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MECHANICAL PROPERTIES OF STEEL AISI 1045 VARIATION OF AUSTENITIZATION HOLDING TIME IN THE QUENCHING-TEMPERING PROCESS WITH ICE WATER MEDIA

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Abstract

AISI 1045, Medium-carbon steel is commonly used as machining components like bulldozer bushings and widely used in construction equipment such as hammerheads. Hence, it needs good hardness and impact resistance. The methods to achieve these properties are through a heat treatment process called quenching and tempering. This research analyzed the effects of various austenitizing holding times during the quenching and tempering process on the microstructure, hardness, and impact strength of AISI 1045 steel. The procedure involved quenching the steel at a temperature of 850°C with austenitizing holding times of 5, 15, and 25 minutes, followed by rapid cooling using ice water. Subsequently, tempering was performed at 500°C with a holding time of 15 minutes, followed by air cooling. The research showed that all three test specimens exhibited bainite and martensite phases. The hardness of the steel increased after undergoing the quenching and tempering process, with the highest hardness value obtained at a 5-minute austenitizing holding time, measuring 32.37 HRC. Additionally, there was an increase in impact strength after the quenching and tempering process. Tobe found the highest impact strength value observed at with a 25-minute austenitizing holding time at 27.39 J/cm².

***Keywords**: Ice-water, Medium-carbon, Quenching, Tempering*

1. PENDAHULUAN

Carbon steel is one of the materials often used in the world of manufacturing, not only as the raw material of products but also as components in machines. Carbon steel is divided into 3 types, which depend on the amount of carbon mixture they owned. where the higher the carbon mixture, will affect mechanical properties possessed, such as strength, ductility, toughness, and hardness. Medium carbon steel is one of the most widely produced materials because it is easily modified and has ductile and tough properties[1]. One specific example is AISI 1045. AISI 1045 steel has a chemical composition of 0.45% C, 0.8% Mn, and 0.3% Si. This specification steel is widely used in machining components such as bushings on bulldozers[2] and construction equipment such as hammerhead drills[3].

Apart from its various uses, AISI 1045 steel still needs additional treatment before use to increase hardness and impact resistance with a heat treatment process, one of which

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is the hardening process[4, 5]. One of the factors in the hardening process determines its austenitization temperature and holding time. The hardening process was applied on AISI 1045 steel by using temperature of 830-850˚C[6, 7] and produces a stable austenite phase with the holding time of 5 - 15 minutes because the carbide dissolution process or time to homogenize is relatively fast[8] . The holding time of metal in the austenization process can be determined based on the thickness of the test piece[9].

The heat treatment method used is quenching. This process removes heat using intermediates such as water, oil, or salt water to produce an austenite phase that partially transforms to form a martensite structure[10]. The steel with medium carbon content quenched with cooling media and ice water (2 ℃) obtained the most optimal hardness[11]. However, this process makes the metal have high hardness properties and internal stress, making it prone to initial crack. To avoid this, tempering can be done[12]. The tempering process with a holding time of 15 minutes at 500 ℃ and with air cooling produced optimal results for the toughness and hardness of medium carbon steel that had been quenched[13].

Therefore, based on the above background, research will be conducted on the effect of variations in austenitization holding time in the quenching-tempering process on the mechanical properties of AISI 1045 steel. To obtain an optimal increase in mechanical properties, especially in the hardness and impact strength of AISI 1045 steel.

2. RESEARCH METHODS AND MATERIALS

The tools used in this study are divided into 3 equipment used. The first is specimen preparation equipment, namely grinding and gum. The second piece of equipment is equipment research in the form of a furnace and basin. The third piece of equipment is equipment for testing in the form of impact test equipment, hardness test with Zwick/Roell machine brand, and optical microscope with Zeiss machine brand. The materials used in this study include ice cubes as a cooling medium during quenching, sandpaper grade 80 - 2000 to flatten the surface of metallographic specimens, 3% nital as etching, AISI 1045 steel. This research was carried out in several stages as shown in Fig. 1, namely the preparation stage of research tools and materials.

The research and data collection stage are then carried out in the data processing stage. The AISI 1045 steel plates were cut and their dimensions were measured in the experimental material preparation stage. At the experimental stage, the heat treatment process, the AISI 1045 steel was heated on temperature of 850 ℃ with variation of holding time of 5, 15, and 25 minutes then cooled quickly by using ice water cooling media. Furthermore, the tempering process was applied on those AISI 1045 steel by reheating AISI 1045 steel that has been quenched using a temperature below its critical temperature at 500 °C with a holding time of 15 minutes and with air cooling media. In the data collection stage, several tests were carried out from the experimental stage in the form of hardness testing, impact testing, and metallography.

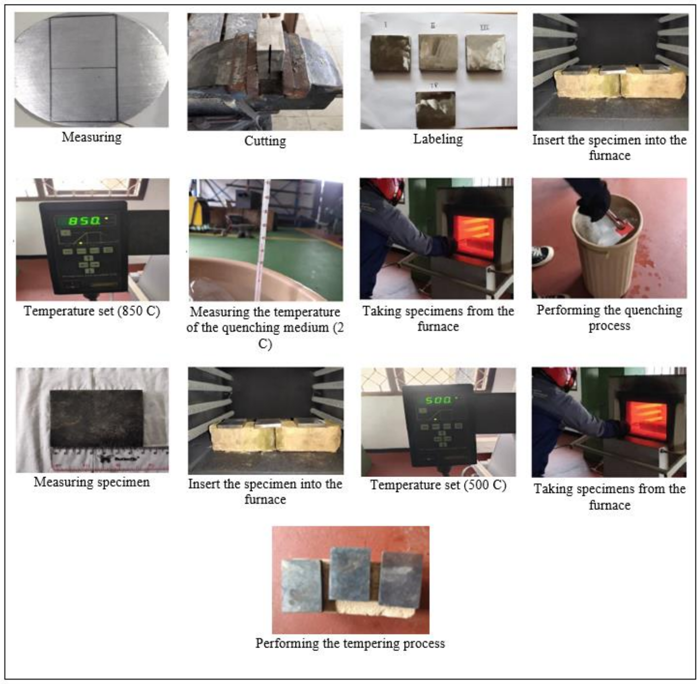

Figure 1. Methods steps

3. RESULTS AND DISCUSSION

3.1 Metallographic Test Results

The results of metallographic testing on AISI 1045 steel specimens without treatment can be seen in Fig. 2. Based on Fig 2, the metallographic testing of specimens without treatment with an optical microscope magnification of 100 times can be seen that the phases formed in the microstructure are ferrite and pearlite. Ferrite is shown with a light-colored area, while Pearlite is shown with a lamellar black color[14].

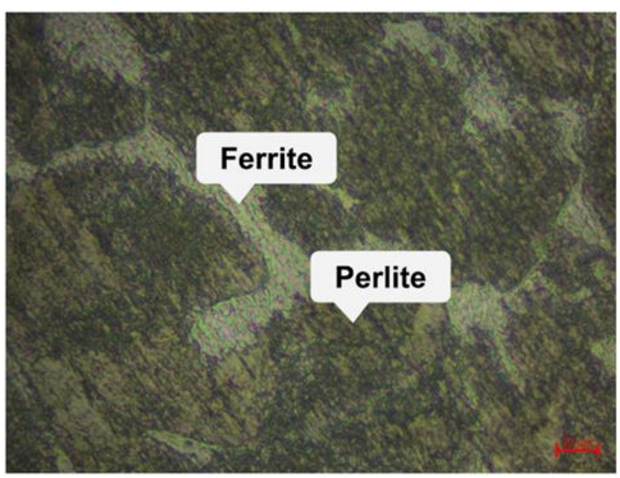

Figure 2. Metallographic Test Results of Untreated Specimens (10 µm Scale)

Based on the picture, pearlite is more dominant than ferrite. The higher the carbon content in steel, the more pearlite, and the less ferrite[15]. Pearlite is a structure consisting of intermittent ferrite and cementite lamellas, where ferrite is a solid solution with minimal solubility, so it is very soft and malleable. In contrast, cementite is a carbide compound that is very hard and brittle so pearlite will be more complex and stronger than ferrite, but it is not as strong as ferrite. It is also more brittle. Therefore, the higher the carbon content in the steel, the more complex and robust it will be, but it will also be more brittle.

From the results of metallographic in Fig. 3 testing on specimens Q 1, Q 2, and Q 3 that have gone through the quenching process with a heating temperature of 850˚C and with a holding time of 5 minutes, 15 minutes, and 25 minutes in Fig 3A to 3C, martensite and remaining austenite phases form in the three specimens. At a holding time of 5 minutes, Close observe that the martensite phase formed is still small with a dominant residual austenite phase, while at a holding time of 1 minutes and 25 minutes, we can see that the residual austenite phase formed is less dominated by martensite. The hardened steel will achieve maximum hardness when the structure is entirely martensite[15, 16].

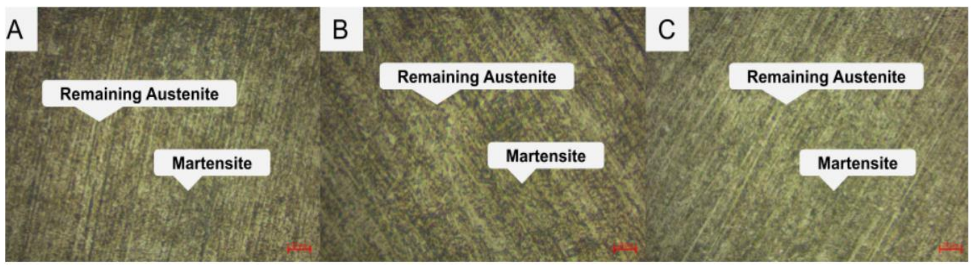

Figure 3. Metallographic Test Results of Quenching Specimens (A) Q1 5 min hold time, (B) Q2 15 min hold time, (C) Q3 25 min hold time (10 µm Scale)

Table 1. Phase Percentage Results (Quenching)

Speciment	Remaining Austenite Areas (%) (Bright)	Martensite Areas (%) (Dark)
Q 1	63,615	36,385
Q 2	59,587	40,587
Q 3	43,962	56,038

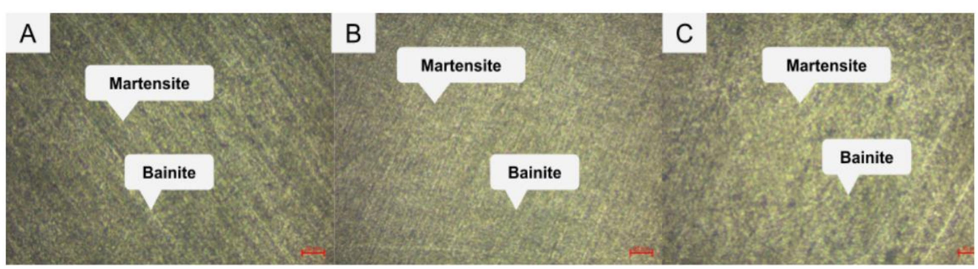

Figure 4. Metallographic Test Results of Quenching - Tempering Specimens (A) QT1 holding time 5 minutes, (B) QT2 holding time 15 minutes, (C) QT3 holding time 25 minutes (10 µm Scale)

Table 2. Phase Percentage Results (Quenching-Thempering)

Speciment	Bainite Areas (%) (Bright)	Martensite Areas (%) (Dark)
QT 1	54,122	45,878
QT 2	74,977	25,023
QT 3	87,175	12.825

As can be seen in Table 1 where it is clear that the percentage of the austenite phase decreases with the longer holding time given but is inversely proportional to the growing martensite phase. This is because the difference in holding time really affects forming a homogeneous phase, and making a small grain size, which results in a shorter holding time, will make the phase not homogeneous, and a small grain size which makes a phase that can transform into a martensite phase less, the same results are also obtained by previous studies[8, 17].

From the results of metallographic testing on specimens QT 1, QT 2, and QT 3 that have gone through the tempering process with a heating temperature of 500˚C and with a holding time of 15 minutes, Fig 4a to 4c show the presence of martensite and bainite phases formed in the three specimens, where QT 1 has more bainite followed by QT 2 and QT3. The martensite phase is characterized by a shape that resembles a blackish needle. However, the martensite phase produced after the tempering process differs from that produced after the quenching process. In the tempering process, martensite will undergo decomposition into ferrite and cementite or carbide particles where the ferrite phase itself is a phase that has ductile and soft properties while cementite or carbide has hard properties[15]. So, the martensite resulting from this tempering process has lower hardness properties than the martensite after the quenching process. Then martensite after the quenching process and is referred to as tempered martensite. In addition to the martensite phase, the bainite phase also formed. The phase formed due to the tempering process with a heating temperature of 500˚C, where during this stage, the austenite retained from the quenching process transformed into bainite[18]. Phase bainite is formed due to the tempering process with a temperature of 500 ˚C level of medium austenite that is retained from the quenching process and transforms into bainite. This can be seen in Table 2, with the longer holding time given will make a high bainite phase change as well.

3.2 Hardness Test Results

The results of hardness test data and discussion obtained in this study can be seen in Table 3. Based on Fig. 5, there is an increase in the hardness value of the specimen after going through the quenching-tempering process. In comparison, the specimen without treatment has a hardness value of 6.27 HRc. The increase in hardness value occurred in quenching-tempering with a variation of austenization holding time for 5 minutes, which became 32.37 HRc, followed by a 15-minute holding time of 31.17 HRc and a 25-minute holding time of 28.63 HRC.

The QT 1 specimen has a higher hardness value than the QT 2 and QT 3 specimens. This correlates with the resulting metallographic results where the QT 1 specimen has more bainite phases than the QT 2 and QT3 specimens, causing the QT 1 specimen to have a higher hardness value than the QT 2 and QT 3 specimens. The bainite structure is able to produce harder properties but does not exceed the hardness of martensite[18]. The hardness of bainite itself is caused because bainite is a mixture of carbide and ferrite, where the presence of carbide causes bainite to have hard properties but does not exceed the hardness of martensite.

Table 3. Hardness Test Results

Specimen	Section	HRC				
		1	2	3	Average	Standard Deviation
Untreated	Surface	5.8	4.8	8.2	6.26	1,23
QT 1	Surface	24.9	35.1	37.1	32.3	4,62
QT 2	Surface	27.2	33.4	32.9	31.1	2,43
QT 3	Surface	25.2	29	31.7	28.6	2,30

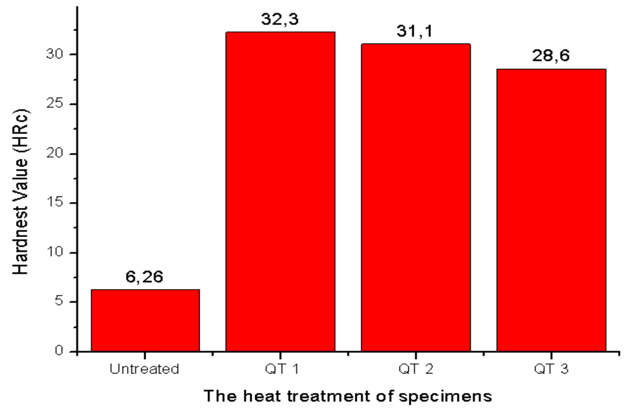

Figure 5. Hardness Test Result Graph

3.3 Impact Test Results

The results of the impact test data and the discussion obtained in this study are shown in Table 4. Based on Fig. 6, there is an increase in the impact strength of the specimen after going through the quenching-tempering process. The increase in impact strength occurs in specimens QT 1 (5 minutes), QT 2 (15 Minutes), and QT 3 (25 Minutes) and is influenced by variations in austenitization holding time and cooling media in the quenching-tempering process.

Table 4. Impact Test Results

Specimen	Impact Strength (J/cm^2)				Standard Deviation
	1	2	3	Average	
Untreated	13,12	8,07	16,37	12,52	3,41
QT 1	8,55	10,8	18,86	12,73	4,42
QT 2	24,77	24,92	21,86	23,85	1,4
QT 3	35,51	22,62	24,05	27,39	5,76

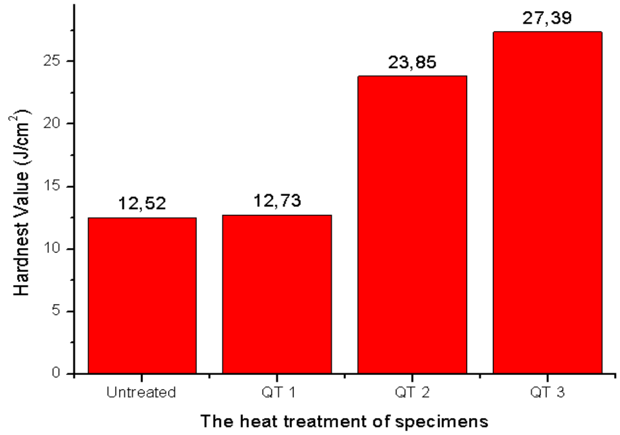

Figure 6. Graph of Impact Test Result

The highest impact strength was obtained after going through the quenching-tempering process with a variation of austenitization holding time for 25 minutes which amounted to 27.39 J/cm2, followed by a holding time of 15 minutes which amounted to 23.85 J/cm2 and a holding time of 5 minutes which amounted to 12.73 J/cm2, based on these data, there is a correlation with the hardness value produced in this study where the increase in austenitization holding time causes an increase in the impact strength of the specimen followed by a decrease in the resulting hardness (Fig 5). The tempering process is a stage of the steel hardening process where tempering itself functions to restore the toughness or ductility of the metal and eliminate internal stress after the hardening process[11]. The tempering process carried out in this study can increase the impact strength value of AISI 1045 steel. In addition, if the holding time in the austenitization process is given too long, the transformation that occurs during heating will be followed by grain growth which can reduce hardness and increase the toughness of the metal[16].

4. CONCLUSIONS

There have been extensive results that an effect of austenitization holding time and quenching with cold water is impacting the microstructure of AISI 1045 steel, which has been quenching-tempering that observe the presence of martensite and bainite phase. Also found that for optimum holding time for austenitization on hardness and impact strength is 15 minutes with 31.1 HRc and 23.85 J/cm2. Comparison for the hardness of the optimum holding time of materials is five times than does the non-treatment material, and double for the impact strength compared to the material without treatment. This indicates a significant performance improvement.

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