Effect of Heat Treatment on Fatigue Behavior of (A193-51T-B7) Alloy Steel

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Abstract- **This research comprises a study of the effect of heat treatment on fatigue behavior of (A193-51T-B7) alloy steel. Two heat treatment processes were conducted, namely, annealing and quenching followed by tempering at 200°C. All fatigue tests were carried out using a rotary bending machine with constant stress ratio, R=-1. The eddy current probe was used to measure the crack length propagation. From the obtained results, it was found that fatigue crack growth rate of the quenched and tempered specimens is lower than that of the standard specimens. While the fatigue crack growth rate of the annealed specimens is higher than that of the standard specimens.**

Index Terms- **crack growth rate, fatigue, heat treatment, stress intensity factor.**

I. INTRODUCTION

Fatigue failure is generally considered as the main problem affecting any component under dynamic loading condition. Almost 90% of failure conditions in mechanical components are due to fatigue [1]. According to the importance of this type of failure, many researchers had investigated the factors affecting on fatigue and how to enhance the service life of any mechanical component.

Guiyun [2], studied the effect of nitriding after heat treatment on the fatigue properties of (No20) alloy steel. They found that the effect of nitriding on the quenched specimens is more than its effect on normalized specimens.

Bourassa and et.al. [3], studied the effect of heat treatment on the fatigue strength of micro knurled (Ti-6A-4V) alloy. Rotating-bending fatigue tests showed that such a microstructure had some benefits, but this was offset by the reduction in compressive strains imparted to the surface by the heat treatments needed to obtain this microstructure.

Gayda and et.al. [4], studied the effect of heat treatment on the fatigue behavior of alloy 10. They found that improvement in fatigue life at lower solution temperatures was most likely produced by finer grain sizes at this temperature.

Fukaura and et.al. [5], made an evaluation of the fatigue properties of two types of cold-work tool steels tempered at various temperatures. They found that the enhancement of fatigue properties can be achieved by carbide refinement.

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In this research, two main test groups were taken into consideration. The first group aimed to construct the (S-N) diagram for the standard alloy, annealed alloy, and the quenched and tempered alloy. For each alloy the number of cycles required for both crack initiation and failure were recorded. The second group was performed to establish the fatigue crack growth rate model for the alloy, before and after heat treatments, using Paris equation. This investigation was implemented on (A193-51T-B7) alloy steel for its usage in many engineering applications due to its high strength and good machinability [6].

II. EXPERIMENTATIONS

The chemical composition of the alloy used is listed in Table I.

Table I. Chemical composition of (A193-51T-B7) alloy steel

Element	%
C	0.3888
Mn	0.7955
P	0.0054
S	0.0249
Ni	0.1398
Si	0.2043
Cr	0.8451
Mo	0.2781
V	0.0060
Cu	0.1203
Fe	97.1918

Fatigue test specimens, shown in Fig.1, were prepared according to the standards of the rotating beam fatigue testing machine used in this study.

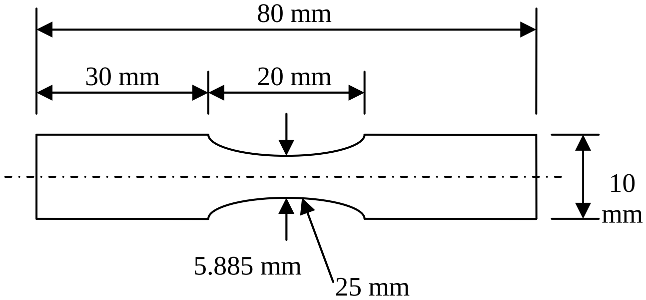

Fig.1 Fatigue test specimen

Two separate heat treatment processes were carried out on specimens, namely,

1- Annealing, specimens were heated in an electrical furnace to 890^{o}C for one hour duration, then cooled gradually while kept in the furnace.

2- Quenching followed by tempering, specimens were heated to 890^{o}C for one hour duration then cooled by oil, followed by heating at 200^{o}C for two hours then left in air to cool down.

Before performing fatigue tests, and in order to obtain the mechanical properties of the alloy before and after heat treatments, tensile and hardness tests were conducted.

Fatigue tests were carried out on a rotary beam fatigue testing machine at constant stress ratio, R=-1. Crack length was measured via an eddy current probe. In the first set of experiments, in which the (S-N) diagram is obtained, for each stress amplitude two number of cycles were recorded, one for the crack initiation (N_i) and the other for the occurrence of failure (N_f). In the second set of experiments, the stress amplitude was fixed at 450 MPa and the crack length was measured for different number of cycles until failure.

III. RESULTS AND DISCUSSION

A- *Mechanical Properties*

Measured mechanical properties of (A193-51T-B7) alloy steel before and after each heat treatment process are listed in Table II.

Table. II Mechanical properties

Type of alloy	Yield stress (MPa)	Ultimate strength (MPa)	% elongation	Brinell hardness (N/mm^2)
Standard	884.00	1008.00	15.0	293.0
Annealed	380.39	636.90	21.0	206.0
Quenched and tempered	1360.00	1521.58	9.0	391.0

It can be seen that annealing increases ductility and decreases yield stress, ultimate strength, and hardness. While quenching followed by tempering has reversed action.

B- *S-N Diagram*

Results of S-N tests are shown in Figs.2, 3, and 4. It is clear that fatigue life of annealed specimens is less than that of standard specimens. Quenching followed by tempering tends to increase fatigue life and endurance limit as compared to the standard alloy. As the crack initiates, the number of cycles required for failure is decreased for both heat treatment processes.

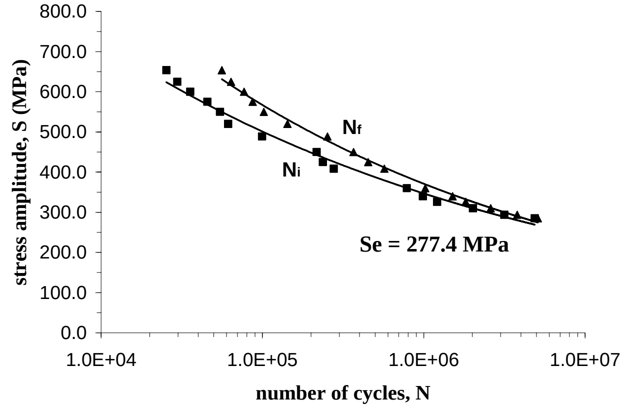

Fig.2 S-N diagram of the standard alloy

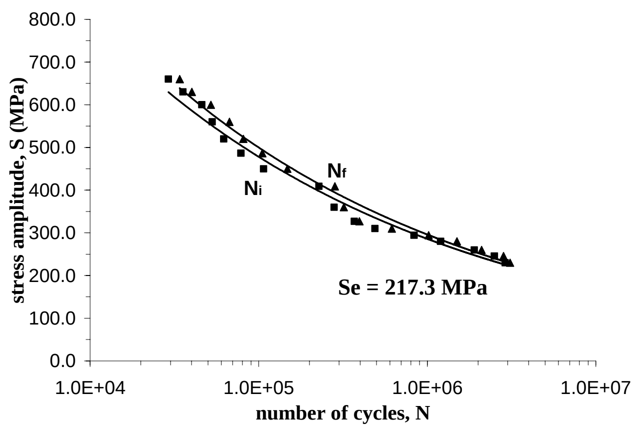

Fig.3 S-N diagram of the annealed alloy

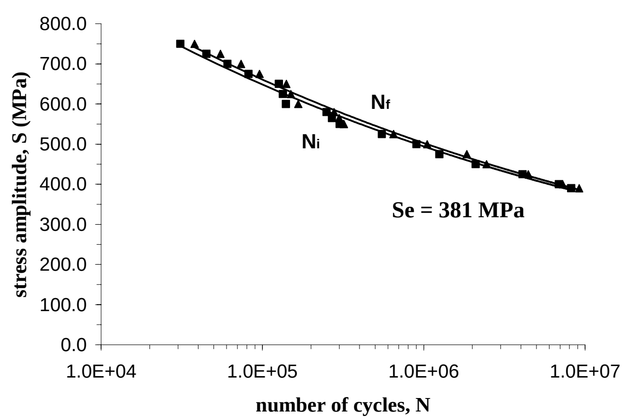

Fig.4 S-N diagram of the quenched and tempered alloy

C- Crack Growth Rate

The crack growth rate was recorded at a stress amplitude of 450 MPa. Data of crack length as related to number of cycles are plotted as shown in Fig.5.

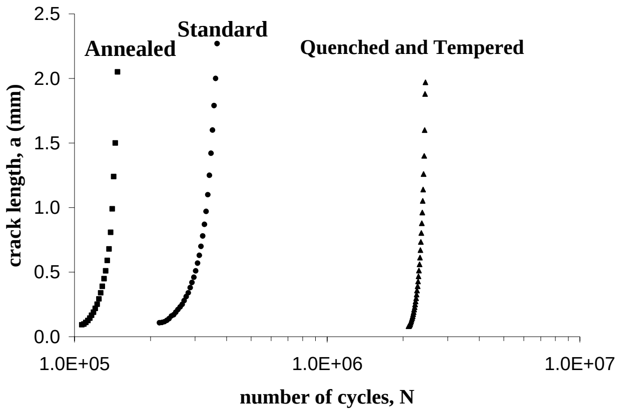

Fig.5 Crack length versus number of cycles

For any specific crack length, the number of cycles for the quenched and tempered specimens is almost four times that of the standard specimens, while the number of cycles is reduced to half that of standard specimens due to annealing. The crack growth rate as related to stress intensity factor is plotted as shown in Figs. 6, 7, and 8.

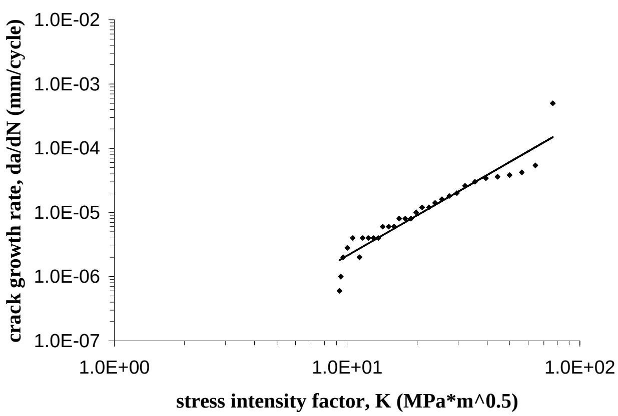

Fig.6 Crack growth rate versus stress intensity factor for the standard alloy

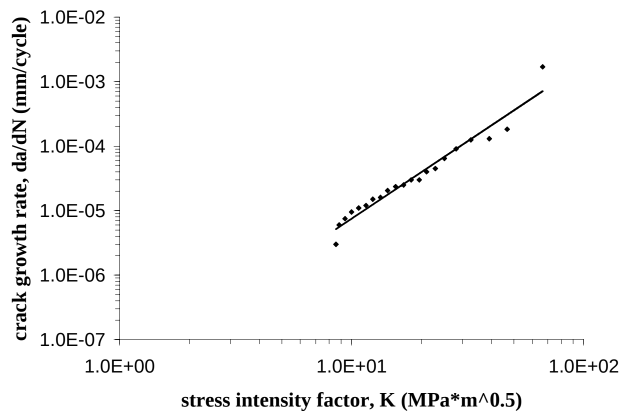

Fig.7 Crack growth rate versus stress intensity factor for the annealed alloy

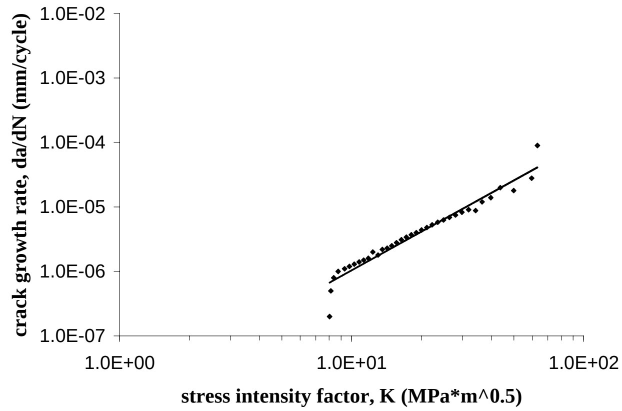

Fig.8 Crack growth rate versus stress intensity factor for the quenched and tempered alloy

From these figures, the three regions of different behavior can normally be identified, namely,

1- The threshold region, which is attributed to low levels of stress intensity factor.

2- The stable propagation region, where the cracks grows incrementally according to Paris equation,

$$\frac{da}{dN} = C(\Delta K)^m \qquad (1)$$

3- The unstable region, where the crack propagates more rapidly.

From these plots, the constants C and m in (1) can be found and tabulated as shown in Table III.

Table III Values of the constants C and m in Paris equation

Type of alloy	C	m
Standard	$2.0x10^{-8}$	2.0897
Annealed	$3.0x10^{-8}$	2.4019
Quenched and tempered	$1.0x10^{-8}$	1.9939

It can be observed that quenching followed by tempering decreases the crack growth rate, while annealing increases this rate.

The reduction of strength and endurance limit, and enhancement of ductility that happened due to annealing is due to the formation of soft coarse ferrite grains. Quenching followed by tempering produces the hard tempered martensite grains, thus leading to increase strength and endurance limit while ductility is reduced.

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