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EFFECT OF HEAT TREATMENT AND SURFACE FINISH ON FATIGUE FRACTURE CHARACTERISTICS IN 0.45% CARBON STEEL

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ABSTRACT
The effect of heat treatment and surface finish on fatigue fracture properties of 0.45% carbon steel was investigated. The fundamental fatigue behavior of the medium carbon steel was studied by using rotating bending fatigue testing machine. The steel specimens of rough as well as smooth surfaces were prepared and heat treated at 930°C for a period of 15 minutes followed by quenching in oil. The specimens were tempered at temperatures of 100°, 200°, 300° and 400 °C for periods of 30, 90 and 180 minutes, and their fatigue fracture behavior was investigated. The experimental results show an initial increase in the number of cycles to fail when tempering was changed from 100° to 200 °C for 30 minutes. Further increase in tempering time and temperature reduces the resistance to fatigue failure. Scanning electron microscope (SEM) was used to characterize the structural properties resulting from different heat treatment processes. SEM results for the fractured specimens showed a brittle fracture surface with inter granular facets, and fatigue striation in the photomicrograph.
Keywords: Heat treatment, surface finish, fatigue, brittle fracture, carbon steel

1. INTRODUCTION

Bayoumi and Abdellatif [1] studied the effect of surface finish on fatigue strength. A correlation of various surface finish parameters with the endurance fatigue strength of a commercial aluminum alloy was investigated. Surface roughness of each group of specimens was measured and the quality of surface was evaluated from the profile graph. The results indicate a great effect for all surface finish parameters. This leads to a significant correlation between the fatigue initiation life, final separation life and the fatigue endurance limit.

A study on effect of low cycle fatigue on surface finish was conducted by Rashed and Nassef [2]. It was found that the surface of ground finish is the one which is mostly impaired by fatigue loading, as deduced from the drastic increase of R_{max}. The evolution of roughness of shaper finished surface was the least significant. Roos et al. [5] conducted a detailed assessment of fatigue life analysis procedures in the technical codes and standards. The experimental results verified the most important parameters influencing the fatigue analysis, such as plastification factor, the correction factors with respect to mean stress, surface finish, temperature, environment, and unwelded and welded components.

Wei et al. [7] studied the fatigue behavior of 1500 MPa bainite/martensite duplex phase high strength steel. It was observed that fatigue strength increases and fatigue crack threshold gives lower crack propagation. The steel produces a better combination of strength, toughness and fatigue properties when tempered at 370°C for 2 hours. A new technique for prediction of fatigue failure in crankshaft using the technique of crack modeling (using linear elastic finite element analysis) was developed by Taylor et al. [8]. Using the derived stress intensity factor (K) for the component under load, the fatigue limit for a crankshaft was successfully predicted when compared to experimental data.

The effect of intercritical heat treatment on the mechanical properties of AISI 3115 steel was investigated by Maleque [9]. The experimental results showed that tensile strength increases but impact strength decreases with increasing intercritical temperature, correspondingly with the increase in amount of martensite in the steel. Influence of cold rolling threads before or after heat treatment on high strength SI grade 12.9 bolts for different fatigue preload conditions was carried out by Horn [10].

Most fracture surfaces contained crescent-shaped cracks and SEM evaluation indicated all fatigue crack growth regions contained multiple facets with no striations.

2. EXPERIMENTAL PROCEDURES

0.45% carbon steel was selected as a material to study the effect of surface finish on its fatigue behavior. Composition of the alloy is summarized in Table 1. Standard fatigue specimens were prepared according to WP 140 Fatigue Testing Machine standards. Machined specimens were polished using emery paper of 400 grit size. Rough and smooth surfaces were created particularly at R_2 position of the specimen to see the effect of surface roughness on fatigue fracture behavior. Surface roughness of the specimens was measured using Talysurf 10 with amplifier and recorder.
Heat treated samples (quenched and tempered) were fixed in the WP 140 fatigue testing machine with constant load of 130 kN. Steel specimens were austenitized at 930^{o}C for a period of 15 minutes to achieve uniform grain structure and then cooled rapidly by quenching in oil. These specimens contain lot of interval stresses and are extremely hard and brittle. In this condition the specimen can fail even with a mild shock. In order to remove internal stresses, tempering of the specimens was carried out by reheating the martensite steel specimens at 100°, 200°, 300° and 400^{o}C for a period of 30, 90, and 180 minutes respectively.

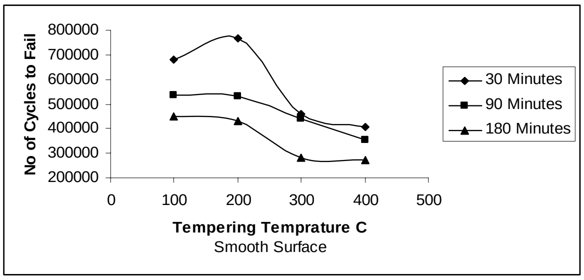
Table 1 Chemical composition of the carbon steel

AISI No.	UNS No.	Carbon (%)	Manganese (%)	Phosphorus (%)	Sulfur (%)
1045	G10450	0.42-0.50	0.60-0.90	0.04	0.05

3. RESULTS AND DISCUSSION

3.1 Effect of tempering temperature on fatigue fracture behavior of smooth samples

Figure 1 (a) represents the effect of tempering temperature on the number of cycles to fail. The number of cycles required to fail the specimen were 681,603 when specimen was tempered at 100^{o}C for 30 minutes. There was an increase in the number of cycles to fail when tempering was carried out at 200^{o}C. Further increase in temper temperature to 300^{o}C reduced the fatigue life to 457,531 cycles. A further decrease in number in cycles to fail was observed for samples tempered at 400^{o}C.



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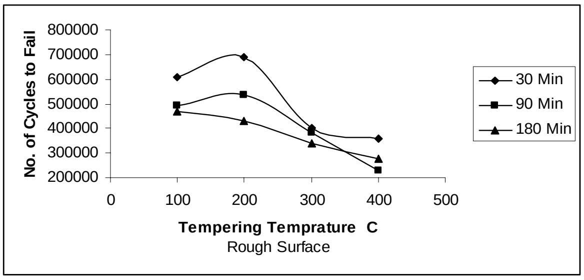

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Figure 1 The Effect of tempering temperature on the number of cycles to fail: (a) smooth surface, (b) rough surface

A small decrease in the fatigue life from 534,185 to 532,922 cycles took place when samples were tempered at 100^{o}C and 200^{o}C respectively for 90 minutes. Higher tempering temperature (400^{o}C) annealed out the defects in the material, making it soft, further reducing the fatigue life to 353,728 cycles. The third curve in Fig. 1 (a) shows a constant decrease in the number of cycles required to fail with increasing tempering temperature. This could be related to the decrease in toughness and hardness of the quenched steel specimens because of longer heating time and temperatures. The initial increase in number of cycles could be due to replacement of some of the brittleness with toughness.

3.2 Effect of tempering temperature on fatigue fracture behavior of rough samples

All specimens reported in this section had a surface roughness equivalent to position of R_2 Talysurf. For the first two sets of specimens (tempered for 30 min and 90 min), an increase in number of cycles to fail takes place when the tempering temperature of the quenched specimens was increased from 100° to 200°C; Fig-1 (b). Further increase in tempering temperature reduces the fatigue resistance property of steel and the material fails in a shorter period of time. For the third set of the rough-surface fatigue specimens (tempered for 180 minutes), as the tempering temperature increases the number of cycles required to fail the material has decreased. The increase in number of cycles when tempered at 200^{o}C can be due to decrease in brittleness and increase in toughness of the material. Further decrease in number of cycles to fail is due to annealing of defects at higher tempering temperatures which increases the ductility of steel.

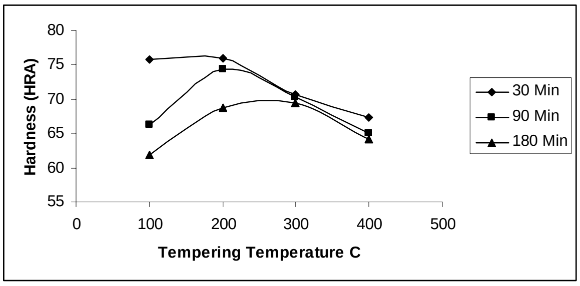

Figure 2 Effect of tempering temperature on hardness of steel

3.3 Effect of tempering temperature and time on hardness

As shown in Fig. 2, for the specimens tempered for 30 min, tempering beyond 200°C decreases the hardness. For the second and third sets of specimens (tempered for 90 and 180 min), hardness increases when the tempering temperature goes from 100° to 200°C, and then starts to gradually decrease with increasing temperature. The initial increase in hardness may be due to tempering of steel, because of which brittleness is replaced by toughness, resulting in a change in microstructure as well as the mechanical properties of the material. Further tempering at higher temperature decreases the hardness of the fatigue specimen which could be due to the gradual transformation of martensite into more stable structure which consists of iron carbide in ferrite. As the tempering temperature increases the coarser carbide particles will form which are much softer than bct martensite structure.

3.4 Fatigue fracture surfaces

Some of the fatigue fractured surfaces are shown in Fig. 3 (a) and 3(b) for smooth and rough specimens. The fractured surface results appear brittle on macroscopic scale. They are characterized by incremental propagation of crack, the cross section has been reduced to where it can no longer support the maximum applied load and fast fracture occurs. All the photo micrographs show a fast fracture region and crack initiation region. Brittle fracture shows a bright granular appearance in micrographs.

3.5 Effect of heat treatment and surface roughness on fracture behavior

Figure 4 (a) represents a SEM photomicrograph showing fatigue striation when the (smooth) specimen was tempered at 400^{o}C for a period of 3 hours. An increase in the magnitude in stress will produce an increase in striation spacing. At certain places one can also see local cracks. Figure 4 (b) shows the fracture surface of the smooth specimen which was tempered at 200°C for 3 hours. The specimen has failed by brittle fracture under load. Microscopic examination of brittle fracture reveals cleave steps and tear ridges with river pattern. At some places the fracture surface shows inter-granular cracks.

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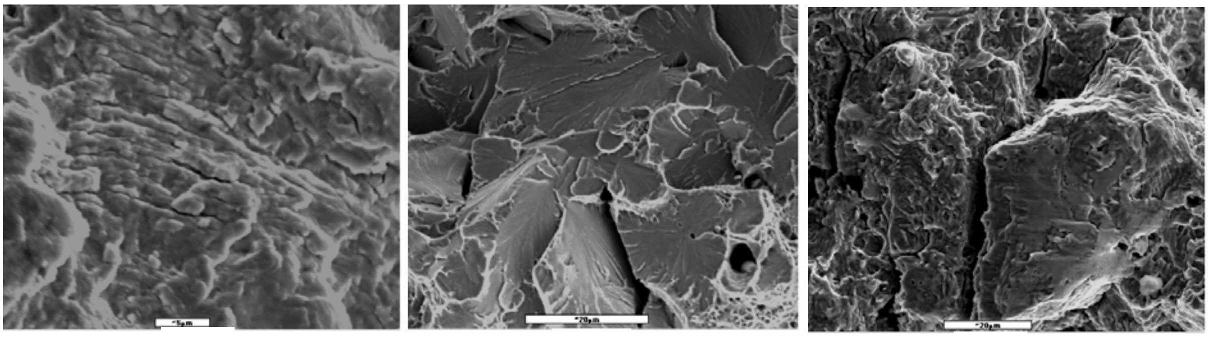
Figure 3 Fatigue fractured surfaces: (a) tempered at 400^{o}C for 30 minutes; smooth surface, (b) tempered at 200^{o}C for 30 minutes; rough surface

Figure 4 (c) represents SEM micrograph of steel specimen (rough surface) which has failed under fatigue loading. The specimen was tempered at 200^{o}C for 30 minutes. The SEM examinations of the specimen show a brittle fractured surface with inter-granular facets. These inter granular facets are grain surfaces that have been exposed by crack propagation along grain boundaries.



(a) (b) (c)

Figure 4 SEM photomicrographs: specimens tempered at (a) 400^{o}C for 180 minutes (smooth surface); (b) 200^{o}C for 180 minutes (smooth surface); (c) 200^{o}C for 30 minutes (rough surface)

4. CONCLUSIONS

The experimental results clearly indicate an initial increase in fatigue fracture property of the 0.45 % carbon steel specimen when tempering temperature increases from 100^{o}C to 200°C. Further increase in temperature reduces the resistance to fracture as well as hardness. This initial increase and then decrease in the fatigue and hardness property could be explained due to structural changes occurring in the steel. Martensitic steel is produced when the medium carbon steel is quenched from 930^{o}C to room temperature in oil. Martensite is only a metastable phase and in a sense may be regarded as an intermediate transition product since its structure is broken down by tempering. During tempering, the highly strained martensitic structure of steel is gradually transformed into a more stable structure consisting of a dispersion of iron carbide in ferrite. It is also factual that the higher the tempering temperature the coarser the resulting carbide precipitate will be. It is well known that steel components acquire maximum hardness when tempered below 200^{o}C while those requiring good toughness are tempered above 400^{o}C. The results show that the endurance stress is greatly affected by the surface finish condition and the surface finish will greatly affect the overall life of the material under fatigue loading. It is concluded from the experimental results that the number of cycles required to fail for rough surface fatigue specimens are much less than the smooth surface specimens, as expected.

5. REFERENCES

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