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Research Article

Experimental Investigation of the Effect of Quenching Temperature on Fatigue Life of Plain Low-Carbon Steel

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Abstract: This study presents an experimental study of the effect of quenching temperature from the inter-critical region (α+γ region) on the fatigue life of AISI 1010 plain low-carbon steel. In this study identical test specimens of the AISI 1010 were heat-treated by oil quenching followed by tempering, specimens were heat-treated at different quenching temperatures between 750°C to 850°C and followed by tempering at 550°C. The specimens were then tested to compare their fatigue life at constant stress amplitude; the standard high speed rotating beam test was adapted for this purpose. It was found that there is a direct relation between quenching temperature from the inter-critical region and fatigue life; the fatigue life can be increased up to 625% by increasing the quenching temperature to 850°C. This finding is important as it enhances much the ability of the AISI 1010 steel to resist fatigue failure.

Keywords: Fatigue life, heat treatment, incomplete quenching, plain low-carbon steel, quenching temperature, stress amplitude

INTRODUCTION

The term "Fatigue" is used to describe the failure of the material under a repeatedly applied stress. The stress required to cause failure under repeated load is much less than that necessary to break the material with single pull (Rollason, 1980). Fatigue is an important parameter to be considered in the behavior of mechanical components subjected to repeated loading. Mechanical, metallurgical and environmental variables can influence the fatigue resistance of components (Pelloux, 1993). There are several ways to improve the fatigue life of the components; one way is shot peening used to induce a compressive residual stress in the surface layers of material, making nucleation and propagation of the fatigue cracks more difficult (De los Rios *et al*., 1995; Torres and Voorwald, 2002). Carburizing is also frequently used to enhance fatigue strength/life (Akita and Tokaji, 2006). Severe quenching is another way of enhancing fatigue strength/life by producing high compressive surface residual stresses. The severe quenching produces a non uniform microstructure throughout the work piece in which martensite forms in the surface layers and ferrite-carbide aggregates in the core. Since the martensite has a greater specific volume than the ferrite-carbide aggregates, this results in compressive stresses in the surface layers and tensile stresses in the core and hence improves the fatigue strength/life of the piece (Liss *et al*., 1965).

Complete quenching of the plain carbon steel involves heating the steel above the upper critical temperature and then cooling the austenite rapidly enough to form the martensite. Tempering is a heat treatment applied to hardened steels to reduce brittleness, increase ductility and toughness and relieve stresses in the martensite (Rollason, 1980; Groover, 2011). Quenching followed by tempering is a usual heat treatment used to improve the mechanical properties of steels. Htun *et al*. (2008) have shown that oil quench and temper process offer enormous advantages to the heavy duty springs steel; their mechanical properties including endurance limit were significantly changed by increasing the tempering time and temperature. Miernik *et al*. (2010) have demonstrated the effect of incomplete quenching technique on the mechanical properties of low carbon structural steel, where significant influence of the heating to the α + γ field (inter-critical region) was observed on the strength and plasticity after hardening process; high level of toughness with relatively high strength have been observed. Wei *et al*. (2004) have shown that the proper selection of tempering temperature and time has a positive effect on the fatigue properties of C-Si-Mn-Cr low alloy steel; proper selection (370°C for 2 h.) can provide a better combination of strength, toughness and fatigue properties. Kwon *et al*. (2014) have shown that tempering temperature has a significant influence on the low cycle fatigue of a high strength steel; proper

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selection of tempering temperature can improve its fatigue life.

Hanguang *et al*. (2009) have demonstrated the effects of quenching temperature on the microstructure and mechanical properties of centrifugal casting High Speed Steel (HSS) roll; the tensile strength and the impact toughness of HSS roll increased when the quenching temperature is raised from 980°C to 1040°C. However, the tensile strength and the impact toughness have not changed significantly when the quenching temperature exceeds 1040°C. Lai *et al*. (1974) have studied the effect of quenching temperature on the microstructure and mechanical properties of as-quenched 4340 steel. It has been shown that plane strain fracture toughness in the specimens quenched from 1200°C is larger by ~80% as compared to those quenched from 870°C. Mahasneh *et al*. (2010a) have investigated the influence of quenching temperature on hardness and torsional strength of D2 alloy steel; they studied the hardening of the D2 at different quenching temperature (1070, 1040, 1010 and 980°C) followed by tempering at 540°C. It was found that there is a direct relation between microhardness magnitude and quenching temperature. This finding was of considerable significance due to the observation of a great enhancement in the ability of the D2 alloy steel to sustain high torsion loads, where the maximum enhancement for 191.1% was achieved at 1070°C. In a similar study, Mahasneh *et al*. (2010b) have also investigated the effect of quenching temperature on the torsional aspects of AISI H13 alloy steel. In that study, different heat treatment regimes were carried out on the H13 alloy steel to investigate the torsion properties. It was found that there is an enhancement in the maximum shear stress of the H13 steel after heat treatment and that the micro-hardness is enhanced as the quenching temperature is increased. The maximum enhancement for 88.9% was attained at 1070°C.

Due to its versatility and low cost, AISI 1010 plain carbon steel has been widely used in industry. In practice, lots of mechanical components made of this steel are subjected to variable loading. Nevertheless, the influence of quenching temperature on fatigue life of the AISI 1010 steel has not been considered before.

This study presents an experimental study of the effect of quenching temperature within the inter-critical region (α+γ region) on the fatigue life of the AISI 1010 plain carbon steel.

MATERIALS AND METHODS

This study was conducted at An-Najah National University, where the facilities of the Materials Properties Lab and the Engineering Workshop were used.

Materials: The material of the test specimens used in this study is the AISI 1010 plain carbon steel whose chemical composition is as shown in Table 1.

Table 1: Chemical composition of the AISI 1010 plain carbon steel (www.AZom.com, 2012)

Element	Content%
Iron, Fe	99.18-9.62%
Manganese, Mn	0.30-0.60%
Sulfur, S	≤0.050%
Phosphorous, P	≤0.040%
Carbon, C	0.080-0.13%

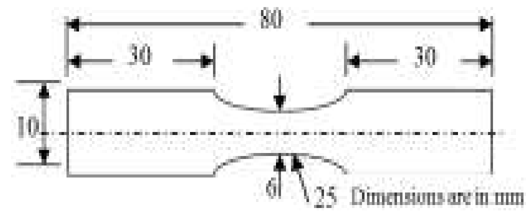

Fig. 1: Shape and dimensions of the test specimens

Test specimens: Figure 1 shows the shape and dimensions of the test specimens prepared according to the standards of the fatigue testing machine used in this study.

Equipment: The following equipments were used in conducting this study:

- Lath machine to prepare test specimens
- Grinding paper grits 120, 240, 320, 400 to surface finish the test specimens
- Nabertherm furnace with maximum temperature 1100°C to heat the test specimens
- Quenching oil SAE 10W-40
- High-speed rotating beam test machine to measure fatigue life of test specimens

Procedures:

Preparation of test specimens: Twelve identical test specimens having the shape and dimensions as shown in Fig. 1 were first cut from the same steel bar and then prepared by machining using lathe machine; after that the specimens were grinded using grinding paper with grits 120, 240, 320, 400 to get unified surface finish for all specimens.

Quenching of the test specimens: The twelve test specimens were divided into four equal groups, with each group consists of three specimens. Specimens from the first group were heated in the furnace up to 750°C (hereafter we shall call it "incomplete quenching" temperature), kept at this temperature for 15 min and then quenched rapidly in the SAE 10W-40 oil. The same quenching procedure was implemented for the specimens of second and third groups but the quenching temperatures for these groups were 800°C and 850°C, respectively. The forth group of the specimens was left without any heat treatment.

Tempering: To reduce hardness and improve toughness of the quenched steel, the three quenched

Table 2: Heat treatment details of the test specimens

		Quenching		Tempering	
Group number	Number of specimens	Quenching temperature °C	Holding time (min)	Tempering temperature °C	Holding time (min)
1	3	750	15	550	60
2	3	800	15	550	60
3	3	850	15	550	60
4	3	No heat treatment			

Table 3: Summary of fatigue testing results

Group number	Number of specimens	Qenching temperature °C	Average number of stress cycles until failure (life of specimen)	Percent of inhancement in specimen life (rounded)
1	3	750	137150	160%
2	3	800	426706	490%
3	3	850	545868	625%
4	3	No Heat Treatment (NHT)	87250	

specimens from each group were tempered in the furnace at 550°C for one hour and then left to cool in air. Note that the fourth group of the specimens received no heat treatment. Conditions of the heat treatment of the test specimens are summarized in Table 2.

Fatigue testing: The standard high-speed rotating beam test machine was used to conduct fatigue testing. The three specimens from each group were tested individually on this machine, each specimen was supjected to completely reversed stress cycle with a constant amplitude. Specimens from all the groups were supjected to the same stress amplitude. Each specimen was tested until failure and the corresponding number of stress cycles was recorded. The average number of stress cycles until failure for the three speciemens of each group was calculated.

RESULTS AND DESCUSSION

Table 3 summarizes the fatigue testing results. The table presents also the percent of enhancement in specimen life.

The above results are presented in Fig. 2.

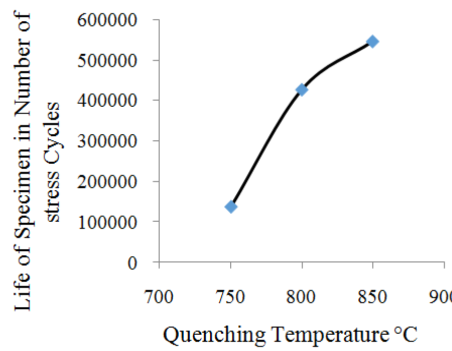

Fig. 2: Relation between quenching temperature and fatigue life of the test specimens

It is obvious from the above results that there is a direct relation between quenching temperature from the inter-critical region and fatigue life of the AISI 1010 plain carbon steel. The average fatigue life of the untreated specimens was 87250 cycles; this life was increased by 160% upon quenching from 750°C, by 490% upon quenching from 800°C and by 625% upon quenching from 850°C. The above results indicate that the fatigue strength, as a mechanical property, can be much improved by increasing the quenching temperature within the inter-critical region for the AISI 1010 steel. This result is in line with other related results obtained in Miernik *et al*. (2010) and Liss *et al*. (1965). This improvement in the fatigue strength/life is due to the development of compressive surface residual stress caused by the specific volume difference between the martensite in the case and the ferrite aggregates in the core as was reasoned in Liss *et al*. (1965). In fact, the resulting structure after rapid quenching of the low plain carbon steel is dual phase "ferritic-martensitic phase" (Miernik *et al*., 2010; Smith, 1993). Actually, higher quenching temperature within the inter-critical region increases percentage of the austenite, which results in increasing percentage of the martensite developed upon quenching and hence increasing the compressive surface residual stresses in the case of the piece. Future research may be conducted to investigate the effect of austenitizing temperature on the fatigue life of the AISI 1010 steel, which we expect to have a similar direct proportional relation.

CONCLUSION

This study presented an experimental study of the effect of quenching temperature within the inter-critical region (α+γ region) on the fatigue life of the AISI 1010 plain carbon steel. Specimens were heat treated at different quenching temperatures between 750°C to 850°C and followed by tempering at 550°C, the specimens were then tested to compare their fatigue life at constant stress amplitude. It was found that there is a direct relation between quenching temperature from the inter-critical region and fatigue life/strength; the life could be increased up to 625% by increasing the quenching temperature to 850°C. This improvement in the fatigue strength/life is due to the development of compressive surface residual stress caused by the specific volume difference between the martensite in the case and the ferrite aggregates in the core. The finding in this study is important as it shows a way to enhance the ability of the AISI 1010 steel to resist fatigue failure.

CONFLECT OF INTEREST

The authors state that there are no financial/relevant interests that influence the development of the manuscript.

REFERENCES

Akita, M. and K. Tokaji, 2006. Effect of carburizing on notch fatigue behaviour in AISI 316 austenitic stainless steel. Surf. Coat. Tech., 200(20-21): 6073-6078.

De los Rios, E.R., A. Walley, M.T. Milan and G. Hammersley, 1995. Fatigue crack initiation and propagation on shot-peened surfaces in A316 stainless steel. Int. J. Fatigue, 17(7): 493-499.

Groover, M.P., 2011. Principles of Modern Manufacturing. John Wiley.

Hanguang, F., C. Xiaole, D. Zhongze, L. Yingping and F. Zhenjun, 2009. Effect of quenching temperature on structure and properties of centrifugal casting high speed steel roll. China Foundry, 6(1): 15-19.

Htun, M.S., S.T. Kyaw and K.T. Lwin, 2008. Effect of heat treatment on microstructures and mechanical properties of spring steel. J. Met. Mater. Miner., 18(2): 191-197.

Kwon, H., F. Barlat, M. Lee, Y. Chung and S. Uhm, 2014. Influence of tempering temperature on low cycle fatigue of high strength steel. ISIJ Int., 54(4): 979-984.

Lai, G.Y., W.E. Wood, R.A. Clark, V.F. Zackay and E.R. Parker, 1974. The effect of austenitizing temperature on the microstructure and mechanical properties of as-quenched 4340 steel. Metall. Trans., 5(7): 1663-1670.

Liss, R.B., C.G. Massieon and A.S. Mckloskey, 1965. The Development of Heat Treat Stresses and their Effect on Fatigue Strength of Hardened Steels. Technical Paper 650517, SAE International, pp: 870-877.

Mahasneh, M.M., S.M.A. Al-Qawabah and U.F. Al-Qawabeha, 2010a. Experimental and FEM investigation of heat treatment on the torsional aspects of D2 alloy steel. Res. J. Appl. Sci. Eng. Technol., 2(6): 552-557.

Mahasneh, M.M., U.F. Al-Qawabeha and S.M.A. Al-Qawabah, 2010b. Investigation of heat treatment on the torsional aspects of H13 alloy steels. Int. J. Mater. Sci., 5(4): 547-556.

Miernik, K., R. Bogucki and S. Pytel, 2010. Effect of quenching techniques on the mechanical properties of low carbon structural steel. Arch. Foundry Eng., 10(3): 91-96.

Pelloux, R.M., 1993. Case studies of fatigue failures in aeronautical structures. Proceeding of the Conference on Fatigue 93, Montreal, pp: 1727-1737.

Rollason, E.C., 1980. Metallurgy for Engineers. Chaucer Press Ltd., Great Britain.

Smith, W.F., 1993. Foundations of Material Science and Engineering. 2nd Edn., McGraw-Hill, New York.

Torres, M.A.S. and H.J.C. Voorwald, 2002. An evaluation of shot peening, residual stress and stress relaxation on the fatigue life of AISI 4340 steel. Int. J. Fatigue, 24(8): 877-886.

Wei, D.Y., J.L. Gu, H.S. Fang, B.Z. Bai and Z.G. Yang, 2004. Fatigue behavior of 1500 MPa bainite/martensite duplex-phase high strength steel. Int. J. Fatigue, 26(4): 437-442.