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Austenitizing Temperature and Quenching Media Effects on Hardness and Microstructure in Hardening of AISI 1040 Steel

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Abstract. *Hardening process is an important to make materials have harder properties related to wear resistance. This research determined the effects of austenitizing temperature and quenching media on the hardness and microstructure of AISI 1040. The austenitizing temperatures varies at 850°C, 900°C, and 950°C with PVA 10%, SAE 20W-50 oil, and salt water as quenching media. The method to measure hardness was the Brinell hardness test. The results showed changes in the microstructure from untreated steel with the structures of ferrite and pearlite to bainite and martensite. The highest hardness value of 416.22 kgf/mm^2 was obtained in specimens with salt water media at an austenitizing temperature of 850°C.*

Keywords: *Austenitizing temperature, Quenching media, AISI 1040*

Abstrak. Proses pengerasan (*hardening*) merupakan suatu hal yang penting agar bahan mempunyai sifat lebih keras karena berkaitan dengan sifat ketahanan aus. Penelitian ini bertujuan untuk menganalisis pengaruh temperatur austenitisasi dan media quenching terhadap kekerasan dan struktur mikro AISI 1040. Temperatur austenisasi bervariasi pada 850°C, 900°C, dan 950°C dengan PVA 10%, minyak SAE 20W-50, dan air garam sebagai media pendinginan. Metode untuk mengukur kekerasan adalah dengan uji kekerasan Brinell. Hasil penelitian menunjukkan adanya perubahan struktur mikro dari baja yang tidak diberi perlakuan dengan struktur ferit dan perlit menjadi bainit dan martensit. Nilai kekerasan tertinggi sebesar 416,22 kgf/mm^2 diperoleh pada spesimen dengan media air garam pada suhu austenitisasi 850°C.

Kata Kunci: Temperatur austenitisasi, Media pendingin, AISI 1040

I. INTRODUCTION

Hardening is one of heat treatment processes for increasing the hardness value of steels. It is carried out by heating the steel to a high temperatur (reaching a homogenous phase, austenite) for a certain period of time, then quenching the steel rapidly in a medium [1]. This process is commonly used in medium carbon steels. Previous studies show that hardening applied for medium carbon steel is proven to be able to increase the hardness value and other mechanical properties, such as tensile strength and fatigue [2], [3].

The medium carbon steel is widely researched steel for the heat treatment process. This is due to its wide range of industrial applications and heat-treatable property. One of the steels is AISI 1040 type, it is often used in automotive components such as gears, bearings and shafts that require high hardness and wear [4]. This type of steel commonly has carbon content around 0.4% with the tensile strength of 590 MPa [5]. However, further research is still needed to improve the mechanical properties of numerous type of medium carbon steel with one of the ways is through hardening.

The hardening result is influenced by several factors, such as, austenitizing or quenching temperature, holding time, quenching media, concentration, and flow rate of media [6], [7], [8], [9], [10], [11]. The enhancement of hardening or austenit temperature with range of 800 – 900^{o}C is proven to increase the hardness value of AISI 1045 [6]. Moreover, the use of brine and SAE 20W-50 are evidenly capable to elevate the hardness along with the microstructure transformation [6], [12]. Apart from that, the cooling media that is starting to be developed is polymeric media. The polymeric solution, such as polyvinyl alcohol (PVA), indicates

an increase in the mechanical properties of the hardening process of alloy steel [13].

Since the use of polymer as the cooling media from the previous study was concerned in the impact test results with varying the concentration of the polymeric media [13], this research was carried out to compare not only between the polymeric solution but also to other common cooling media on the hardness and microstructure of the hardening process for the medium carbon steel. In addition, another variation, austenitizing temperature was also applied to evaluate the hardness and microstructure transformation results.

II. METHODOLOGY

Materials, tools, and hardening process are detailed in the following section.

A. Materials and tools

The steel used in this research is AISI 1040 with the dimension of 40 x 15 x 10 mm. The cooling or quenching media are polyvinyl alcohol (PVA) 10%, salt water or brine 10%, and SAE 20W-50 oil. Etching solution of nital (nitric acid:aquadest = 95%:5%) to prepare the specimen for microstructure analysis.

The heat treatment process used a muffle furnace with maximum operation temperature of 1200^{o}C. The hardness test was carried out using Universal Hardness Tester with Brinell indenter and testing standard of ASTM E10. Microstructure was analyzed using metallurgical microscope Olympus with testing standard of ASTM E3.

B. Hardening Process

The process is started by heating the specimen inside the furnace at austenitizing temperature to transform the metal's crystal structure into a homogenous form. The variations of the austenitizing temperature used are 850^{o}C, 900^{o}C, and 950^{o}C [7]. The holding time applied is 60 minutes at the determined temperature [9]. After the holding process, all specimens are cooled rapidly (quenching) in various cooling media (PVA 10%, brine, and oil). Then, the microstructure analysis is begun with grinding (using grid 100 – 2000) and polishing (using autosol) the specimens, then etching the specimens with nital solution. The hardness testing is carried out to evaluate the hardness value. The load applied is 150 kgs with three times indentation at 5 mm distance. The formula to calculate hardness value is present as follows:

$$HB\left({}^{kgf}/_{mm^2}\right) = \frac{2P}{\pi D\left(D-\sqrt{D^2-d^2}\right)} \ldots (1)$$

where,

P = load applied (150 kgf)
D = indenter ball diameter (1.2 mm)
d = indentation result diameter (mm)

III. RESULTS AND DISCUSSIONS

The results and discussions of this research cover the results of hardness testing, microstructures, and cooling rates.

A. Hardness results

The hardness results are shown in Table 1 with the value of resulted indentation diameters and calculated hardness value using equation 1. The highest hardness is reached at an austenitizing temperature of 850^{o}C in salt water medium with a value of 416.22 kgf/mm^2. The lowest hardness value is 152.57 kgf/mm^2 with untreated AISI 1040 steel.

Table 1. The experiment results of hardness Brinell for untreated and heat-treated AISI 1040 with variations of austenitizing temperature and quenching media

Austenitizing temperature (^{o}C)	**Quenching media**	**Indentation diameter (mm)**	**Hardness value (kgf/mm^2)**
Untreated	Untreated	0.99	152.57
850	PVA 10%	0.97	162.83
	SAE 20W-50	0.94	182.80
	Salt water 10%	0.65	416.22
900	PVA 10%	0.88	210.19
	SAE 20W-50	0.81	248.21
	Salt water 10%	0.7	353.35
950	PVA 10%	0.87	215.18
	SAE 20W-50	0.84	260.55

	Salt water 10%	0.73	318.29

Based on Figure 1, the austenitizing temperatures provide different influences. In salt water medium, higher austenitizing temperature results in lower hardness value, but still has the highest result than other media. However, in PVA and oli media, higher austenitizing temperature results in higher hardness value. This shows that salt water is a quenching medium that is suitable for hardening steel because it adds very high hardness values compared to other media as in the previous study [14]. In addition, the results of lower hardness in oil and PVA will be further analyzed and correlated in the following section.

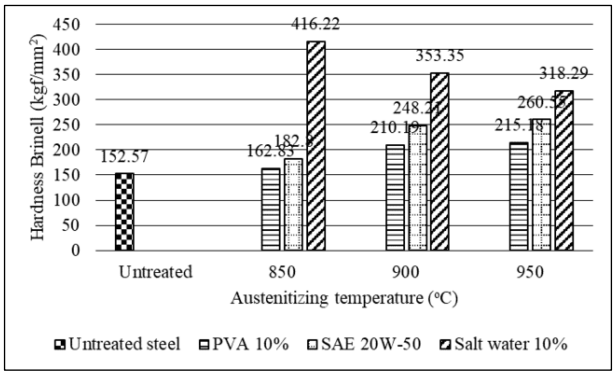


Figure 1. Comparison graph of hardness value with variations of austenitizing temperature and quenching media

B. Microstructure results

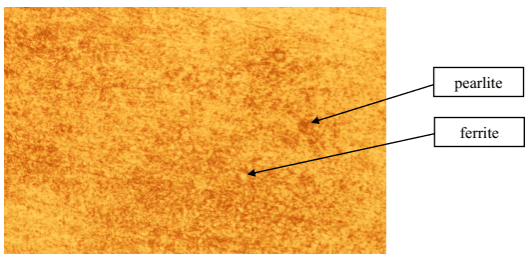


Figure 2. Microstructure of untreated or raw AISI 1040 steel

Figure 2 exhibits the microstructure images of the untreated AISI 1040 steel at 50 times magnification. Untreated specimen shows the appearance of fine ferrite and pearlite with percentage of 37.2% and 62.8%, respectively.

The austenitizing temperature of 850°C results in microstructure characteristics as in Figure 3. In Figure 3(a) the microstructure of the specimen in PVA medium has a pearlite phase of 26.92%, ferrite 51.28% and bainite 21.79% with coarse and sparse grains, for Figure 3(b) the microstructure in oil medium has a pearlite phase of 32.24 %, bainite 26.92%, and martensite 7.4% with quite a small amount of martensite, while Figure 3(c) in salt water medium has a martensite phase of 72.68% and bainite 13, 41% with very fine grains so that the hardness value increases drastically.

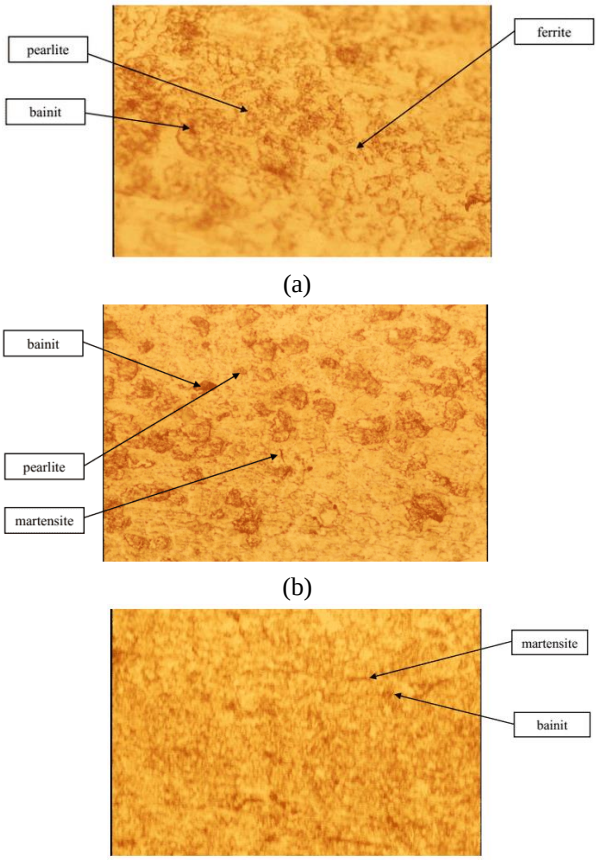


Figure 3. Microstructure of hardening AISI 1040 at 850°C with quenching media of (a) PVA 10%, (b) SAE 20W-50, and (c) salt water 10%

Figure 4 shows the microstructures of hardened AISI 1040 at austenitizing temperature of 900°C. In Figure 4(a) the microstructure of the specimen in a cooling medium of PVA has several phases including ferrite 15.48%, pearlite 66.07%, and bainite 18.44% which are very coarse due to the

high cooling rate. quite slow. Meanwhile, Figure 4(b) shows the microstructure of the specimen in oil as a cooling medium has phases including 29.68% pearlite, 28.99% bainite and 13.41% martensite with fairly fine grains. Figure 4(c) is the microstructure of the specimen in salt water medium having a martensite phase of 70.21% and 12.22% bainite with fine grains.

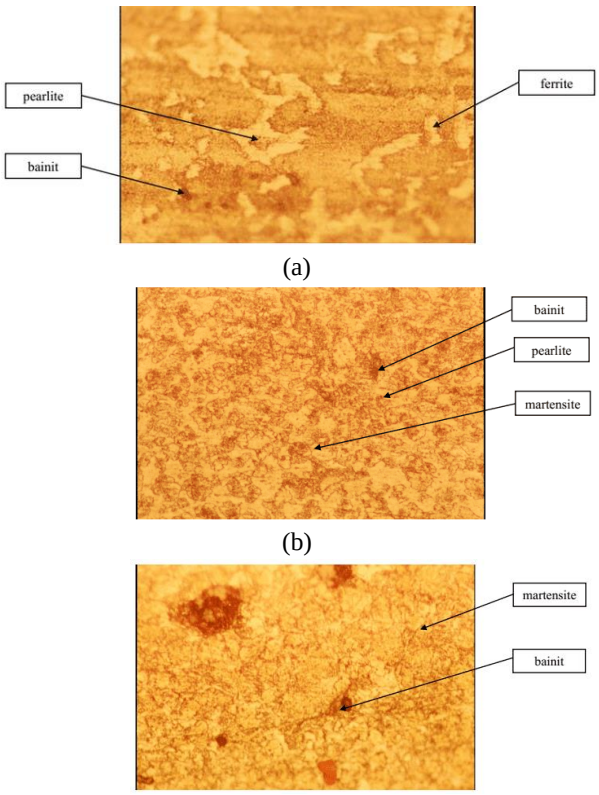
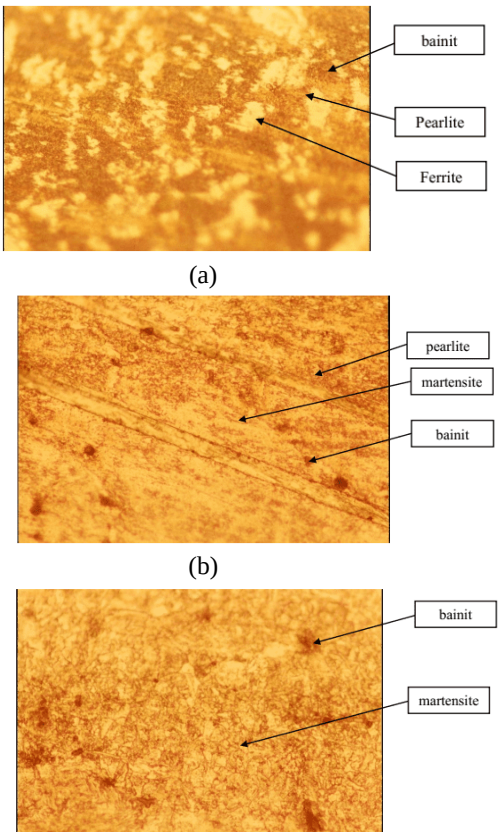


Figure 4. Microstructure of hardening AISI 1040 at 900^{o}C with quenching media of (a) PVA 10%, (b) SAE 20W-50, and (c) salt water 10%

Seen in Figure 5, the microstructures of hardening results at the austenitizing temperature of 950^{o}C. In Figure 5(a), PVA medium gives phases in the form of 37.27% ferrite, 20.31% pearlite, and 42.40% bainite with coarse grains, (b) microstructure of the specimen in oil medium has a fairly fine phase of 23.17% pearlite, 27.41% bainite, and 11.04% martensite, (c) microstructure of the specimen in salt water medium results in a fine phase of 66.46% martensite and 11.04% bainite, thus making the hardness value of the specimen increase very much.

The microstructures in specimens with PVA as quenching media (Figures 3(a), 4(a), and 5(a)) only have the bainite, pearlite, and ferrite with coarse grains due to a slow cooling rate compared to other media. PVA (polyvinyl alcohol) is a polymeric solution, then the formation of air bubbles occurs which then continues with the formation of an air envelope on the surface of the specimen. The air envelope inhibits heat transfer to the quench medium which causes a slow cooling rate. Bainite is formed at a cooling time above the martensite formation time [15]. Meanwhile, the microstructures with salt water media (Figures 3(c), 4(c), and 5(c)) shows the structures of bainite and martensite due to the fast cooling rate, it forms a martensite structure with fine grains. A higher proportion of martensite leads to a higher hardness value as also proven in the previous study [11]. From the pictures, it can be seen that the structure formed is martensite, a microstructure that is flat and sharp like a needle, bainite is a very dark black structure that forms above the martensite finish boundary, pearlite is a black structure but not as dark as bainite and bright white ferrite [16].



(c)

Figure 5. Microstructure of hardening AISI 1040 at 950ºC with quenching media of (a) PVA 10%, (b) SAE 20W-50, and (c) salt water 10%

C. Cooling rate results

The cooling rates are provided in Figure 6 as the comparison between the microstructure formed and the hardness value of the hardened specimens.

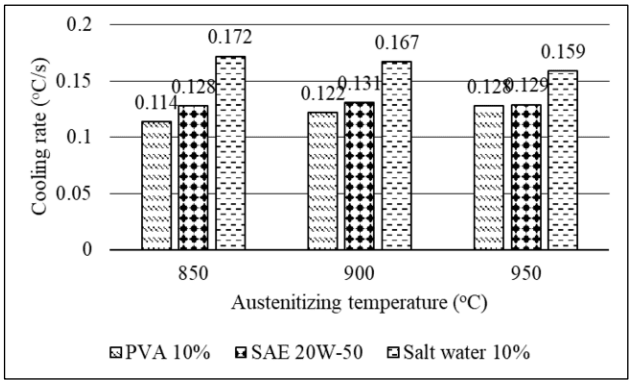


Figure 6. Cooling rate against variations of austenitizing temperature and quenching media

The cooling rate in the salt water media is the fastest among the other quench media, so the greatest hardness value is found in the specimen with the salt water media and the lowest hardness value is in the PVA media because the cooling rate is slow. This due to the longer the quenching duration applied, the more material grains will enlarge due to slow cooling. Materials that have a smaller grain size will have higher strength and hardness values with those with larger grains [17].

IV. CONCLUSION

This research concludes that the increase in austenitizing temperature affects the hardness value, the higher the heating temperature, the higher the average hardness. The highest hardness was obtained by specimens with salt water quench media at a heating temperature of 850ºC of 416.22 kgf/mm². Moreover, the increase in heating temperature affects the percentage of phases and structures formed, the higher the austenitizing temperature, the higher the average percentage of bainite/martensite phases. These results are also confirmed with the cooling rate results.

Further research may be focused on the use of polymeric solutions as a cooling medium. Since the use of PVA media provides an opportunity to increase the hardness value.

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