OK

Fatigue Behavior, Monotonic Properties and Microstructure Data for SAE 9254 (Mod.), Quenched and Tempered (Iteration No. 34)

By

M. Khalil,

T. H. Topper

Department of Civil Engineering,

University of Waterloo

May 2000

TABLE OF CONTENTS

SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for SAE 9254 (Mod.), Quenched and Tempered (Iteration No. 34) have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of 0.65" bars. These bars were machined into smooth axial fatigue specimens. The specimens were heat treated to temperature 1650 °F in a nitrogen medium for 45 minutes and quenched in hot oil at 150 °F and tempered at 770 °F for 45 minutes to give a hardness of about Rc 51-55 then water quenched. Two monotonic tensile tests were performed to measure the yield strength, the tensile strength and the reduction of area. Twenty seven 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 27 SAE 9254 (Mod.), Quenched and Tempered 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 tests 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 then sent to be heat treated at Cambridge Heat Treatment Inc. 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, 27 fatigue data points were generated.

Test Equipment and Procedure

Two monotonic tension tests 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 80 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 martensitic microstructure of SAE 9254 (Mod.), Quenched and Tempered steel. A Type D inclusion severity level of $1\frac{1}{2}$ 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 SAE 9254 (Mod.), Quenched and Tempered steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of SAE 9254 (Mod.), Quenched and Tempered steel was provided by the supplier (Meritor Inc.), and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for SAE 9254 (Mod.), Quenched and Tempered 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.

A fatigue strain-life curve for the SAE 9254 (Mod.), Quenched and Tempered 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 $\sigma'_f = 2914$ MPa, $b = -0.0973$, $\varepsilon'_f = 4.17$ and $c = -0.926$. These values of the strain-life parameters were determined from fatigue testing over the range: $0.0034 < \frac{\Delta\varepsilon}{2} < 0.01$.

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 true 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 $K' = 2168$ MPa and $n' = 0.0757$.

D) Mechanical Properties

The engineering monotonic stress-strain curve is given in Figure 6. The monotonic and cyclic properties are included in Appendix 1. The Hardness of the SAE 9254 (Mod.), Quenched and Tempered steel 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. The true monotonic and true cyclic stress-strain curves plotted together are given in Figure 7.

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.

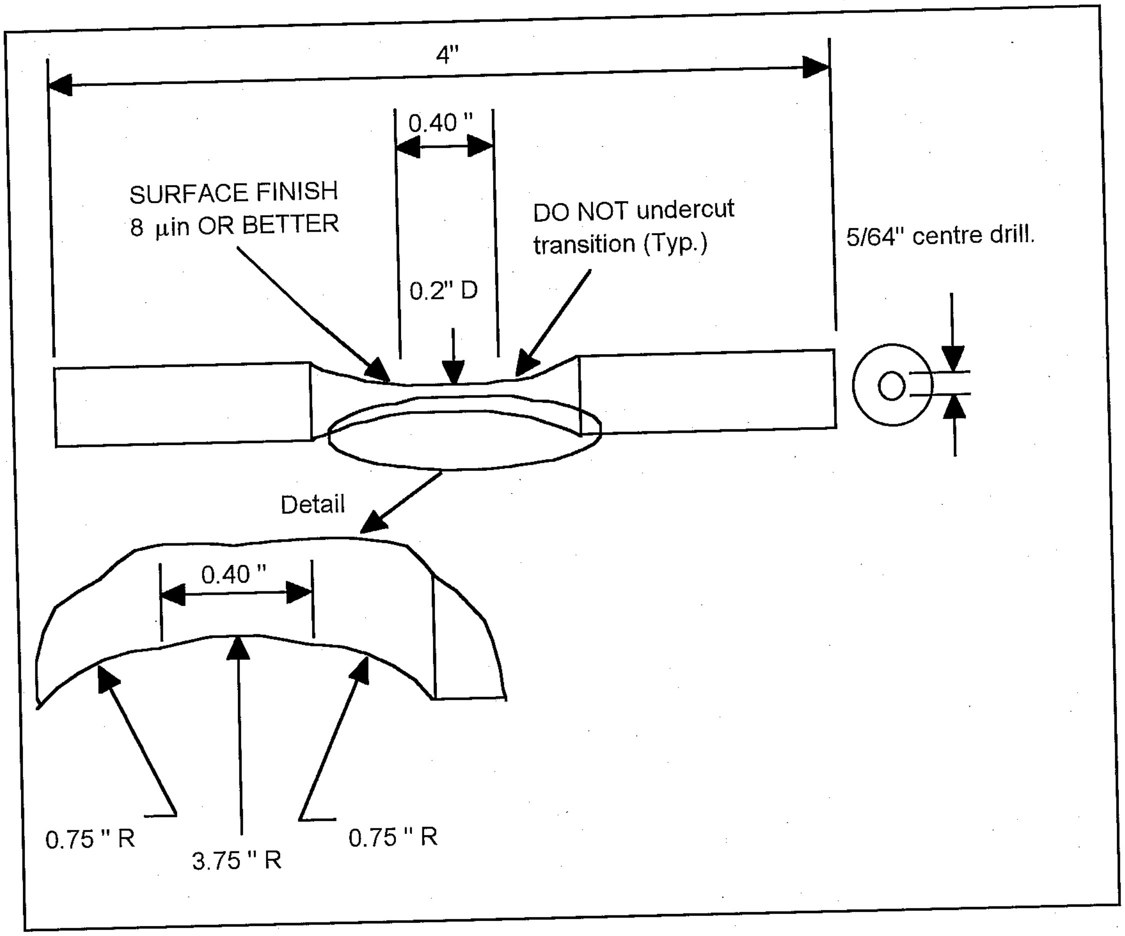
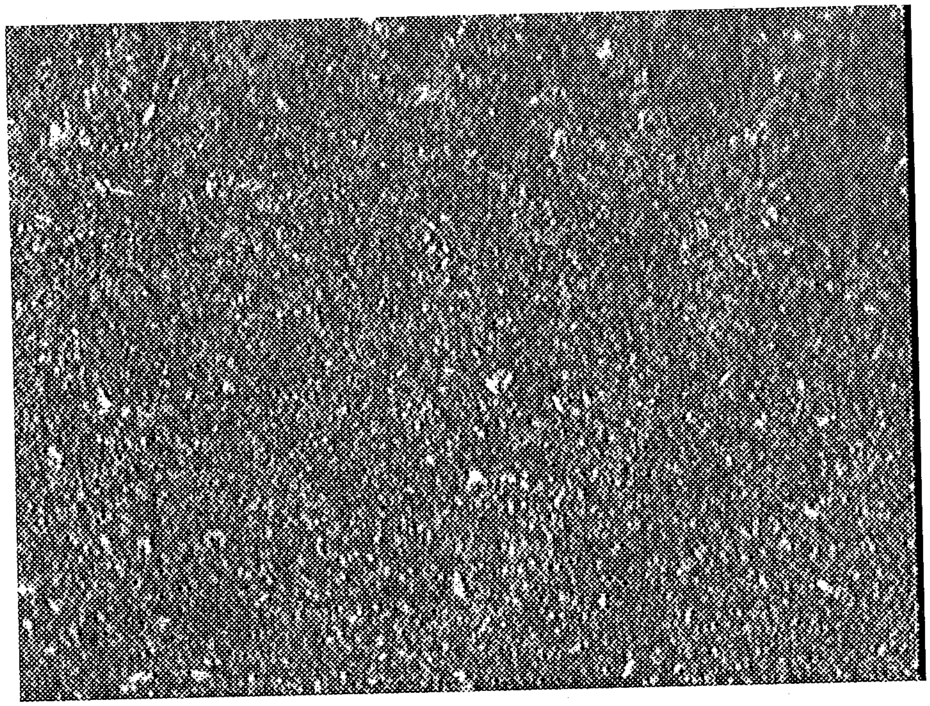
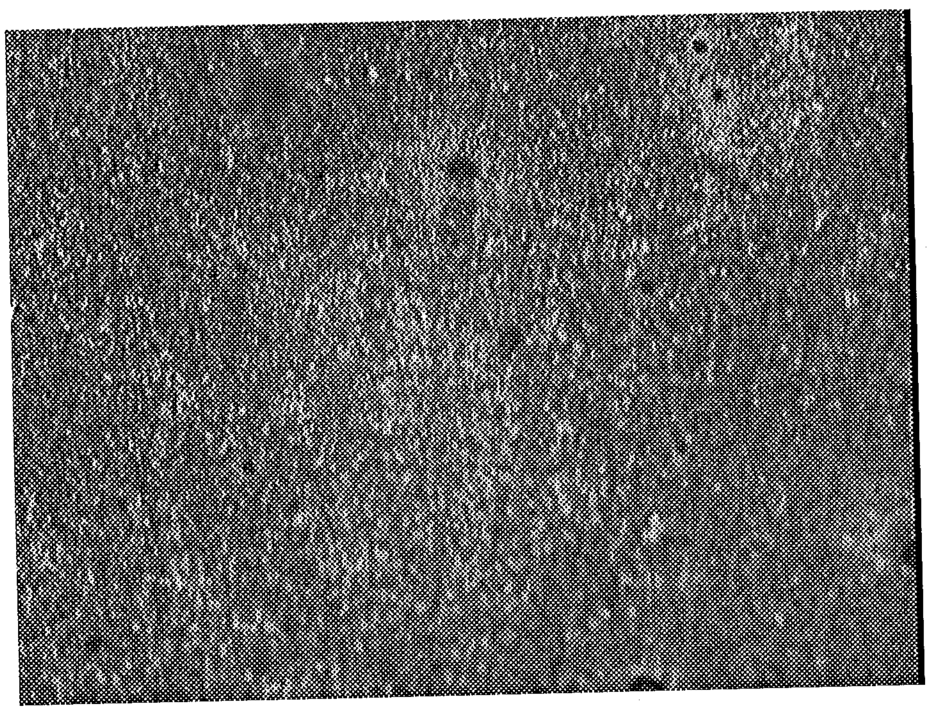


Figure1. Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

Figure 2. Photomicrographs of SAE 9254 (Mod.), Quenched and Tempered (X200)

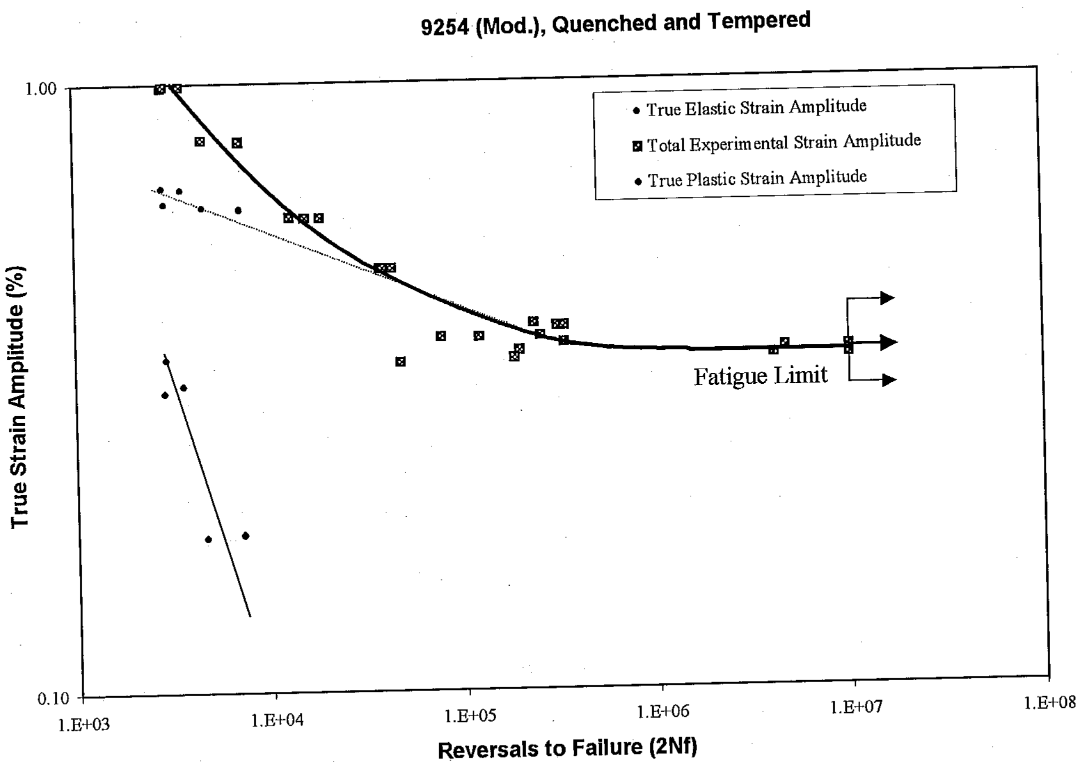


Figure 4. Constant amplitude fully reversed strain-life curve for SAE 9254 (Mod.) Quenched and Tempered steel.

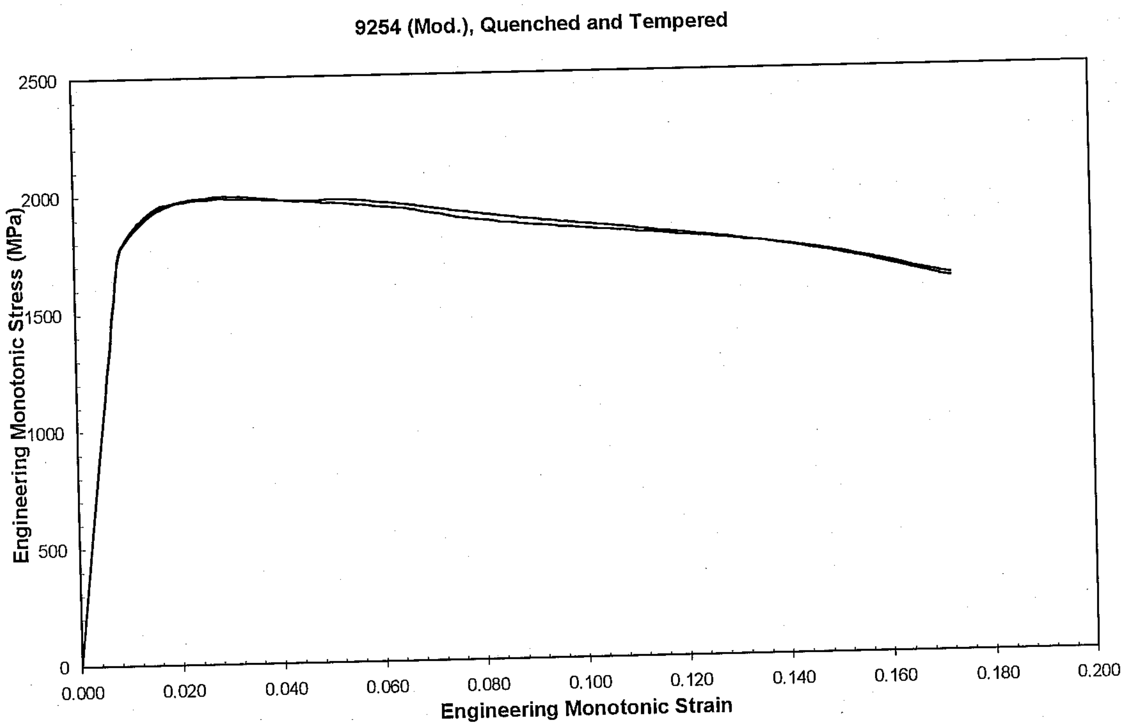


Figure 5. Monotonic stress-strain curves for SAE 9254 (Mod.), Quenched and Tempered steel.

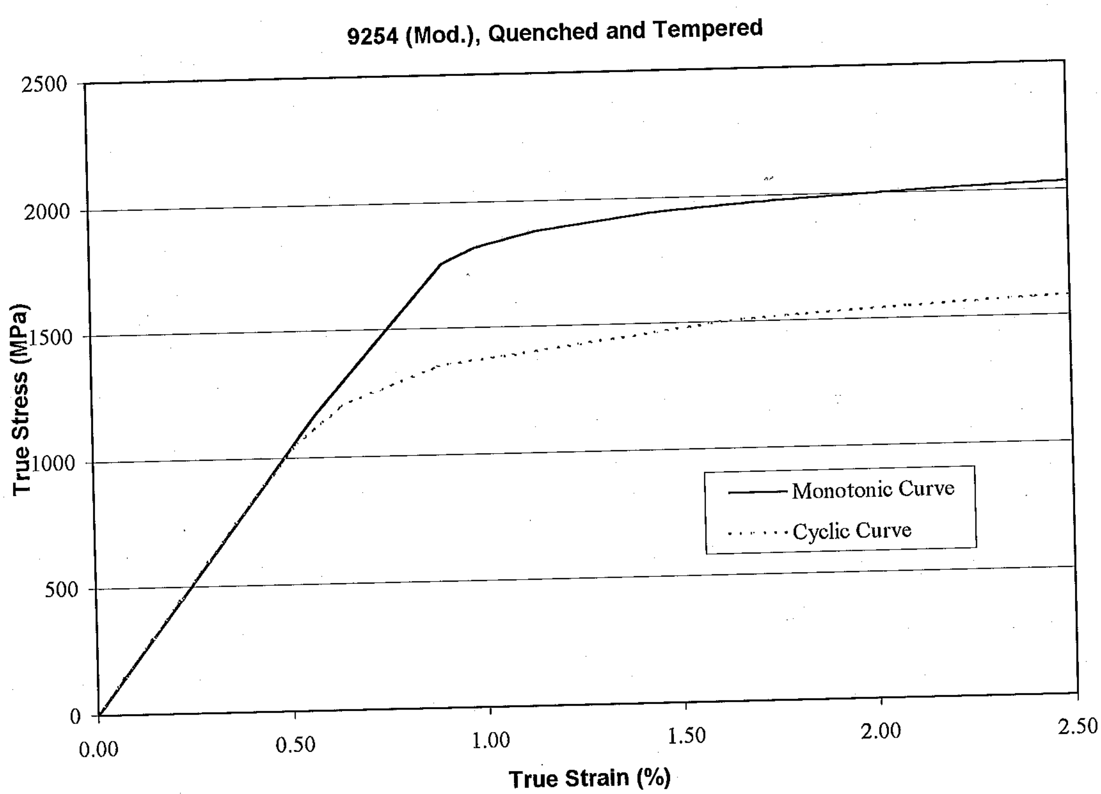


Figure 7. Monotonic and Cyclic stress-strain curves for SAE 9254 (Mod.), Quenched and Tempered steel.

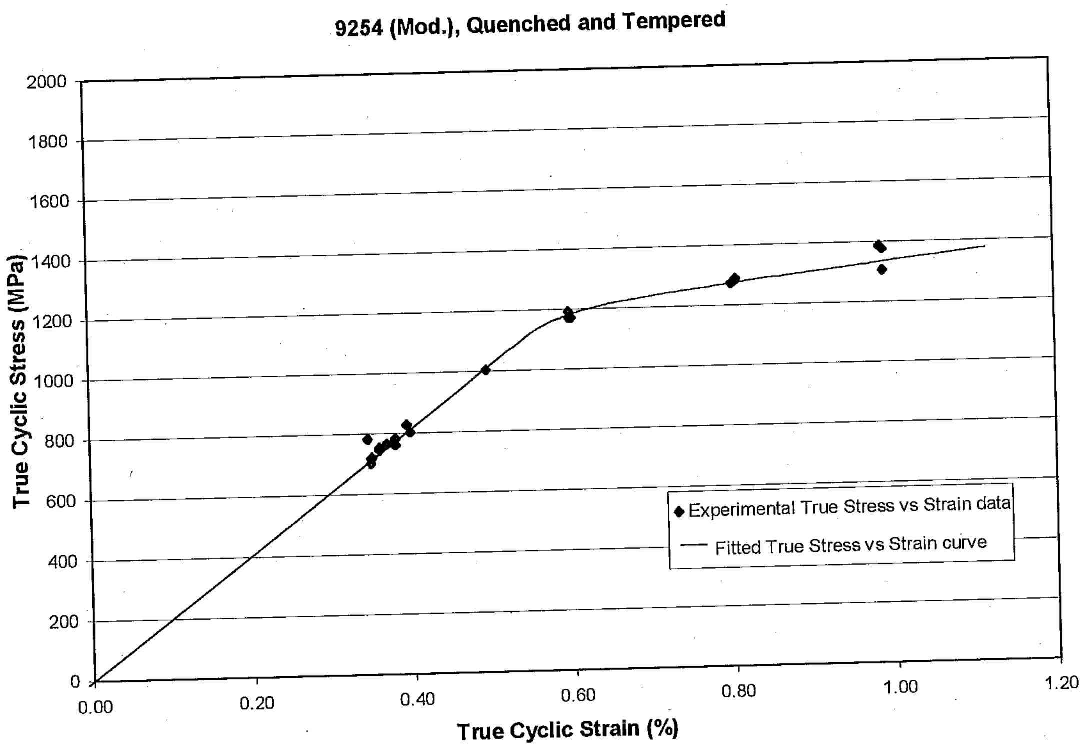


Figure 6. Cyclic stress-strain curve for SAE 9254 (Mod.), Quenched and Tempered steel.

Table 1 Chemical composition of SAE 9254 (Mod.), Quenched and Tempered steel.

Carbon, C	0.52%
Manganese, Mn	0.45%
Phosphorous, P	0.011%
Sulfur, S	0.011%
Silicon, Si	1.49%
Copper, Cu	0.01%
Nickel, Ni	0.01%
Chromium, Cr	0.72%
Molybdenum, Mo	0.09%
V	0.19%
AL	0.024%
N	0.01%

Table 2 Tensile and Fatigue Test Data for SAE 9254 AL FG, Quenched and Tempered steel.

Sp#	Total Strain Amplitude(%)	Stress Amplitude (MPa)	Plastic Strain Amplitude(%)	Elastic Strain Amplitude(%)	(50% load drop) Fatigue Life (Reversals, 2Nf)	MONOTONIC Young's Modulus(GPa)	Hardness (HRC)
25	0.985	1525	0.244	0.741	2878	196	53
14	0.988	1436	0.290	0.698	2926	197	53
20	0.988	1514	0.252	0.736	3566	202	55
9	0.807	1417	0.118	0.689	4608	208	54
18	0.804	1406	0.121	0.683	7188	199	54
5	0.801	1400	0.120	0.681	7174	209	53
29	0.601	1287	0.000	0.601	12970	208	55
15	0.598	1287	0.000	0.598	15512	207	53
17	0.598	1309	0.000	0.598	18598	207	53
24	0.494	1103	0.000	0.494	37694	203	54
3	0.490	1099	0.000	0.490	38818	203	54
28	0.494	1102	0.000	0.494	43196	203	55
22	0.398	882	0.000	0.398	234064	201	52
23	0.394	909	0.000	0.394	307530	210	55
26	0.393	908	0.000	0.393	335388	210	54
21	0.345	859	0.000	0.345	473600	200	53
4	0.379	860	0.000	0.379	774880	206	55
1	0.374	838	0.000	0.374	122250	201	52
11	0.379	838	0.000	0.379	252216	201	55
7	0.369	843	0.000	0.369	335478	207	52
31	0.359	826	0.000	0.359	196180	209	54
2	0.363	821	0.000	0.363	4714006	207	54
32*	0.359	826	0.000	0.359	10000000	209	52
12	0.349	791	0.000	0.349	184484	205	53
16	0.350	793	0.000	0.350	4100030	206	54
27*	0.349	791	0.000	0.349	10000000	205	52
30*	0.348	771	0.000	0.348	10000000	201	53

* Run out

Appendix 1

Average Monotonic Properties for SAE 9254 (Mod.), Quenched and Tempered steel.

Average Elastic Modulus, E	=	205.7	GPa
Yield Strength	=	1870	MPa
Ultimate tensile Strength	=	2050	MPa
% Elongation	=	16.2	%
% Reduction of Area	=	35.1	%
True fracture strain, $Ln\ (A_i / A_f)$	=	43.6	%
True fracture stress, $\sigma_f = \dfrac{P_f}{A_f}$	=	2495	MPa

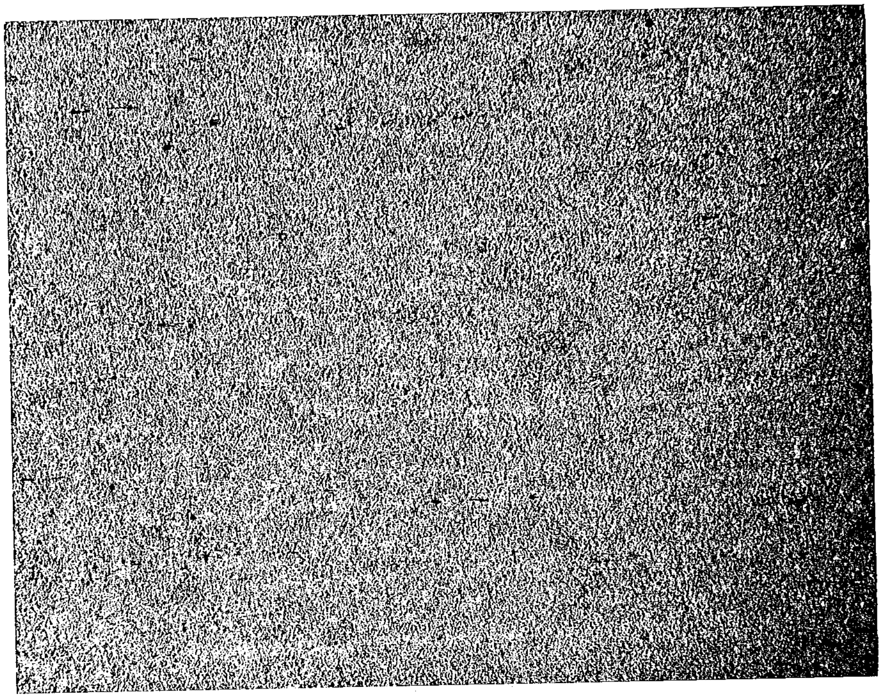
Bridgman correction, $\sigma_f = \dfrac{P_f}{A_f} \bigg/ \left(1+\dfrac{4R}{D_f}\right) Ln\left(1+\dfrac{D_f}{4R}\right)$ =2118MPa

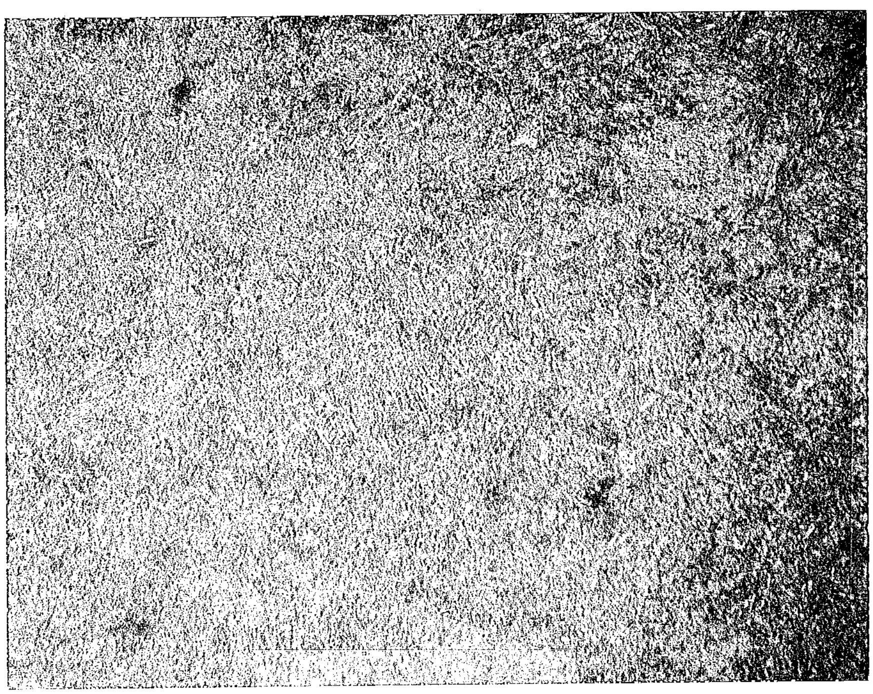
Monotonic strength coefficient, K	=	2413	MPa
Monotonic strain hardening exponent, n	=	0.0418	
Hardness, Rockwell C (HRC)	=	54	
Hardness, Brinell	=	536	

Cyclic Properties for SAE 9254 AL FG, Quenched and Tempered steel.

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$	=	1354	MPa
Cyclic strength coefficient, K'	=	2168	MPa
Cyclic strain hardening exponent, n'	=	0.076	
Fatigue Strength Coefficient, σ'_f	=	2914	MPa
Fatigue Strength Exponent, b	=	-0.0973	
Fatigue Ductility Coefficient, ε'_f	=	4.17	
Fatigue Ductility Exponent, c	=	-0.926	

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 34 SAE 9254 Quench and Tempered 100X 500X

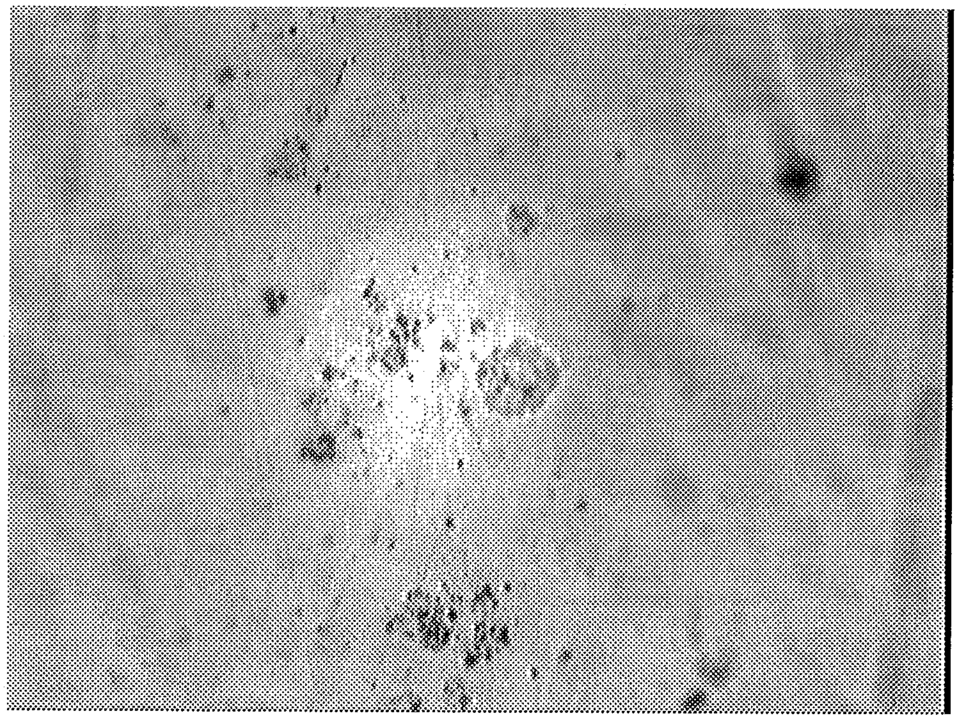


Figure 3. Inclusions photomicrograph of SAE 9254 (Mod.), Quenched and Tempered steel (X500)