OK

Fatigue Behavior, Monotonic Properties

and

Microstructure Data

for

SAE 9254 AL FG, Quenched and Tempered

(Iteration No. 35)

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SUMMARY

The required chemical analysis, microstructure data, mechanical properties, cyclic stress-strain data and strain-controlled fatigue data for SAE 9254 AL FG, Quenched and Tempered (Iteration No. 35) have been obtained. The material was provided by the American Iron and Steel Institute (AISI) in the form of metal bars. These bars were machined into smooth axial fatigue specimens. The specimens were heat treated to temperature 930 C^{o} in nitrogen media and quenched in oil and tempered to give a hardness of about Rc 58. Two monotonic tensile test was performed to measure yield strength, tensile strength and reduction of area. Eighteen 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 19 SAE 9254 AL FG, 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, 18 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 AL FG, Quenched and Tempered steel. A Type A and D inclusion severity level of $1\frac{1}{2}$ was obtained based on ASTM E45 (Method A). It was observed that 78% of type D inclusions were of the thin series and 22% were of the thick series. Inclusions of types B, and C were not observed. Figure 3 shows the inclusions observed in the SAE 9254 AL FG, Quenched and Tempered steel. The inclusion area was measured using a JAVA image analysis system. The chemical composition of SAE 9254 AL FG, Quenched and Tempered steel was provided by the supplier (Stelco Inc.), and is shown in Table 1.

B) Strain-Life Data

The fatigue test data for SAE 9254 AL FG, 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 AL FG, 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 σ'_f = 4108 MPa, b = -0.109, ε'_f = 1.13 and c = -0.954. These values of the strain-life parameters were determined from fatigue testing over the range: $0.0032 < \frac{\Delta\varepsilon}{2} < 0.01$.

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 $K' = 3322$ MPa and $n' = 0.088$.

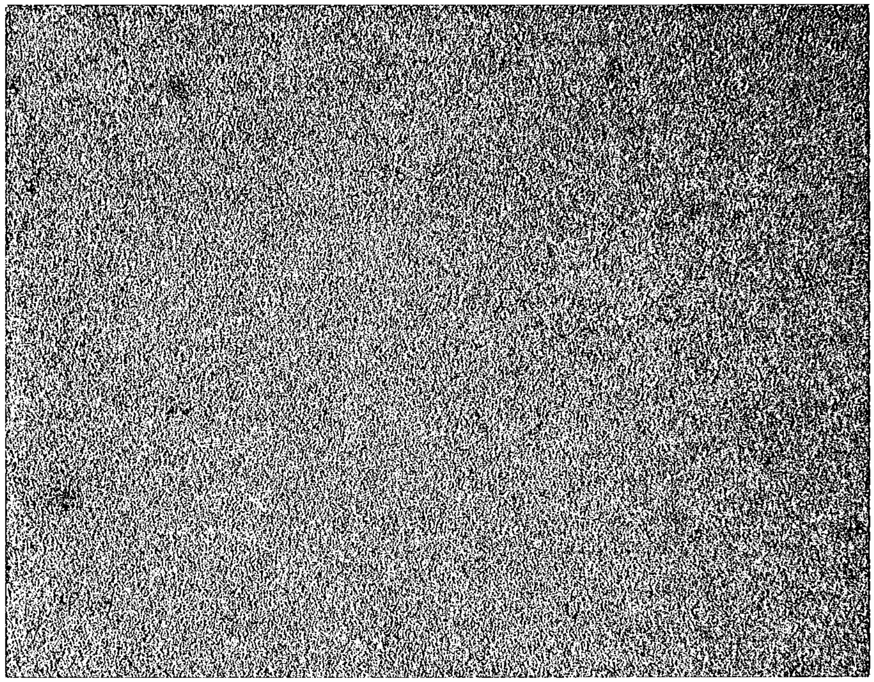
D) Mechanical Properties

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 AL FG, 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.



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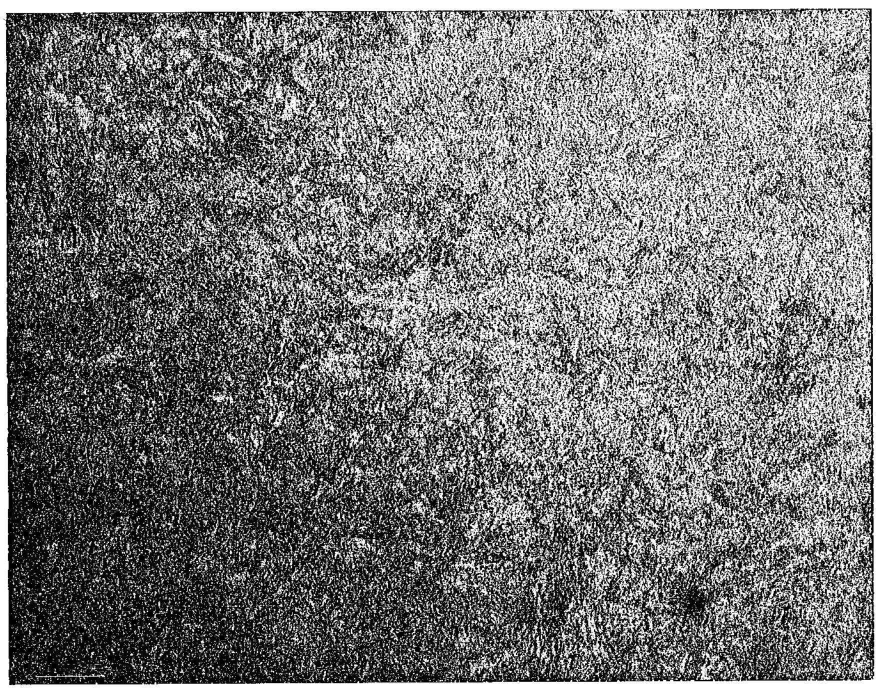

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Fig. 1-2 Iter. 35, 9254 Steel, Quenched and tempered to Rc 53
Upper- 100X Lower- 500X Nital Etched

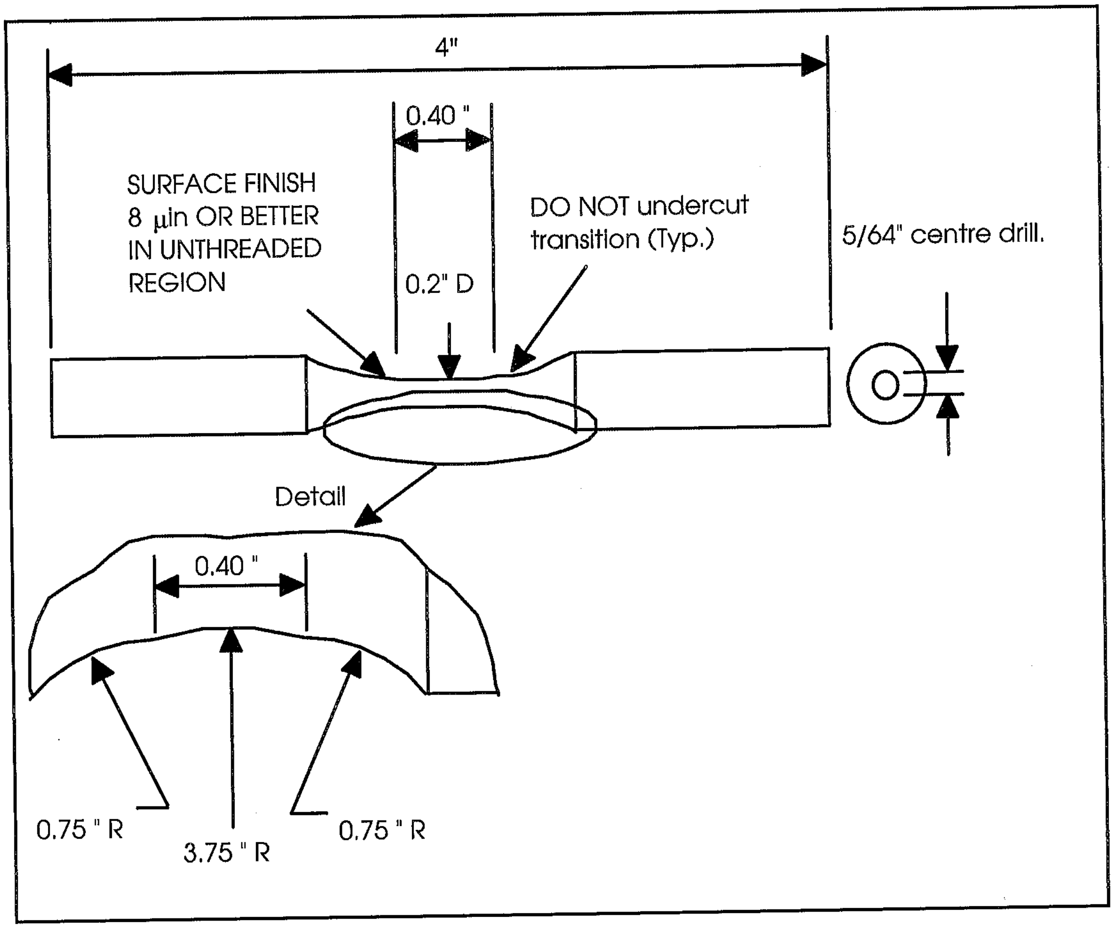
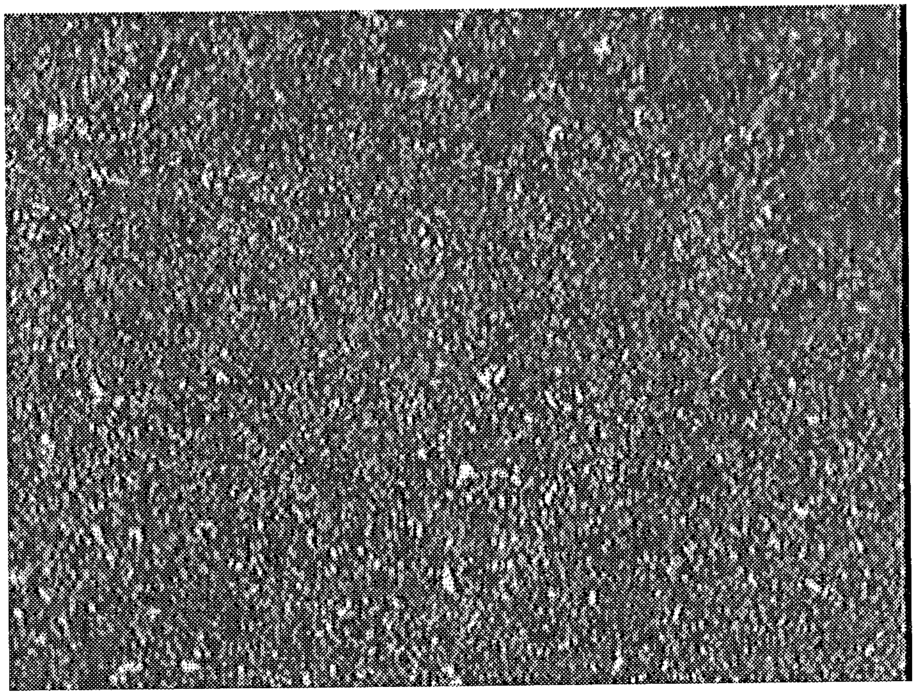
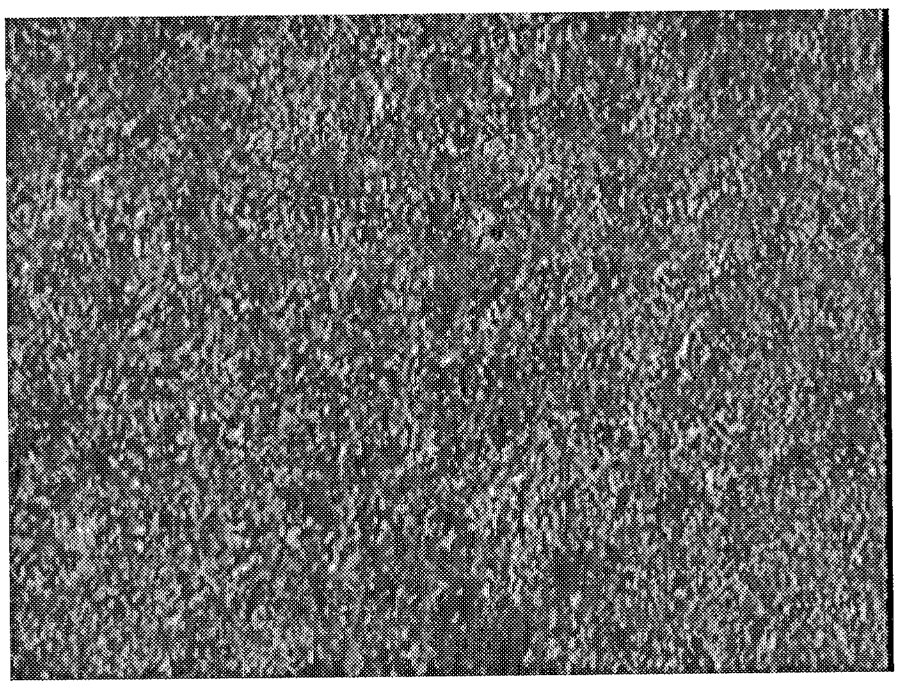


Fig. 1 Smooth cylindrical fatigue specimen



(a) Longitudinal Direction



(b) Transverse Direction

Fig. 2 Photomicrographs of SAE 9254 AL FG, Quenched and Tempered (X200)

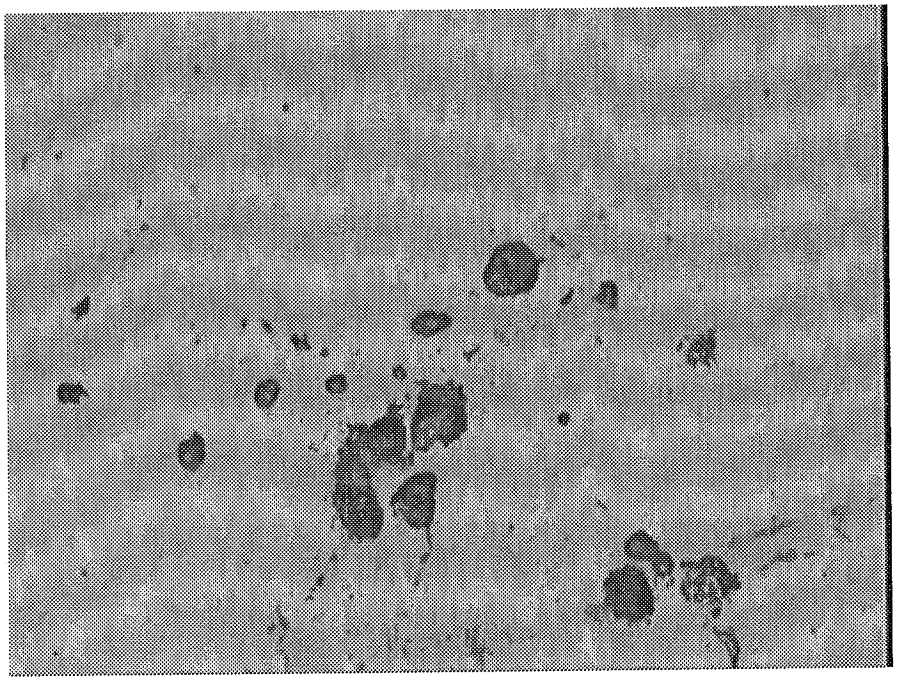


Fig. 3 Inclusions photomicrograph of SAE 9254 AL FG, Quenched and Tempered steel (X500)

SAE 9254 AL FG, Quenched and Tempered steel.

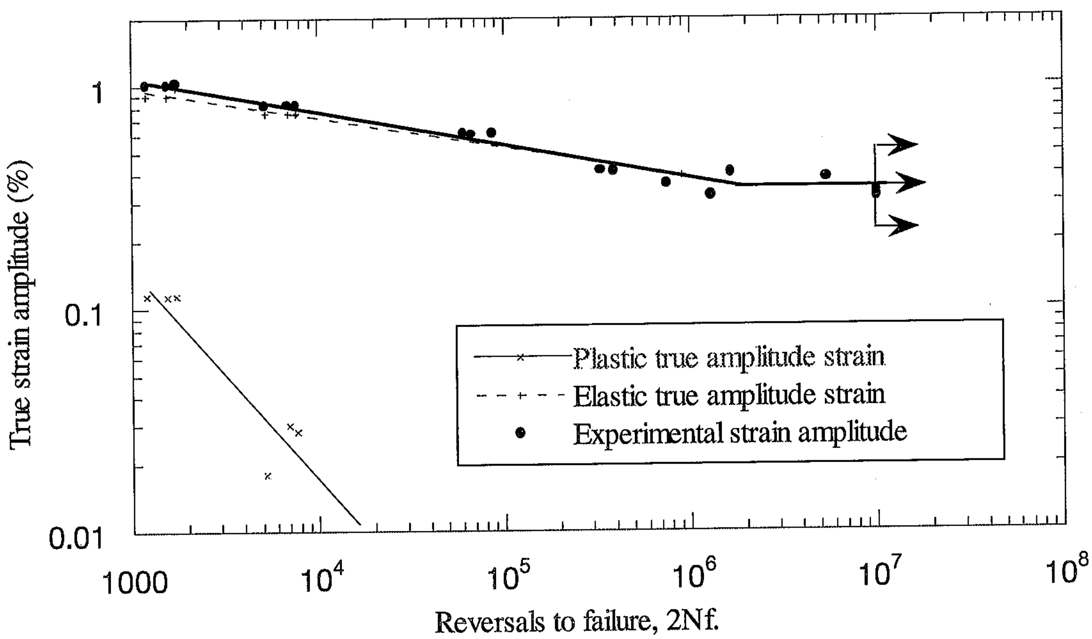


Fig. 4 Constant amplitude fully reversed strain-life curve for SAE 9254 AL FG, Quenched and Tempered steel.

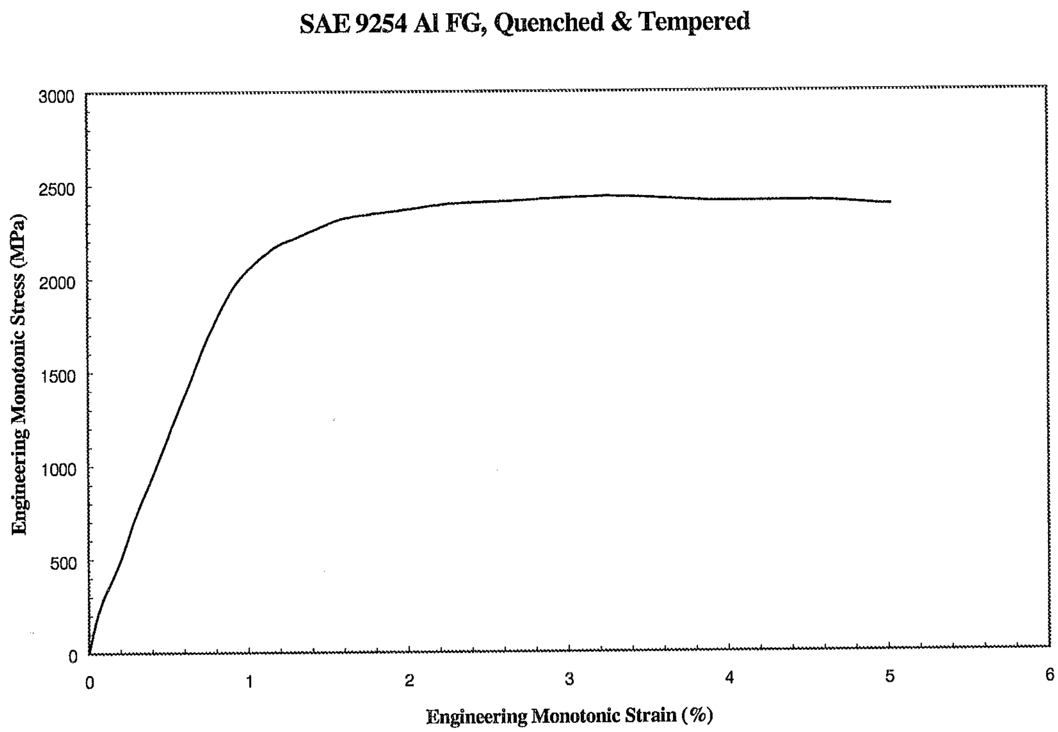


Fig. 5 Monotonic stress-strain curve for SAE 9254 AL FG, Quenched and Tempered steel.

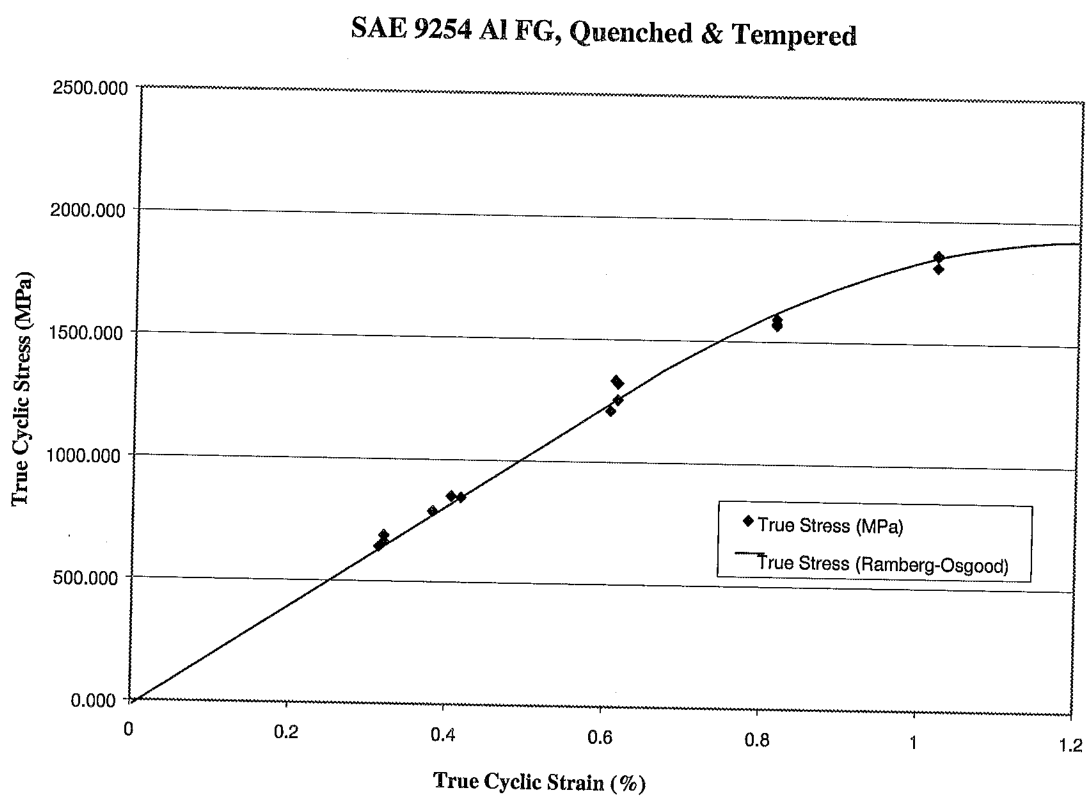


Fig. 6 Cyclic stress-strain curve for SAE 9254 AL FG, Quenched and Tempered steel.

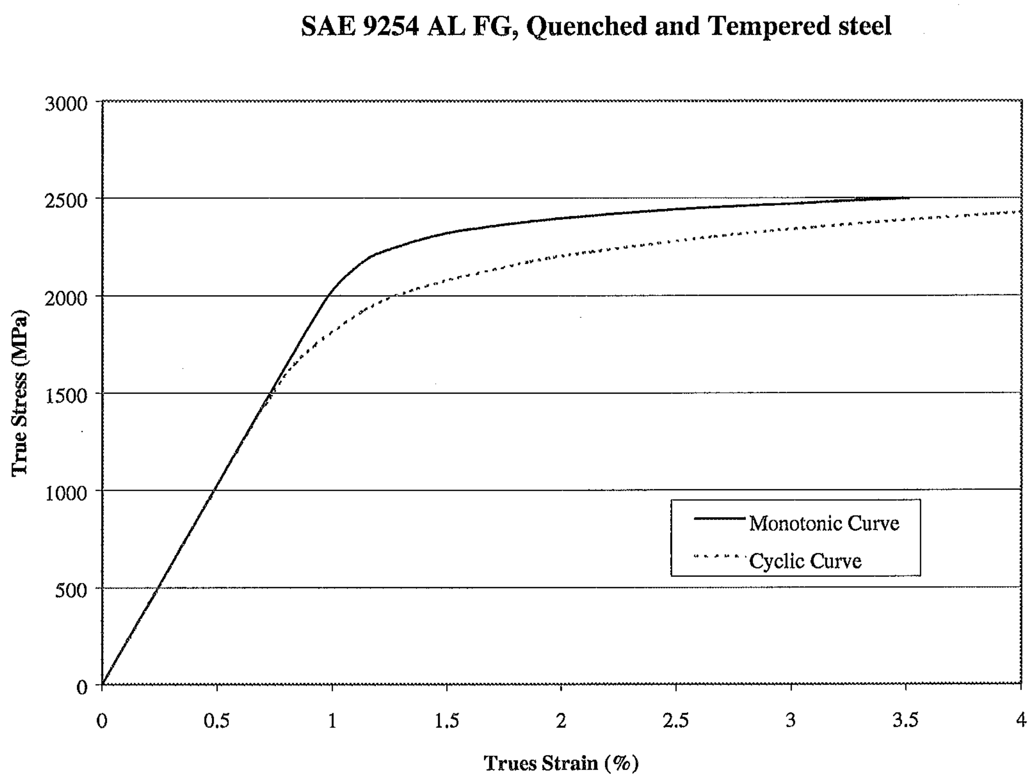


Fig. 7 Monotonic and Cyclic stress-strain curves for SAE 9254 AL FG, Quenched and Tempered steel.

Table 1 Chemical composition of SAE 9254 AL FG, Quenched and Tempered steel.

Carbon, C	0.57%
Manganese, Mn	0.71%
Phosphorous, P	0.011%
Sulfur, S	0.009%
Silicon, Si	1.57%
Copper, Cu	0.011%
Nickel, Ni	0.01%
Chromium, Cr	0.72%
Molybdenum, Mo	0.005%
Vanadium, Va	0.007%
ASA	0.028%
N	0.007%
Columbium, Cb	0.002%

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)
11	1.015	1854	0.114	0.901	1726	206.8	59
12	1.015	1860	0.113	0.902	1550	203	58
19	1.015	1809	0.114	0.901	1200	205	57
18	0.813	1565	0.030	0.786	6926	201	58
10	0.813	1570	0.028	0.788	7628	207	58
9	0.810	1590	0.018	0.798	5202	206	58
17	0.615	1254	0.000	0.615	60194	212	60
8	0.612	1333	0.000	0.612	87254	202	58
15	0.606	1208	0.000	0.606	67620	203.5	58
1	0.417	845	0.000	0.417	329726	208.6	58
2	0.405	851	0.000	0.405	164522	206.1	58
20	0.410	840	0.000	0.410	392004	209	57
3	0.381	789	0.000	0.381	5432572	202	57
4	0.360	714	0.000	0.360	745818	207	58
14*	0.330	687	0.000	0.330	10000000	208	58
5	0.320	687	0.000	0.320	1284974	206	61
13*	0.320	661	0.000	0.320	10000000	203	57
6*	0.314	642	0.000	0.314	10000000	206.3	58

* Run out

FATIGUE STRG.

Appendix 1

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

Average Elastic Modulus, E	=	205.4	GPa
Yield Strength	=	2270	MPa
Ultimate tensile Strength	=	2950	MPa
% Elongation	=	3.92	%
% Reduction of Area	=	3.99	%
True fracture strain, $Ln\ (A_i / A_f)$	=	4.08	%
True fracture stress, $\sigma_f = \frac{P_f}{A_f}$	=	2483	MPa

Bridgman correction, $\sigma_f = \frac{P_f}{A_f} \Big/ \left(1+\frac{4R}{D_f}\right) Ln\left(1+\frac{D_f}{4R}\right)$ =2047MPa

Monotonic strength coefficient, K	=	2916	MPa
Monotonic strain hardening exponent, n	=	0.0418	
Hardness, Rockwell C (HRC)	=	58	
Hardness, Brinell	=	584	

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

Cyclic Yield Strength, (0.2% offset)= $K'(0.002)^{n'}$	=	1922	MPa
Cyclic strength coefficient, K'	=	3322	MPa
Cyclic strain hardening exponent, n'	=	0.088	
Fatigue Strength Coefficient, σ'_f	=	4108	MPa
Fatigue Strength Exponent, b	=	-0.109	
Fatigue Ductility Coefficient, ε'_f	=	1.13	
Fatigue Ductility Exponent, c	=	-0.954	

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.