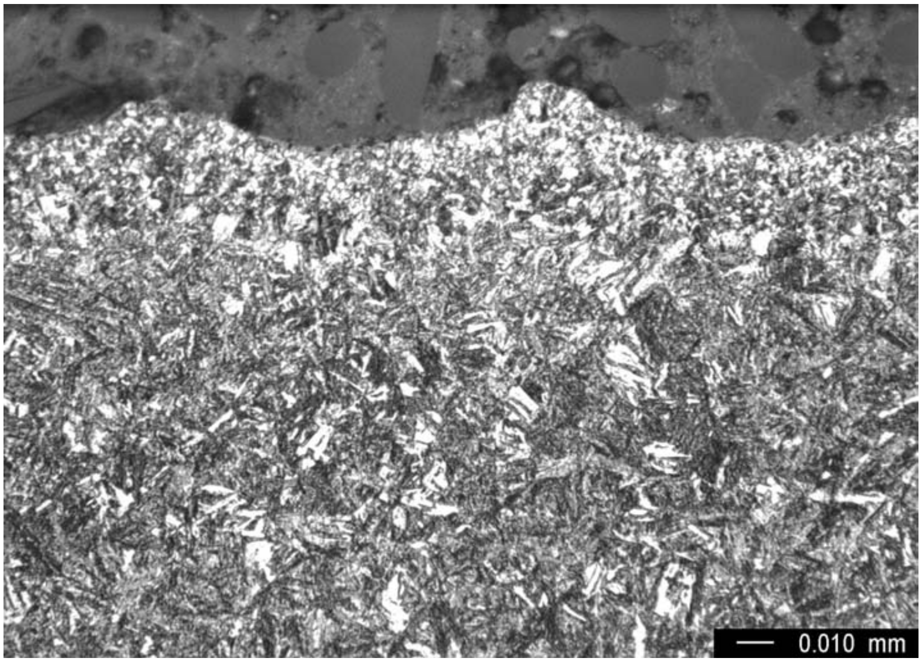


Fig.2 Microstructure at the surface, high magnification.

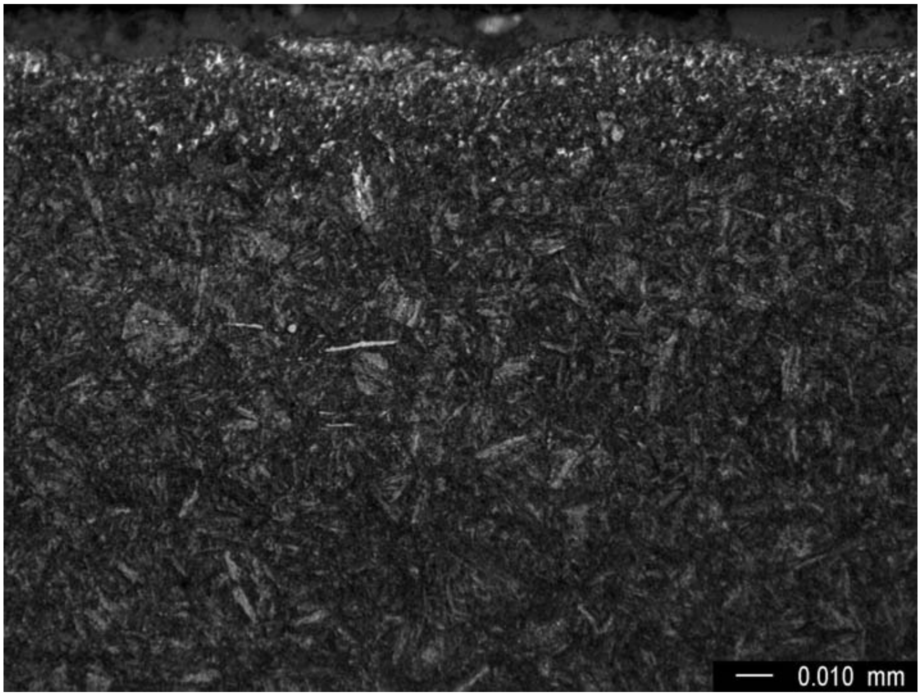


Fig.3 Microstructure at the surface showing no apparent retained austenite (white phase), high magnification.

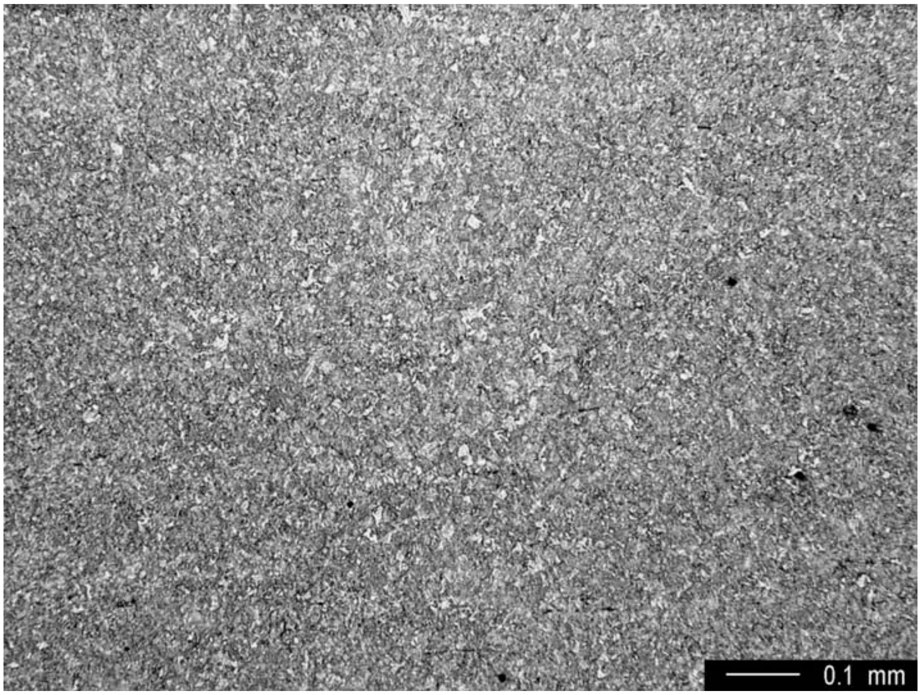


Fig.4 Core microstructure, medium magnification.

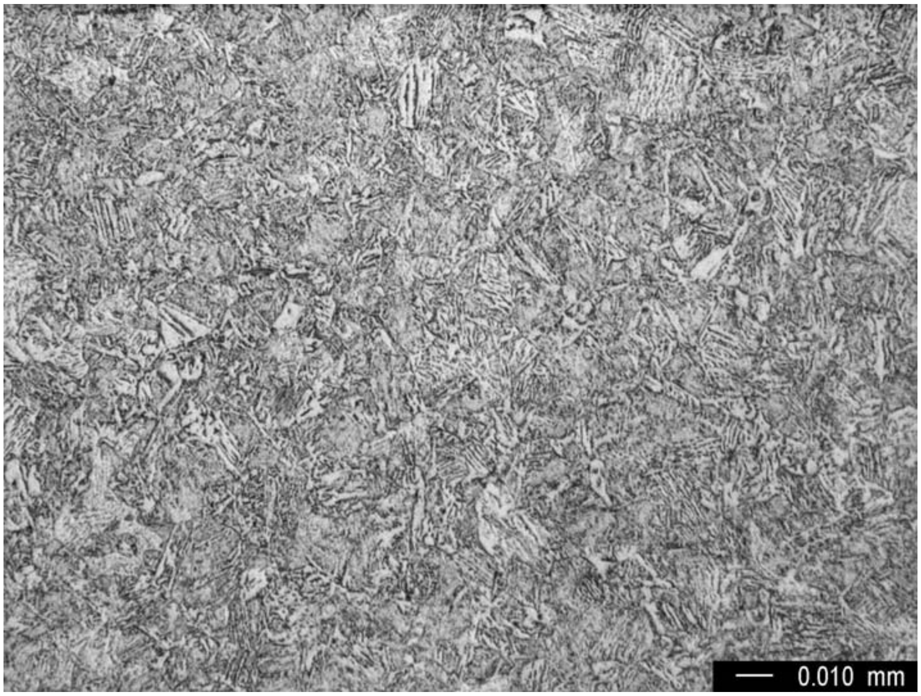


Fig.5 Core microstructure, high magnification.