Effect of Heat Treatment Process on the Fatigue Behavior of AISI 1060 Steel

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Abstract

This experimental study investigated the effects of quenching and tempering heat treatment on fatigue behavior and also tempering temperature and time holding of AISI 1060 steel. At first, the specimens were austenitized at 800˚C for 1 hour, and then were quenched in the water bath of 25˚C temperature. After that, tempering process was done at the temperature of 250˚C, 450˚C and 650˚C for 1 and 2 hours. The results of mechanical properties indicated that hardness, tensile strength and fatigue limit was decreased with increasing the holding time and tempering temperature. Scanning electron microscope (SEM) results showed that crack propagation in the tempered specimens at the 250˚C temperature in the 1 hour was slower than in the specimens in the higher temperature and higher period time. As well, with increasing of the tempering temperature, germination areas of fatigue crack was increased and crack propagation was done faster.

Keywords: AISI 1060 Steel, Tempering, Hardness, Tensile, Fatigue.

1. Introduction

In recent years, the heat treatment in the steel industry is one of the main production processes to optimize the desired properties of making fragment [1)].

One of the procedures for obtaining optimal properties of steels like hardness, tensile strength and fatigue strength is heat treatment process. Also, different quenching processes and tempering have led to different mechanical properties that is possible with changing microstructure. An important element of fractures due to dynamic loading is fracture of fatigue. So, considerable efforts have been directed toward improving their lifetime period [2-4)]. At the beginning of 1950s, some investigation in fatigue context evidenced that without fundamental perception of fatigue process under the microscopic level without systematic study about fatigue occurrence step, none higher progress is possible in safe designing of fatigue. In recent years, more reliability and durability of machines and constructions strengthen difficulty of this subject.

Fatigue process is occurred due to effect of deformation in cyclic forms. Indeed, cyclic forms of fatigue without deformation cannot be occurred. If cyclic strain is repeated, it won't cause a significant change in the structure of material. However, if very low cyclic strain occurred frequently, may lead to increasing injuries and fracture of material ultimately. But cyclic deformation led to irreversible changes in the microstructure of the material, especially dislocation microstructure. So, only deformation of cyclic form is an important factor of fatigue process [5)]. Haftirman and et al. investigated the effect of tempering temperature on fatigue strength of THYSSEN 6582 steel. In this research mechanical properties in different tempering temperature is compared. It has been cleared that the optimal fatigue strength was achieved at 300˚C. Their results showed that in this temperature, micro crack length is the lowest. Lee and et al. focused at mechanical properties and microstructure of AISI 4340 high strength alloy steel under quenched and tempered condition. Their results indicated that the mechanical properties and microstructural features are affected significantly by tempering temperature and holding time. However, microstructural observation revealed that the carbide precipitates have a plate-like structure at low temperature.

In this study, the effects of quenching heat treatment and tempering on fatigue behavior of AISI 1060 steel were investigated.

2. Materials and Methods

All experiments were carried out on AISI 1060 steel. The chemical composition of this steel being given in

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Table 1. The steel was supplied in normalized condition. In this regard, a group of specimens were subjected to conventional hardening and austenitizing at 800˚C for 1 hour in the furnace. Then the specimens were removed from the furnace and quenched in a water bath at 25˚C temperature.

Table 1. Chemical analysis of AISI 1060 steel.

Element	C	Si	Mn	P	S	Cu	Mo
wt. %	0.62	0.34	0.78	0.02	0.017	0.1	0.02

After that, tempering process was carried out at three temperatures at 250˚C, 450˚C and 650˚C using the same process for 1h and 2h and were cooled at room temperature.

In terms of microstructural examinations, standard metallography was employed. The metallographic specimens were polished and etched in 2% nital solution. The different specimens of heat treatment were examined for tension and fatigue properties. The size and geometry of the specimens for testing procedure are based on the ASTM-E8M standard for tension testing at room temperature at the rate of 1mm/min, and fatigue testing was based on ASTM-E466 standard using a fatigue test machine of bend-rotate type, conducted with a frequency of 5800 rpm and tension ratio of R=-1. The plot of fatigue specimens of the heat treated bar have been shown in Fig. 1. Stress at 10^7cycles was considered as the fatigue limit. Furthermore, fracture surfaces and micro structure were examined by scanning electron microscopy (SEM) model Leica Cambridge at an accelerating voltage of 20kv for fractography. Hardness of specimens after heat treatment was measured on HRC scale.

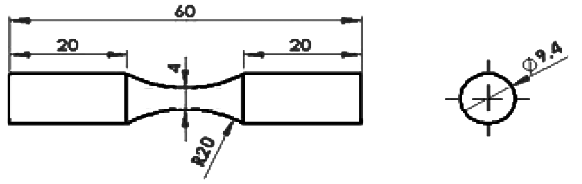

Fig. 1. Size and shape of fatigue test specimen, dimensions are in mm.

3. Results and Discussions

SEM features of the microstructure of specimens tested under tempering temperature 250˚C and 650˚C are shown in Fig. 2. As can be seen, the structure is completely martensite, so during the austenite process were provided sufficient opportunity for transformation. Tempering process was done at three temperatures of 250˚C, 450˚C and 650˚C for 1h and 2h. The results showed that tempering time and tempering temperature have a great influence on the mechanical properties. Fig. 2a,b shows the microstructure of tempering specimens at 250˚C and 650˚C, respectively. The blades of martensite of tempered specimen at 250˚C were fine and the blades of martensite were larger with increasing the tempering temperature to 650˚C temperature. It is because by increasing the tempering temperature the carbides became larger which would lead to larger martensite blades.

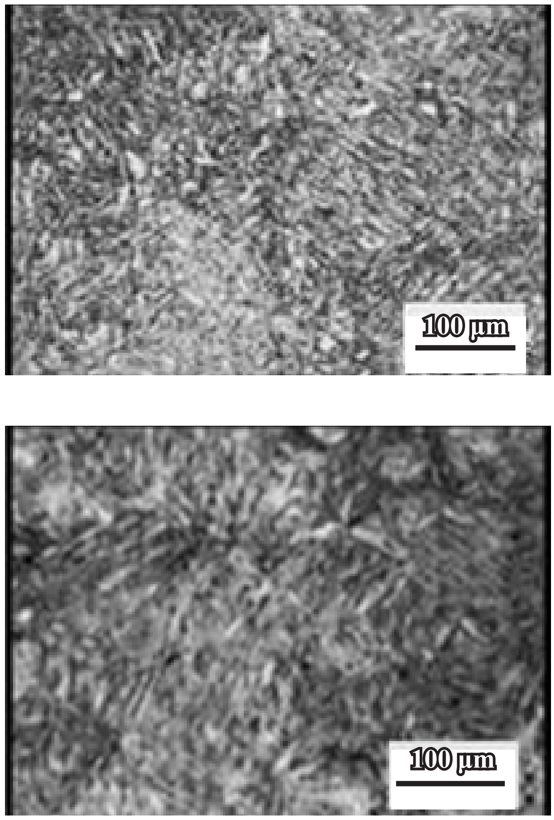

Fig. 2. SEM micrographs of tempered specimens at (a) 250˚C, (b) 650˚ C for 1 h.

The results obtained from mechanical testing are listed in Table 2. Changes in the mechanical parameters can be interpreted on Fig. 3. It is clear that changes in tensile strength were downside with increasing tempering temperature and time from 1 to 2 hours that caused to larger martensite blades. This tempering temperature yields a rapid decrease of the dislocation density and internal stress.

Table 2. Variation in mechanical properties of AISI 1060 steel of heat treatment processes.

Samples	Ultimate Strength(MPa)	Yield strength (MPa)	Elongation (%)	Fatigue strength(MPa)	Hardness (HRC)
Q.T/ 1h- 250°C	989	843	12.3	562	64
Q.T/ 1h- 450°C	887	730	22	542	61
Q.T/ 1h- 650°C	845	618	24	523	57
Q.T/ 2h- 250°C	945	820	18.5	493	62
Q.T/ 2h- 450°C	726	504	24.4	402	59
Q.T/ 2h- 650°C	780	610	25.3	425	55

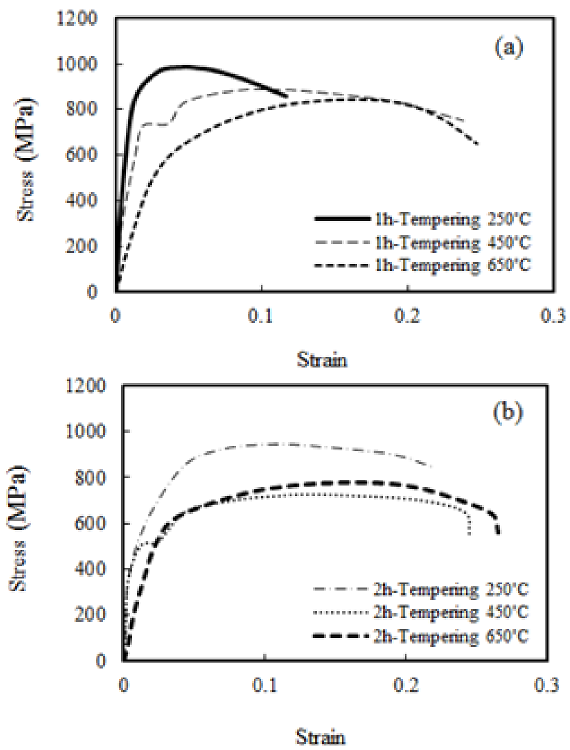

Fig. 3. stress–strain curves at different tempering temperature for 1h and 2h.

Internal stress cannot be completely removed if the tempering temperature was done under 300˚C temperature. With increasing of tempering temperature to higher than 300˚C temperature, yield stress and ultimate strength were reduced because of better dislocation distribution, sediment of cemented phase, and larger martensite blades [6].

Hardness test results for tempering temperature changes shown in Fig. 4. As can be observed, by increasing tempering temperature, hardness reduced. Because by increasing tempering temperature, carbon removed from martensite lattice and formed carbides caused to loss of dislocation sub-structure.

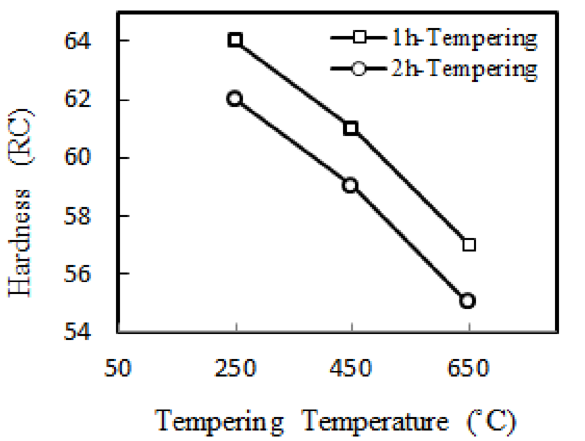

Fig. 4. Hardness curves at different tempering temperature for 1h and 2h.

The S-N curves (stress- cycle plots) of the tempered specimens at 3 temperatures have been plotted in Fig. 5. Fatigue limit assumed to be at 10^7 cycles. The curves, as expected, show that by increasing tempering temperature and holding time from 1 to 2 hours, fatigue strength is reduced. Tensile tests showed that the highest hardness and tensile strength belong to the tempered specimen at 250˚C for 1h. So it can be seen, increase of material strength caused to increase of the fatigue limit Table 2, because strengthened material shows more resistance to plastic deformation and obstacles to crack propagation [7].

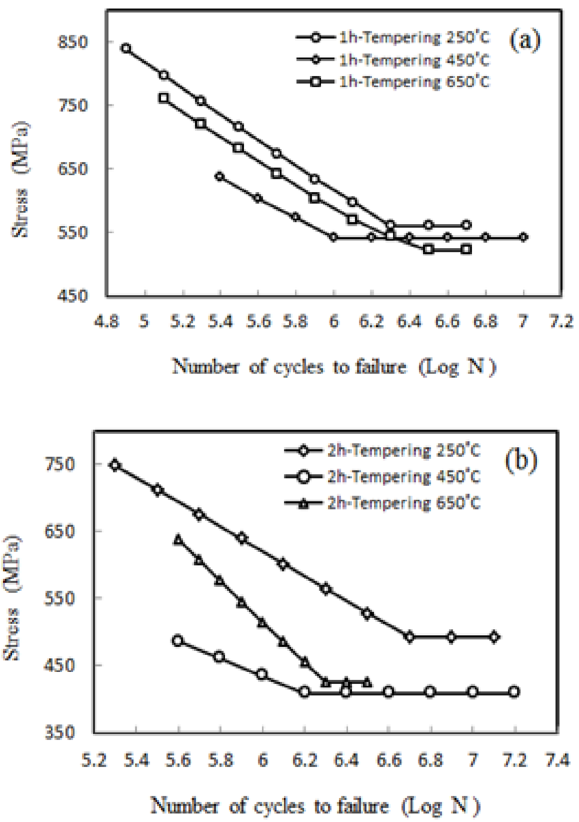

Fig. 5. S-N curves of fatigue at different tempering temperature for 1h and 2h.

The other factors of fatigue behavior were the size and form of cemented phase, quantity of 'retained austenite' and dislocation density [8]. Fine and spheroid–like sediment of cemented phase acted as an obstacle to dislocation slip and also uniform distribution of remained austenite help to the propagation of the slip. However, high density of dislocation in tempered specimens at 250˚C temperature has been led to an increase in fatigue life. In addition, it can be seen at tempering temperature of 450˚C and 650˚C temperature that the fatigue resistance decrease which corresponds with the lower dislocation density and larger sediment cemented phase [9]. Fatigue fracture surface of tempered specimens at 3 different temperatures shown at Fig. 6.

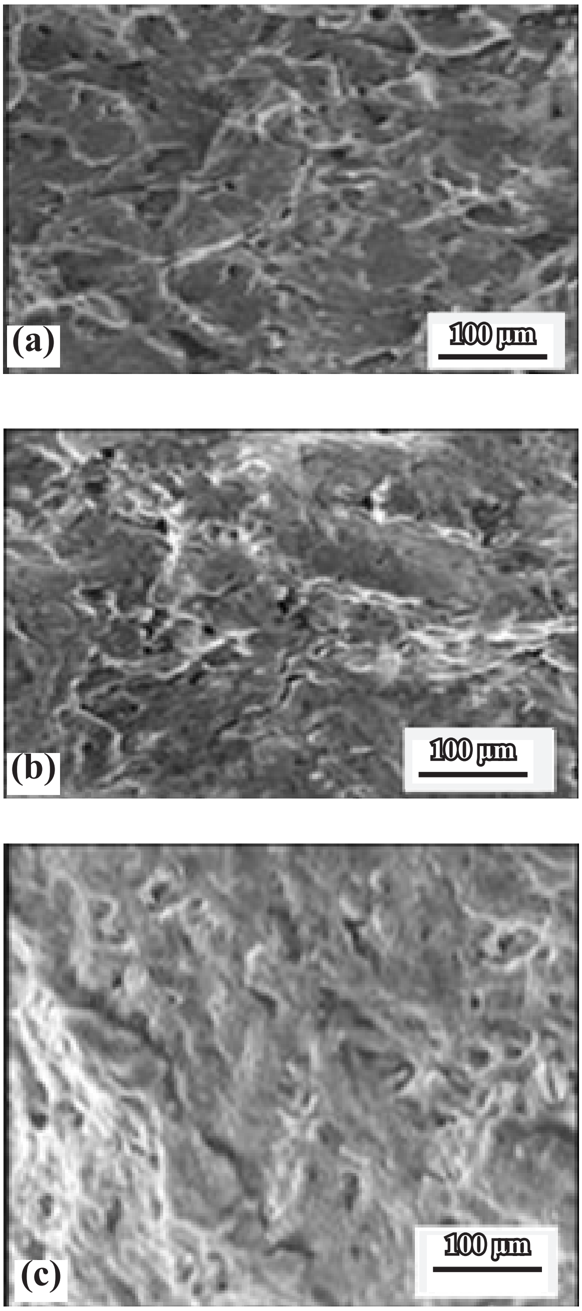

Fig. 6. SEM fractographs of fatigue tests for 1 h and tempered at (a) 250°C, (b) 450°C, (c) 650°C.

It can be seen the ultimate failure of tempered specimens at 250˚C temperature Fig. 6a which is a mixture of ductile-brittle surface. Also can be viewed dimples and flats, which is the main characterized of brittle failure. Tempered specimens at this temperature has flatter failure surface than other 2 temperatures. This is related to fine grain and spheroid-like carbides, which acts as an obstacle to crack propagation. Fine grain and spheroid-like carbides have high strength and toughness which cracks has not been the ability to cut the grain and pass them. So cracks constantly change direction and their speed is less. Fig. 6b shows the fatigue fracture surface of ductile manner. It can be seen the dimples in fracture surface and impurities that have accumulated on the center of surface. However, some parts, few failures are in brittle manner. Fig. 6c shows ups and downs and holes, and these holes have been led to facilitate the germination of fatigue crack and in some parts of fracture surface near germination holes are not found, which indicates that germination occurred between layers. In these specimens, crack does not have the ability to pass the cemented particles and grows directly and because of short distance of crack, the speed of cleavage crack propagation is high.

4. Conclusions

A study of the effect of heat treatment process on fatigue behavior in AISI 1060 steel produced the following conclusion.

- Strength and hardness have been associated with time holding and tempering temperature. Tensile strength, hardness and fatigue limit have been decreased by increasing of tempering temperature and holding time.

- Mechanical testing results revealed that tempered specimens at 250˚C for 1 hour, in comparison with other tempering temperature, had higher tensile strength (989MPa), fatigue limit (561MPa) and hardness (64RC). This was attributed to martensite microstructure changes and finally caused changes in boundary of fatigue crack initiation and propagation.

- The fatigue fracture of tempered specimen at 250˚C had a plate-like and brittle structure. However the fatigue fracture had ductile mode in higher tempering temperature.

- By increasing the tempering temperature the area of initiation of fatigue crack increases, in addition, crack propagation at 250˚C tempering temperature for 1 hour was slower than other specimen with the higher tempering temperature.

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