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Microstructure and Mechanical Properties Analysis of Quenched and Tempered AISI 4340 Steel

Imam Basori[1], Almalia Surocaena[1], Siska Titik Dwiyati[1], Yunita Sari[1], and Balbir Singh[2]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Jakarta, Jl. Rawamangun Muka, Jakarta 13220, Indonesia
[2]Department of Mechanical Engineering, S M V D U, Katra 182320, J&K, India

Abstract

This research was conducted to determine the optimum parameters in quenching and tempering processes of AISI 4340 steel. Quenching and tempering processes were carried out to modify the microstructure and mechanical properties, especially to achieve the high strength and toughness resilience for steel armor application. Steel is widely use as armor material due to its ease processing, lower production costs, high strength, good toughness, and heat treatment capabilities. This material has also a reasonable price and good availability. Metallurgical structure becomes a crucial factor, especially for ballistic-resistant vehicle applications. The samples of AISI 4340 commercial steel with dimension of 55x10x10 mm^3 were austenized at temperature of 800 °C for 1 and 2 h in a muffle furnace and followed by quenching process with oil as the media. Furthermore, the quenched samples were then tempered at 300 ° C for 2, 3, and 4 h at the muffle furnace as well. Microstructure analysis was conducted by using optical microscopes. The result showed that quenching process promoted the phase transformation from the combination of ferrite and pearlite to be the ferrite and martensite with the shape like a needle. On the other hand, the tempering process promotes the transformation of martensite to bainite. Quenching has also led to increasing of hardness.

Keywords: AISI 4340, quenching, tempering, martensite.

Corresponding Author:
Imam Basori
unimam_r_one@yahoo.com

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1. Introduction

Armor materials are designed to hold the bullet penetration and others, in which the metallurgical structures become the crucial factor. This material has also designed to be able to break and hold projectiles fired at high velocity [1, 2] due to the good hardness and impact resilience [3, 4]. The kinds of armor materials used for military applications are steel, ceramics, polymers, and composites [5], although steel is the most widely used due to its ease processing, lower production costs, high strength, good toughness, and

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heat treatment capabilities [6]. Steel armor has also well known as the bullet resistant steel in regard with its application as the protective material for civilian and military vehicles [7]. The mechanical properties of steel can be improved by the heat treatment process.

Previous research showed that the heat treatment process was conducted on AR500 [8] steel, 4140 steel [9] and PROTAC 500 steel [10] with the temperature of quenching and tempering between 800-900 °C and 200-300 °C, respectively. This treatment was aimed to improve the physical and mechanical properties, which they heavily depend on optimum temperature, holding time, and also the cooling process. The experiment showed that the microstructure was dominated by martensite and bainite phases and the materials have capability to hold the ballistic loads with the thickness plate above 7 mm. This phenomenon showed that the good ballistic resilience was achieved at a fairly high thickness and resulted in high sample mass which the characteristic is not appropriate for armored vehicle application that requires lower weight to reach a high mobility. This research was intended to comprehend the effect of quenching and tempering process on the microstructure, hardness, and impact properties of AISI 4340 steel. The experiment is expected to produce the better physical and mechanical properties.

2. Methods and Equipment

The samples of AISI 4340 commercial steel with dimension of 55x10x10 mm^3were austenized at temperature of 800 °C for 1 and 2 h in a muffle furnace and followed by quenching process with media of oil. The composition of the steel is shown in Table 1. Furthermore, the quenched samples were then tempered at 300 ° C for 2, 3, and 4 h at the muffle furnace as well. Microstructure analysis was conducted by using optical microscopes. Previously, the samples were mechanically grounded by abrasive paper and polished by metal polish followed by etching with HNO3 0.4% in alcohol in accordance with ASTM E407:2007. The hardness and impact testing were conducted by Vickers and Charpy methods, respectively.

Table 1: Nominal composition of the AISI 4340 steel.

C	Mn	P	S	Ni	Cr	Mo	V
0.3	0.3	0.025	0.4	0.5	0.4	0.15	0.15

3. Results and Discussion

3.1. Microstructures

Figure.1 (a-c) shows the microstructure of the samples; before and after quenching process. As shown in Figure.1a, the microstructure of raw material is dominated by the ferrite and pearlite phases. The quenching process promoted the phase transformation from the combination of ferrite and pearlite to be the ferrite and martensite with the shape like a needle (Figure. 1 b-c). The longer holding time, results in the more martensite phases. The rapid cooling results in the incomplete carbon atoms diffusion and promoted the change of crystal structure from the FCC to BCT.

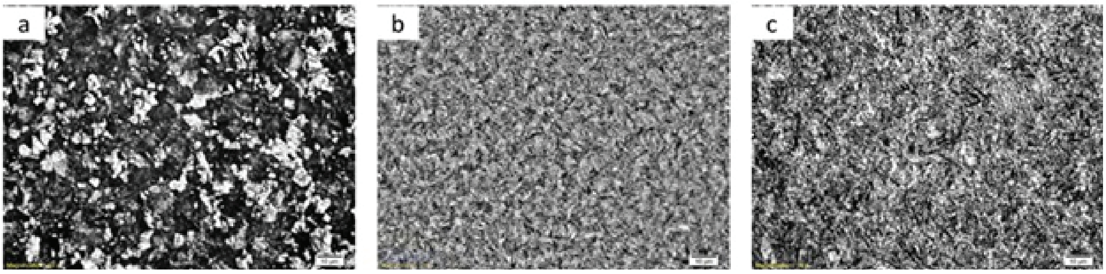

Figure 1: Micrographs of AISI 4340 steel (a) without treatment (b) Quenching 800 ˚C, 1 h (c) Quenching 800 ˚C, 2 h.

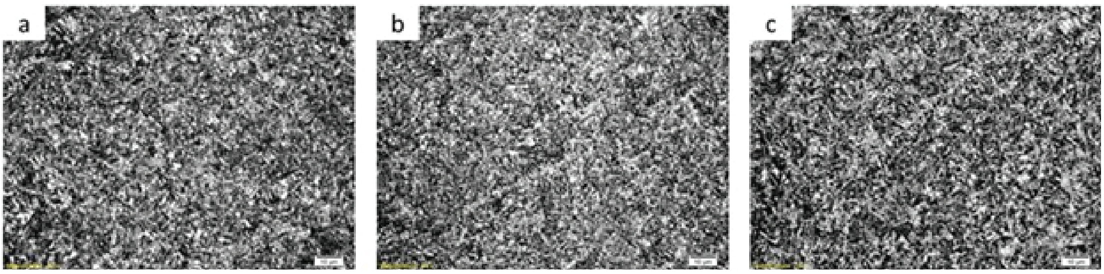

Figure 2: Micrographs of AISI 4340 steel after quenching at 800 ˚C for 2 h followed by tempering at 300 ˚C for (a) 2 h (b) 3 h (c) 4 h.

Figure.2 (a-c) illustrates the microstructure of the samples after quenching at 800 ˚C for 2 h followed by tempering process at 300 ˚C for 2, 3, and 4 h. All samples show the combination of ferrite and bainite phases. The tempering process promotes the transformation of martensite to bainite. Bainite is the intermediate phase before the formation of martensite which diverts the crystal structure from BCT to BCC.

3.2. Mechanical properties

Figure.3 shows the hardness of the samples with different heat treatment process. The figure describes that the quenching process is followed by the increasing in hardness due to the presence of martensite phase. Martensite phases with the crystal structure of BCT has the complicated atom formation and results in harder dislocation movement. The highest hardness occurs at the quenching process with holding time of 2 h (439.3 VHN). As shown in the Fig.3, the tempering process tends to reduce the hardness. The longer the holding time is, the lower the hardness of the tempered samples is. The phase transformation from martensite (BCT) to bainit (BCC) during the tempering process promoted the easier dislocation movement and resulted in the lower hardness.

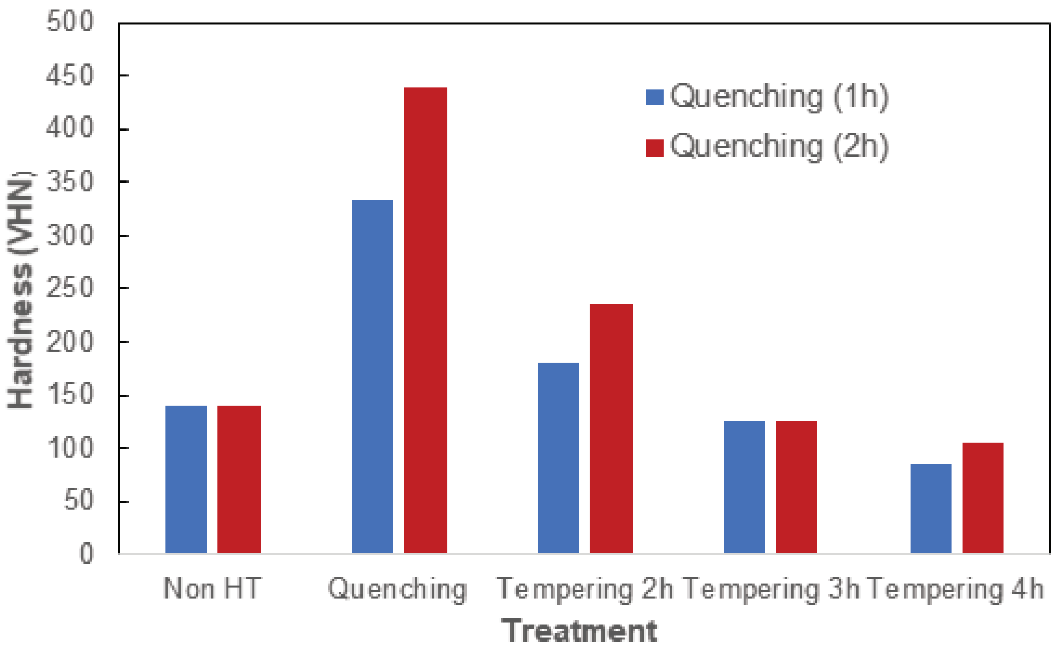

Figure 3: The Hardness change of AISI 4340 steel after quenching and tempering process.

Figure.4 describes the toughness change of AISI 4340 steel after quenching and tempering processes. As shown at Figure.4 that the highest toughness occurs at the sample after quenching process at 800 °C for 1 h followed by tempering at 300 °C for 3 h (144.9 J / mm2). On the other hand, lowest toughness occurs at the sample after quenching process at 800 °C for 2 h (61.13 J / mm2). Quenching process promotes the formation of martensite phase with BCT crystal structure which has the highest hardness and in contrast the lowest toughness. In another hand, tempering process leads to formation of bainit phase which has the higher toughness than that of martensite phase

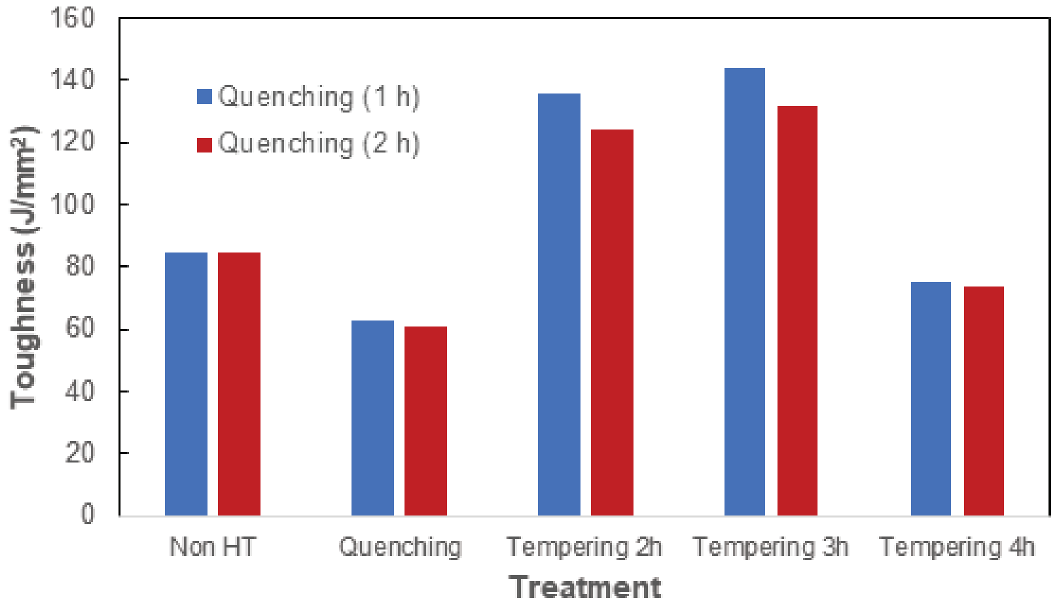

Figure 4: The toughness change of AISI 4340 steel after quenching and tempering process.

due to its BCC crystal structure. In tempering process, time is the crucial factor. As shown at Figure.4 that, the toughness tends to decrease at the tempering process for 3 h.

4. Conclusion

The results of the observation can be concluded as follows:

1. The quenching process changes the microstructure of AISI 4340 steel from ferrite and pearlite phases to be ferrite and martensite, in which the increase in quenching time from 1 to 2 h tends to increase the number of martensite.
2. The tempering process changes the microstructure of AISI 4340 steel from martensite to bainite, wherein the increase in holding time from 2, 3, and 4 h tends to decrease the number of bainite phases.
3. The addition of quenching holding time tends to increase the value of hardness, in which the time addition from 1 to 2 h results in the hardness increase about 31.4% from 334.12 to 439.3 VHN. On the other hand, the impact resistance value tends to decrease with an increase in holding time. The impact resistance value decreases about 3.7% from 63.41 to 61.14 J /mm^2.
4. The increase of tempering time results in a decrease of hardness, wherein the lowest hardness value of 85.48 VHN is found at the sample with quenching time of 2 h and followed by tempering for 4 h.

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Conflict of Interest

The authors have no conflict of interest to declare.

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