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Different Quenching Media Effect on Microstructure, Hardness, and Corrosion of Medium Carbon Steel

Pengaruh Media Pendinginan Berbeda terhadap Mikrostruktur, Kekerasan dan Korosi Baja Karbon Sedang

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Abstract

Medium carbon steel is widely used due to could conduct heat treatment to modify the microstructure and mechanical properties. Quenching is one method to modify the microstructure and mechanical properties. In the present study conducted heating samples at 850¤C using an electric furnace, then held them for 60 minutes and quenched in various media (saline water, oil, and distilled water). Afterward, the quenched sample was investigated microstructure, hardness, and corrosion using an optical microscope, Vickers hardness tester, and weight loss method. 5% NaCl quenching media could result in samples more uniform and martensite due to the high cooling rate. More uniforms and martensite have the beneficial highest hardness and lowest corrosion rate for around 762.4 HV and 76.04 mpy.

Keywords: water, engine oil, saline water, electric furnace.

***SDGs*:**

Abstrak

Baja karbon sedang banyak digunakan karena dapat dilakukan perlakuan panas untuk memodifikasi struktur mikro dan sifat mekaniknya. *Quenching* merupakan salah satu metode untuk memodifikasi struktur mikro dan sifat mekaniknya. Pada penelitian ini dilakukan pemanasan sampel pada suhu 850°C menggunakan tanur listrik, kemudian ditahan selama 60 menit dan diquenching dalam berbagai media seperti air garam (5% NaCl), oli dan air suling. Selanjutnya sampel yang telah diquenching diperiksa struktur mikronya, kekerasannya dan korosinya menggunakan mikroskop optik, alat uji kekerasan *Vickers* dan metode kehilangan berat. Media quenching 5% NaCl dapat menghasilkan sampel yang lebih seragam dan martensit karena laju pendinginannya yang paling tinggi. Lebih seragam dan martensit memiliki kekerasan tertinggi dan laju korosi terendah sekitar 762,4 HV dan 76,04 mpy.

Kata Kunci: air suling, oli mesin, air garam, tungku listrik.

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1. INTRODUCTION

Steel is one of the metals that has good strength and that is widely used in marine components (Baihaqi, Pratikno and Hadiwidodo, 2019; Aruan, Pratikno and Hadiwidodo, 2023). Marine components must have high hardness to withstand abrasion from seawater (Ramandika *et al.*, 2022). In addition, these components must also have high corrosion resistance (Ridho and Rokhim, 2023). Meanwhile, some types of steel are less hard and not resistant to corrosion. Therefore, their hardness and corrosion resistance need to be raised. One method that can be used to improve the quality of steel is by conducting heat treatment (Sopiyan, Syamsuir and Nofendri, 2019; Sopiyan, Basori and Susetyo, 2020; Syaripuddin *et al.*, 2023; Sopiyan *et al.*, 2024).

Several researchers have improved the hardness properties of medium carbon steel by coating it with nickel phosphorus-graphene carbon nitride, nitriding, and heat treatment (Chen *et al.*, 2019; Arulvel *et al.*, 2023). Arulvel et al., coated nickel phosphorus-graphene carbon nitride on medium carbon steel using electroless plating to improve hardness and scratch resistance and found a higher hardness of about 711.23 HV (Arulvel *et al.*, 2023). Buku et al. performed nitriding on carbon steel and significantly reduce abrasion from 89.4 mm^3 to 53.3 mm^3 (Buku *et al.*, 2020). Prabowo and Sunyoto investigated heat treatment followed by cooling with oil and water, resulting in increased hardness of AISI 1010 steel (Prabowo and Sunyoto, 2020). Moreover, Prayitno and Indayanto investigated corrosion on medium carbon steel, when the steel was heat treated it increased its corrosion rate (Prayitno and Indayanto, 2021). However, in our previous study, heat treatment increased its corrosion resistance (Sopiyan *et al.*, 2024). Hence, this condition needs further investigation to be conducted.

Based on what has been explained above, one method that can be used to increase the hardness and corrosion resistance studied is heat treatment, followed by a quenching process. A higher quenching media cooling rate can produce higher material hardness properties due to the formation of martensite in the microstructure (Brito *et al.*, 2019; Chen, Nash and Zhang, 2019). Higher hardness could be reached in materials that form more martensite. On the contrary, lower hardness is found for specimens that form the austenite phase (Haryadi, Utomo and Ekaputra, 2021). Unfortunately, some cracks are often seen where the quenching media cooling rate is too fast.

In our previous study, samples quenched with oil cooling media had better corrosion resistance when compared to air (Sopiyan *et al.*, 2024). Sopiyan et al., found that corrosion rate is influenced by martensite fraction. The highest martensite leads to a reduced corrosion rate (Sopiyan *et al.*, 2024). Moreover, the cooling rate also influences the corrosion rate. Nikhil has found that a rapid cooling rate could decrease the corrosion rate due to the small surface area (Nikhil *et al.*, 2021). Moreover, Rachman and Sakti in their study, medium carbon steel was heated at 850 ºC, and quenched in various media such as air, oil, and water, produced a higher hardness when quenched in saline water of about 59.7 HRC (Rachman and Sakti, 2020). Lostari, heated SUP-9 steel at 860 ºC held it for about 60 minutes, and quenched it in various media such as air, oil, water, and saline water. A higher hardness of around 528 BHN was found in a sample that was quenched in water (Lostari, 2022). In contrast, Djuanda et al. found that the highest hardness could be reached when the AISI 1045 sample is quenched in saline water (Djuanda *et al.*, 2021).

NaCl concentration also could influence the hardness of samples (Wijaya and Rasyid, 2023). Syaifullah et al. have found that higher NaCl concentration promoting to resulting higher hardness (Syaifullah, Subhan and Juanda, 2021).

Based on several researcher findings, the effect of quenching medium resulted in different hardness in various steel. Therefore, in the present study heating samples at 850 ºC using an electric furnace, then held for 60 minutes and quenched in various media such as 5% NaCl, distilled water, and engine oil. Afterward, the quenched sample was investigated microstructure, hardness, and corrosion using an optical microscope, Vickers hardness tester, and weight loss method.

2. METHODOLOGY

2.1. Materials

The material that was used in the present study is cylinder-shaped medium carbon steel with composition presented in Table 1. Distilled water and SAE 10W-40 engine oil were used as quenching media. Commercial-grade NaCl was used for corrosive and quenching media.

Table 1. Chemical composition of medium carbon steel.

Element	Amount (wt.%)
C	0.39
Mn	0.83
Si	0.25
S	0.007
P	0.018
Mo	0.19
Cr	0.99
Cu	0.04
Fe	balance

2.2. Heat Treatment

Cylinder-shaped medium carbon steel was cut using a turning machine with dimension ∅ 20 × 20 mm (Figure 1). Then all samples were entered into the electric furnance Figure 2. The heating treatment process was set around 850 ºC and held for 60 minutes for all specimens (Lostari, 2022). After reaches time was set up then each sample was quenched in 5% NaCl (Q-S), distilled water (Q-W), and engine oil (Q-O) media until it reached room temperature. The volume of each medium used for quenching is 500 mL.

Figure 1. Cylinder-shaped medium carbon steel.

Figure 2. Electric furnace.

2.3. Material Characterization

All cut specimens were polished using sandpaper up to #5000, cleaning and drying. Then etching using Nital, cleaning, and drying. Afterwards, the etching samples were investigated using an optical microscope (Olympus BX51M) to capture the microstructure image.

The hardness test was conducted using the Vickers hardness test apparatus (FV 300e). Five repeatable measurements were conducted using 5 kg of load. The average hardness test was presented as hardness data. A complete hardness test apparatus can be seen in Figure 3.

Figure 3. Vickers hardness test apparatus.

Figure 4. Digital scale.

The corrosion test was conducted using the weight loss method. Each sample was covered using sealant and left one side open (3.14 cm²). Moreover, each sample was weighed using a digital scale (see Figure 4) and then each sample was immersed in 100 mL of 3.5% NaCl. After reaching 24 hours, samples were cleaned using water (smooth wipes using teeth brush), followed by alcohol, and dried using an electric dryer. Afterward, the specimen was weighed and immersed in 3.5% NaCl. A similar step was conducted for the next 24 hours until 96 hours from the beginning of the experiment. Corrosion rate was calculated using the following expression (Maitimu *et al.*, 2024):

$$CR = \frac{W.K}{D.A.T} \quad (1)$$

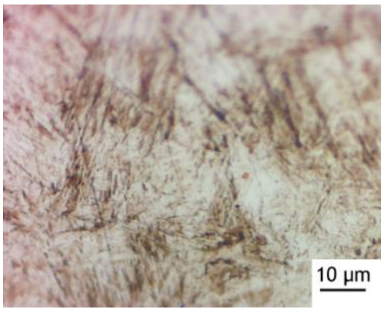
Where CR is corrosion rate (mpy), W is mass loss (g), K is Constant factor (mpy = 3.45×10^6), D is density of the alloy (g/cm³), A is exposure area (cm²), and T is time (hours).

3. RESULTS AND DISCUSSION

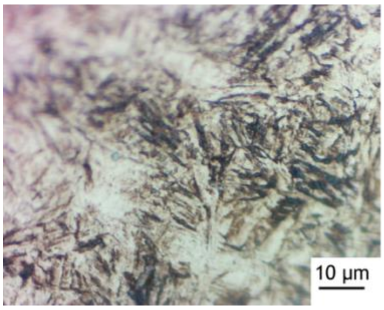
3.1. Microstructure

Olympus BX51M was used to capture the microstructure image after etching. Figure 5 presents the microstructure of various samples after quenching in various media (saline water, oil, and distilled water). The microstructure was captured using an optical microscope. Generally, martensite is seen on all samples, which shows in needle form. Besides martensite, ferrite (white area) is also seen on various samples. Less martensite is seen in the Q-O sample and randomly distributed. Sample Q-W shows martensite more than the Q-O sample and the Q-O sample presented martensite more distributed uniformly than the Q-S sample.

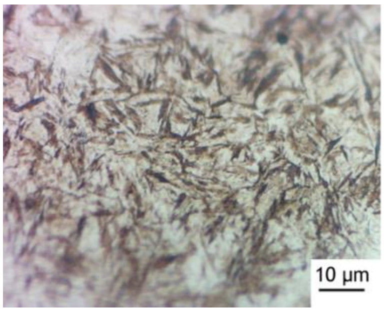
Martensite forms due to rapid cooling during the quenching process. Material that has more carbon content leads to forming more martensite (Lostari, 2022). Martensite is formed, from austenite phase transformation (Basori *et al.*, 2024). Saline water quenching and distilled water quenching resulting more martensite than oil quenching which perfect agreement with another study (Rachman and Sakti, 2020). Another reason is due to water has a higher cooling rate than oil (Chen, Nash and Zhang, 2019).



(a) Q-O



(b) Q-W



(c) Q-S

Figure 5. Microstructure of various samples.

3.2. Hardness

The hardness test was conducted using Vickers hardness test equipment. Five repeatable measurements were conducted using 5 kg of load. The average hardness test is presented in Figure 6.

According to Figure 6, higher hardness is seen in the sample where quenched in 5% NaCl. The lowest hardness is found in sample's that were quenched in engine oil. Hardness is strongly correlated to the microstructure where it was formed. Martensite is one of the phases that strongly influences the hardness of materials (Klemm-Toole *et al.*, 2019).

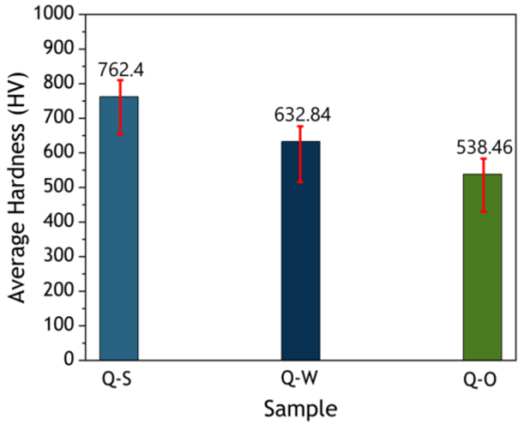


Figure 6. Average hardness of various samples.

Commonly higher hardness is seen in material that forms more martensite. On the contrary, lower hardness is found for specimens that form the austenite phase (Haryadi, Utomo and Ekaputra, 2021). Comparing Figure 6 with Figure 5, lower hardness due to less martensite where formed. The higher proportion of martensite makes hardness enhanced which perfectly agrees with another study (Prabowo and Sunyoto, 2020). Uniform martensite also could result in the highest hardness. Basori et al. have found longer holding time during heating affects the more uniform structure of martensite which contributed to resulting higher hardness (Basori *et al.*, 2024). Moreover, comparing our study to Lostari et al. is different. Higher hardness is found on sample were quenching in water due to different microstructure that formed with the present study (Lostari, 2022).

3.3. Corrosion

The corrosion test was conducted using the weight loss method. All samples were immersed in 3.5% NaCl and periodically weighed using a digital scale. The measurement result is presented in Figure 7.

At 24 hours of mass loss measurement, the Q-W and Q-O samples almost have similar behavior. Those samples result in higher mass loss than Q-S samples. Thus, indicating that samples easily form oxide in the surface. Different with Q-S sample is difficult to form oxide. Moreover, Q-W and Q-O have an almost linear mass loss until 96 hours of immersing time. While Q-S at 24 and 48 hours of immersing time is still difficult to oxidize. At 72 hours of measurement, the Q-S sample has a higher mass loss (around 0.029 g), which indicates the highest oxidation behavior. At the end measurement the highest mass loss is found in Q-O followed by Q-W and Q-S samples.

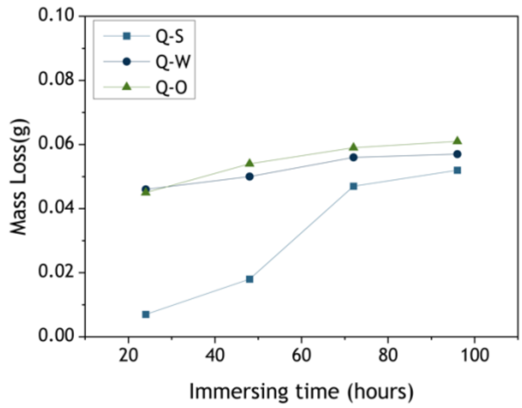


Figure 7. Mass loss of various samples.

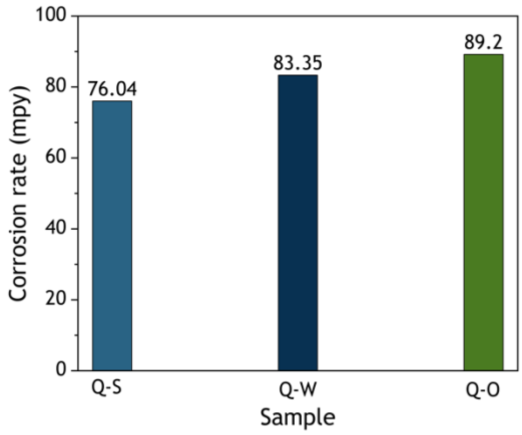


Figure 8. Corrosion rate of various samples.

The corrosion rate of various samples is presented in Figure 8. Corrosion rate was calculated using equation (1). Q-S. Q-W and Q-O samples have corrosion rates of 76.04, 83.35, and 89.2 mpy, respectively. A higher corrosion rate is found in the Q-O sample. The corrosion rate is influenced by martensite, the highest martensite leads to a reduced corrosion rate, which perfectly agrees with the present study (Sopiyan *et al.*, 2024). Moreover, the cooling rate also influences the corrosion rate. The rapid cooling rate could decrease the corrosion rate due to the small surface area (Nikhil *et al.*, 2021). The cooling rate of water is higher than engine oil, therefore sample's quenching in oil media has the highest corrosion rate.

4. CONCLUSION

Quenching of the medium carbon steel in various media has been well synthesized. A higher cooling rate results in more uniform and martensite than a lower cooling rate. While a lower cooling rate resulting less ununiform martensite. The sample where quenching in the 5% NaCl has the highest hardness and corrosion resistance due to more uniform martensite in the microstructure. That sample is suitable for marine components due to its hardness and corrosion resistance properties.

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