Effect of Quenching on the Mechanical Properties of Carbon Steel for Hammer Mill

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Abstract. This paper covers the effect of quenching on the mechanical properties of high carbon steel for hammer mill. The main objective of this study is to investigate the mechanical properties and microstructure of high carbon steel before and after heat treatment (i.e., quenching). In this study, the specimens were heated at different level temperature which are 750 °C, 800 °C and 900 °C prior to quenching process in water with soaking time of 5 minutes. After the heat treatment of quenching process completed, Rockwell hardness test and tensile test were performed, and the results were collected for both untreated and heat-treated specimens. The fractured surfaces of the specimens were also examined by using metallurgical microscope. It was observed that different level of quenching temperature and untreated specimens gave different mechanical properties. The specimen undergone water quenching recorded the highest hardness and tensile strength as 67.9 HRA and 426.11 MPa, respectively. Besides, the microstructure obtained from untreated specimen provided a good combination of ferrite and pearlite, meanwhile in quenched specimens formation of martensite was observed.

1. Introduction

Hammer mill is a particle size reduction equipment that is widely used in the mineral mining industry. It consists of a series of hammers with four or more hinged on a central shaft and enclosed in a metal case. The working principle of hammer mill is to produce size reduction by impact. Objects are struck by rectangular pieces of hardened steel, or hammer which rotates at high speed inside the chamber. The common material for hammer is mild steel or also known as carbon steel. During the operating of hammer mill, the hammers subjected to high impact for crushing the particles into smaller size. The continuous impact energy on hammers in hammer mill shorten the lifespan of hammers.

Operating conditions for hammer mills are difficult to control and their lifespan are short. The operating temperature during daytime would be higher than that during nighttime. Hammer mill must endure the temperature changes during its operating hours. There are a lot of studies that report the effects of heat treatment such as quenching to mechanical properties of carbon steel [1-4]. However, very limited literature can be found in investigating the mechanical properties and microstructure of hammer mill after heat treatment of quenching.

The main objective of this study is to investigate the mechanical properties and microstructure of high carbon steel for hammer mill before and after heat treatment of quenching.
2. Research Methodology

2.1. Materials and Methods
In this study, the material of interest in quenching process is specimen of high carbon steel. The chemical composition of high carbon steel was determined using metal composition analysis and their results are listed in Table 1. The heat treatment of quenching process is listed in Table 2.

| Specimen | Heat treatment | Temperature | Quenching time | Cooling medium |
|----------|----------------|-------------|----------------|----------------|
| A1       | Untreated      | -           | -              | -              |
| B1, B2, B3| Quenching     | 750 °C      | 5              | Water          |
| C1, C2, C3| Quenching     | 800 °C      | 5              | Water          |
| D1, D2, D3| Quenching     | 900°C       | 5              | Water          |

2.2. Specimen Preparation and Mechanical Tests
The high carbon steel specimens were cut into dumbbell shaped using electrical discharge machine (EDM) wire cut, following the standard ASTM E8 with gauge length four times the diameter. Three specimens were prepared for each condition. For heat treatment, all specimens were heat treated in an electrical furnace at pre-set temperature. There are three quenching temperatures used for the specimens testing which are 750°C, 800°C and 900°C. After the temperature reached the pre-set temperature, the specimens were rapidly quenched into water for 5 minutes.

Initially, the hardness level of each specimen was measured by using Rockwell hardness tester before quenching treatment, as it is easy to compare the state after heat treated. After completion of quenching process, the hardness of heat-treated specimens was measured. Next, all specimens were tensile tested by using SHIMADZU AG-IS MS 250kN universal testing machine. From this test, yield strength, ultimate tensile strength, elongation and Young’s modulus were determined.

![Dumbbell shaped specimens according to ASTM E8.](image)
3. Results and Discussions

3.1. Effect of quenching on the mechanical properties

The experimental results show some differences between mechanical properties of the specimens before and after quenching. There are some improvements in mechanical properties of the heat treatment specimens compared to non-heat treatment specimen. Figure 2 shows the average hardness of heat treated and untreated specimens. Based on the data, the highest quenching temperature specimens of 900°C shows the highest hardness level of 67.9 HRA when compared to 750°C heat treated specimens shows hardness level of only 50.8 HRA, and 800°C heat treated specimens shows modest hardness level of 52.1 HRA. However, the hardness level for non-heat treatment specimens remains the lowest compared to heat treatment specimens.

The results of mechanical properties of heat treatment specimens at different temperatures gives different values compared to the untreated specimen’s properties. Figure 3 shows the average tensile strength recorded where the lowest tensile strength value is 188.56 MPa for the untreated specimen while for heat treated specimens are high values for tensile strength which are 194.18 MPa for 750°C, 246.12 MPa for 800°C and the highest value of 426.11 MPa. This result indicates that tensile strength is directly proportional to the quenching temperature, higher temperature gives higher tensile strength and hardness value as it may due to the formation of martensite structure.

Figure 4 shows the average yield strength for heat treated and non-heat treated, the yield strength is higher for untreated specimens which is 110.23 MPa, then it is significantly decreases gradually when the quenching temperature increases which are 91.27 MPa for 750°C, 48.17 MPa for 800°C and 31.46 MPa for 900°C. The subsequent rise in temperature gives lower yield strength is due to rearrangement of grain for strengthening phase.

Figure 5 shows the average of Young’s modulus for heat treated and non-heat treated. Based on the data, the Young’s modulus decreases as the quenching temperature increases, which are 8824.18 MPa for untreated specimens while for heat treated specimens are 8718.18 MPa for 750°C, 6440.32 MPa for 800°C and 6344.11 MPa for 900°C.

Figure 6 shows the average of an elongation percentage of heat-treated and untreated specimens, it increases as the temperature increases which is 2.207% for non-heat-treated specimen while for heat treated specimens are 2.259% for 750°C, 3.957% for 800°C and 6.720% for 900°C which it may due to the tempered martensite carbon content concentration reduction. The effect of quenching on the mechanical properties was clearly shown through the obtained results as summarized in Table 3. This is consistent with the findings reported elsewhere that hardness of specimens increased after undergone water quenching [2].

![FIGURE 2. The average hardness of treated and non-treated specimens](image-url)
FIGURE 3. The average tensile strength of treated and non-treated specimens.

FIGURE 4. The average yield strength of treated and non-treated specimens.
The mechanical properties (tensile strength, yield strength, young’s modulus, percentage elongation and hardness) of carbon steels obtained in this study is summarized in Table 3.

| Specimen | Heat treatment | Tensile strength (MPa) | Yield strength (MPa) | Young’s modulus (MPa) | Percentage elongation (%) | Hardness (HRA) |
|----------|----------------|------------------------|----------------------|-----------------------|--------------------------|----------------|
| A1       | Untreated      | 188.56                 | 110.23               | 8824.18               | 2.207                    | 46.8           |
| B1,B2,B3 | 750 °C         | 194.18                 | 91.27                | 8718.78               | 2.259                    | 50.8           |
| C1,C2,C3 | 800 °C         | 246.12                 | 48.17                | 6440.32               | 3.957                    | 52.8           |
| D1,D2,D3 | 900 °C         | 426.11                 | 31.46                | 6344.11               | 6.720                    | 67.9           |
FIGURE 7. Tensile strength vs Hardness.

FIGURE 8. Young’s modulus vs Hardness

FIGURE 9. Elongation vs Hardness
3.2. Effect of heat treatment on microstructure

The specimens of before and after heat treatment were cut into small to investigate the microstructure changes, then the specimens were carefully polished and etched to study the microstructure behavior. The combination of ferrite in white and pearlite in black can be observed in the microstructure of specimens before heat treatment. However, fine needle structure which is known as martensite could be seen in the specimens after heat treatment. Figures 10 and 11 show the microstructure of the specimen.

4. Conclusions

The aim of the research is to investigate and test the mechanical properties (ultimate tensile strength, Young’s modulus, yield strength, percentage elongation) and hardness before and after heat treatment (quenching) of high carbon steel for hammer mill application.

- The hardness increased as the heat treatment temperature increased.
- The heat treatment process has effect on the mechanical properties and microstructure. The tensile strength and elongation percentage of the heat treatment specimens increases while the yield strength and young’s modulus decrease with the increase of temperature compared to non-heat treatment specimens
- The combination of ferrite and martensite were observed before heat treatment while after heat treatment process, martensite structure was observed.

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