Effect of Salt quenching on the microstructures and mechanical properties of AISI 1045 steel

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Abstract. Steel has a very important role in the industrial applications, especially for the manufacture of automotive components such as gear. In its applications, gear undergoes the compressive and friction loads, so that in the manufacturing process, materials with high hardness and wear resistance are needed. One method to increase steel hardness is by quenching process. In this research, quenching process will be carried out on AISI 1045 steel using pure water and the salt solution as the cooling medium. The austenization process was conducted at a temperature of 850 °C with the holding time of 15 and 30 minutes. The samples were then quenched at the cooling medium of salt solution with concentration of 0, 10 and 23%. The results showed that the quenching process on AISI 1045 steel promotes the phase transformation from mixture of ferrite and pearlite to be martensite. The increase of austenization holding time and salt concentration level resulted in higher martensite intensity and hardness. In contrast, the increase of austenization holding time and salt concentration level resulted in lower toughness.

1. Introduction
AISI 1045 steel is the type of carbon steel with carbon content of 0.42-0.48%. This steel is widely used in the automotive industry as the raw materials of machine structures through the heat forming, rolling and forging. The product samples are gears, connecting rods, piston pins, axes, shafts, crankshafts, railroads and bearings [1,2]. In its applications, these components undergo a lot of pressure and friction so that the wear resistance are needed. The hardness and wear resistance of steel can be reached through heat treatment such as quenching [3]. The aim of this process is to produce the hard-martensitic structure and good wear resistance characteristic of steel. The wear resistance of steel can be increased by increasing its hardness through heat treatment process [4,5].

Cooling media is the crucial component on the quenching process which the media that are often used for quenching are water and salt solution. Water is used as a cooling medium because it can reduce the temperature quickly which is followed by a decrease in temperature inside the object [6]. On the other hand, salt (NaCl) can increase the cooling rate when dissolved in water. The higher the salt concentration, the faster the cooling rate and result in the increasing of steel hardness [7-9].

2. Method
The samples of AISI 1045 commercial steel with dimension of 55x10x10 mm³ were austenitized at temperature of 850 °C for 15 and 30 minutes in a muffle furnace and followed by quenching process with medium of pure and salt water with concentration level of 10 and 23 %. The nominal composition
of the AISI 1045 steel is shown in Table 1. Furthermore, the quenched samples were then characterized through microstructure analysis, hardness and impact test. 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 nital with the composition of 4 ml HNO3 and 96 ml of 95 % alcohol. The hardness and impact testing were conducted by Vickers and Charpy methods, respectively.

### Table 1. Nominal composition of the AISI 1045 steel (wt. %).

| C  | Si  | Mn  | P  | S  | Cr | Ni | Al | Ti | V  | Fe  |
|----|-----|-----|----|----|----|----|----|----|----|-----|
| 0.441 | 0.232 | 0.61 | 0.015 | 0.008 | 0.412 | 0.005 | 0.001 | 0.002 | 0.003 | Bal. |

3. Results and discussions

3.1. Microstructures

Figure 1 shows the microstructure of AISI 1045 steel before the quenching process wherein the phase is dominated by ferrite (white) and pearlite structures (black). Pearlite is a mixture of ferrite and cementite. On the other hand, Figure 2 shows the microstructure of AISI 1045 steel after austenization process at 850 °C for 15 and 30 minutes and followed by quenching at the medium of pure and salt water with concentration level of 10 and 23 %. Figure 2a shows the microstructure of sample after austenization process at temperature of 850 °C with a holding time of 15 minutes with quenching medium of pure water. This Figure describes the domination of martensite phase with a little bit ferrite remaining. This phenomenon shows that not all ferrite and pearlite phases change to be martensite. On the other hand, Figure 2b shows the sample with holding time of 30 minutes with the same cooling medium which the sample shows the same structure of martensite with the higher intensity due to the longer holding time.

Figure 2c and 2d show the microstructures of the samples after austenization process at temperature of 850 °C with a holding time of 15 and 30 minutes and cooling medium of salt water with 10% concentration level. It can be seen in the figures that the microstructures are dominated by martensite phases. The cooling medium of 10 % salt water promoted the formation of higher martensite phase intensity than that of pure water due to it has the higher cooling rate and resulted in more effective martensite transformation. Furthermore, Figure 2d and 2e show the microstructures of the samples with similar treatment but using the 23 % salt water as the cooling medium. These figure show that the samples have the highest intensity of martensite phase than previous treatments process.

The heating rate is an important factor during the heat treatment process. Heat propagates from the outside at a certain speed. When the heating holding time is too short, the samples outside will be much
hotter than the inside so that the structure is not homogeneous. The longer holding time is then carried out to make sure that all section of the samples have the same temperature and resulted in the homogeneous phase transformation. Martensite is produced from the transformation of austenite. At the very low temperatures of cooling media, austenite experiences the driving force to change from the FCC to the BCC which creates a shear force towards the atoms. This phenomenon promotes the atoms to shift slightly to form BCC. However, regarding in the austenite phase still have a lot of carbon and it cannot be diffused again due to very fast cooling time, so that the BCC structure cannot be reached. Further, it forming a new crystal structure as BCT [10,11]. The difference in the amount of martensite formed varies with the speed of the cooling rate. The faster the cooling rate, the faster the martensite formed during cooling process.

The Figure 2 also shows that the differences in cooling media and salt concentration level are followed by the difference of microstructure. From Figure 2a and 2b, it can be seen that the formed martensite is very smooth and a little bit ferrite is still remaining due to not all of austenite phase transform to be martensite during quenching process. Furthermore, Figure 2c and 2d show the higher intensity of martensite phase. These samples were quenched by the 10 % salt water as the cooling medium. Moreover, the Figure 2e and 2f show the highest intensity of martensite phase wherein these samples were quenched using the 23 % salt water. From this the phenomena, we can conclude that the higher the salt concentration level, the higher the intensity of martensite phase due to the higher of cooling rate. Salt water has the faster cooling rate than pure water due to it has a cooling rate of 1100 °C / s while pure water is 600 °C / s [12]. The higher the salt content in the water medium, the higher the martensite phase and resulted in the higher hardness [7].

**Figure 2.** Micrographs of AISI 1045 steel after austenization process at 850 °C for (a, c, e) 15 minutes (b, d, f) 30 minutes followed by quenching process at the medium of (a, b) pure water (c, d) salt 10 % (e, f) salt 23%.
3.2. Mechanical properties

Figure 3 describes the hardness of the samples with different holding time and cooling media. The figure shows that the quenching process promotes the increase of hardness samples due to the phase transformation from the mixture of ferrite and pearlite to be martensite. On the other hand, the increase of austenization holding time and the salt concentration level have also significantly increase the samples hardness too. Martensite phase with the crystal structure of BCT has the complicated atom formation and results in harder dislocation movement [11]. The highest hardness occurs at the sample with the holding time of 30 minutes followed by quenching process with 23 % salt water as the cooling medium of 356.28 VHN. On the other hand, the raw material of AISI 1045 steel has the lowest hardness of 91.8 VHN. The longer holding time promotes the more complete martensite phase transformation. Furthermore, the higher salt concentration level tends to increase the cooling rate and resulted in the higher intensity of martensite phase and hardness.

![Figure 3. The hardness change of AISI 1045 steel after quenching process.](image)

Figure 4 shows the toughness distribution of AISI 1045 after the heat treatment process with different holding time and the cooling media. The quenching process tend to decrease the samples toughness. The increase of austenization holding time and the level of salt concentration have also affect to the toughness decrease. The AISI 1045 steel with no treatment has the highest toughness of 0.46 J / mm².
In contrast, the sample with the lowest toughness occur at the sample with the holding time of 30 minutes followed by quenching process with 23 % salt water as the cooling medium of 0.056 J / mm2.

4. Conclusion
The result of the observation can be concluded as follows:
- The quenching process on the AISI 1045 steel promote the phase transformation from mixture of ferrite and pearlite to be martensite.
- The increase of austenization holding time and the salt concentration level resulted in the higher martensite intensity. The longer holding time promote the more complete phase transformation. On the other hand, the increase of salt concentration level stimulates the higher cooling rate.
- The increase of holding time and salt concentration level tend to increase the hardness. The highest hardness occurs at the sample with holding time of 30 minutes and 23 % salt concentration level of 356,28 VHN. In contrast, the value of toughness tends to decrease with the increase of holding time and salt concentration level. The lowest toughness occurs at the sample with holding time of 30 minutes and 23 % salt concentration level of 0.056 J / mm².

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