

Analysis of Steel Hardness on Crowbars in the Hardening Process with Variations of Cooling Media

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ABSTRACT

The steel hardening process through hardening aims to improve the hardness of steel by rapid heating and cooling. The refrigerant media used, such as brine, plain water, and oil, have a significant influence on the hardness of steel. This study aims to analyze the effect of refrigerant media variations on steel hardness after the hardening process. The research method used is a laboratory experiment, in which the steel specimen is heated to an austenitization temperature and cooled with three different cooling media. The hardness of the steel was tested using the Rockwell hardness test, and the microstructure results were analyzed with a metallographic microscope. The gap of this study is the lack of studies related to the influence of refrigerant media variations on steel hardness with a focus on application to crowbars. The results showed that the brine medium provided the highest hardness (98.7 kgf/mm²), followed by ordinary water (98.1 kgf/mm²) and oil (96.2 kgf/mm²). These results suggest that faster refrigerant media, such as brine, produce higher hardness. This study provides insight into the selection of the optimal refrigerant media to increase steel hardness, especially in industrial applications that require hard and durable steel.

INTRODUCTION

Steel is one of the most widely used materials in various industrial sectors, such as automotive, construction, and heavy equipment, due to its superior mechanical properties, such as high strength, resistance to wear, and resistance to extreme temperatures. However, for certain applications, the hardness of the steel needs to be increased so that the material can function optimally. The process of hardening steel or hardening is one of the techniques used to increase the hardness of steel. This process is done by heating the steel to a certain temperature and then cooling it quickly in different types of cooling media, which has a significant influence on the mechanical properties of the material. The desired result of this process is a high increase in hardness without drastically sacrificing the durability or ductility of the material.

The hardening process consists of two main stages: heating and cooling. In the heating stage, the steel is heated to a temperature high enough to convert the microstructure into an austenite phase. Furthermore, the steel is rapidly cooled through a quenching process to prevent transformation into softer microstructures, such as pearlite or ferrite. This cooling process is carried out using a variety of cooling media, such as plain water, salt water, or oil, each of which has a different cooling rate and characteristics. The selection of the right cooling medium will affect the final result of steel hardening, especially on the hardness obtained (Junaidi, 2019).

Salt water, for example, has a higher cooling rate than regular water, which can produce martensite – very hard microstructures. However, the use of salt water has the potential to cause corrosion in the steel, especially if the steel is not treated properly after the hardening process. On the other hand, oil has a slower cooling rate, resulting in a more stable microstructure but with a lower level of hardness compared to the use of water or brine. Therefore, the selection of the refrigerant medium depends largely on the purpose of the application and the desired properties of the steel after the hardening process (Sinaga et al., 2024).

Steel hardness testing after the hardening process is one of the main indicators in assessing the success of the process. The hardness of steel can be measured using a variety of methods, such as the Brinell, Vickers, or Rockwell hardness test, which provides an objective picture of the change in the mechanical properties of the steel after heat treatment. The results of this test will depend on the cooling speed applied during the quenching process and the type of cooling medium used.

Although many studies have examined the effect of the hardening process on the mechanical properties of steel, few studies have directly compared the effect of refrigerant variations on the hardness of steel under the same conditions. This study aims to fill the gap by analyzing the influence of various variations of cooling media, namely ordinary water, salt water, and oil, on the hardness of steel after the hardening process. It is hoped that the results of this study can provide new insights in the selection of the right refrigerant media to improve steel hardness and its application in industry.

In addition, this research is expected to contribute to the development of more efficient steel hardening techniques, as well as support the manufacturing

industry in selecting the right material based on the required mechanical properties, including hardness, wear resistance, and ductility. By understanding the influence of refrigerant media on these properties, the industry can produce steel that is of higher quality and tailored to the specific needs of each application.

LITERATURE REVIEW

Steel Hardening Process

Hardening or hardening steel is a heat treatment process that aims to increase the hardness of steel by heating the steel to a certain temperature, then cooling it quickly. This process transforms the microstructure of steel into martensitic, which has high hardness but is brittle. The hardening process is greatly affected by the carbon content in the steel, which determines the ability of the steel to form martensitic during the quenching process. The hardening process consists of two main stages, namely heating and cooling. Heating aims to achieve austenite conditions on the steel, which is then cooled with a cooling medium to obtain a martensitic structure (Sutowo & Susilo, 2013).

Martensitic

Martensitic is formed when steel that has been heated to an austenitizing temperature is cooled rapidly (quenching). The rapid cooling process inhibits the diffusion of carbon atoms out of the crystal lattice, resulting in the formation of martensitic structures. Martensitic has high hardness, but it tends to be brittle and less reliable in applications that require toughness. The structure of martens depends on the cooling rate and carbon composition in the steel, where the higher the carbon content, the more martensitic is formed, significantly increasing the hardness of the steel (Septianto & Setiyorini, 2016).

Cooling and Hardening Media

The refrigerant media plays an important role in the hardening process because the cooling speed affects the microstructure that is formed. The common refrigerant used in the hardening process is water, brine, and oil. Ordinary water provides a fast-cooling rate, which causes the steel to quickly reach the martensitic structure. Salt water has a faster cooling rate than regular water, but it can cause corrosion in the steel. Oil, on the other hand, provides a slower cooling rate, which results in a more stable structure but with lower hardness (Handoyo, 2015). The choice of refrigerant media must be based on the application needs and desired properties of the steel.

Effect of Refrigerant Media on Steel Hardness

The variation of the refrigerant media has a significant effect on the hardness of the steel produced. The brine cooled specimen showed the highest hardness, reaching 98.7 kgf/mm², followed by water and oil media with a hardness of 98.1 kgf/mm² and 96.2 kgf/mm², respectively. The use of brine as a refrigerant medium has a higher cooling rate compared to ordinary water, which results in more martensitic formation and higher hardness. However, the use of salt water also increases the potential for corrosion in the steel, which needs to be considered in its selection.

Principle and Importance of Testing To hardness is a method used to assess changes in the mechanical properties of steel after the hardening process. Some commonly used hardness testing methods are the Brinell, Vickers, and Rockwell hardness tests. The Rockwell method is one of the most used because it provides fast and reliable results. The results of the hardness test provide an overview of the material's resistance to penetration, which is an important indicator in determining the quality and resistance of steel to wear and load received (Handoyo, 2015).

METHODOLOGY

This study aims to analyze the influence of refrigerant media variations on steel hardness after the hardening process, focusing on the steel used in the manufacture of crowbars. The research was carried out through a series of stages that included material preparation, hardening process, hardness test, and analysis of test results to determine the effect of cooling media on steel hardness (Irfan Syahroni, 2022).

Type of Research

This study uses a laboratory experimental method, in which the steel is processed with various cooling media and tested to measure the change in hardness after the hardening process. This research is quantitative descriptive, where the data obtained is in the form of steel hardness measurement results which will be analyzed statistically to see the influence of the cooling medium.

Materials and Tools

Material: Steel with a chemical composition suitable for crowbar applications.

Tool:

Furnace for heating steel (heating furnace) that can reach austenitization temperature.

A quenching bath that is equipped with cooling media such as plain water, salt water, and oil.

Rockwell hardness testing machine to measure the hardness level of the material.

Metallurgical microscope to analyze the microstructure of steel.

Research Stages

a. Sample Preparation

The steel used is cut into crowbar-shaped specimens of standard size. Specimens are tested first to determine their initial hardness conditions before further processing.

b. Heating Process (Austenitization)

The steel specimen is heated in a furnace until it reaches an austenitization temperature, around 800–900°C, to convert the microstructure into austenite. The duration of heating is adjusted to the thickness of the specimen to ensure that the entire material reaches an even temperature.

c. Quenching Process

After heating, the steel specimen is then cooled with various cooling media. The three variations of refrigerant media used are:

Plain Water: Cooling medium with a fast-cooling rate.

Brine: A cooling medium with a faster cooling rate than regular water.

Oil: A cooling medium with a slower cooling rate, resulting in a more stable microstructure.

The quenching process is performed at the same time and with the same volume of each medium to ensure consistent results.

d. Hardness Testing

After the quenching process, the specimen is tested using the Rockwell hardness test method to measure the hardness on the steel surface. Hardness tests are performed at several points on each specimen to obtain an average hardness and see the distribution of hardness results on each cooling medium.

e. Microstructure Analysis

Several samples of steel that have been processed are tested using a metallographic microscope to analyze the microstructures formed after the hardening process. This analysis aims to ensure that martensitic is well formed and to identify potential other structures that form because of variations in the refrigerant media.

Data Collection Techniques

Hardness Testing: Hardness test results are recorded in Rockwell units (HRC) for each specimen and each variation of refrigerant media.

Microstructure Analysis: Steel samples are cut and polished for observation under a metallographic microscope, then images of microstructures are analyzed to determine the type of structure formed (martensitic, bainite, pearlite).

Visual Observation: After the cooling process, visual observations are made to ensure that no defects or damage occur to the steel specimen due to the quenching process (Ardiansyah et al., 2023).

RESEARCH RESULT

In this study, steel hardness testing after the hardening process was carried out with a variety of cooling media, namely salt water, plain water, and oil. The test results showed that the specimen cooled with brine medium had the highest average hardness, which was 98.7 kgf/mm², with a hardness value range between 95.9 kgf/mm² to 101.5 kgf/mm². These results show that the brine medium provides the fastest cooling rate, resulting in a martensitic structure with higher hardness than other refrigerant media. Testing on three specimens with brine media showed that two of them were in the same hardness range, with a relative test error of 0.94%.

In contrast, specimens cooled using plain water showed an average hardness result of 98.1 kgf/mm², with a range between 96.9 kgf/mm² to 99.3 kgf/mm². Although slightly inferior compared to the use of salt water, ordinary water still produces high hardness and shows its effectiveness in the hardening process. As for oil-cooled specimens, the test results showed an average hardness of 96.2 kgf/mm², with a range between 94.5 kgf/mm² to 98.0 kgf/mm². This result is lower compared to the use of salt water and regular water, which can be explained by the slower rate of oil cooling. Figure 1 shows a graph image of a hardness comparison.

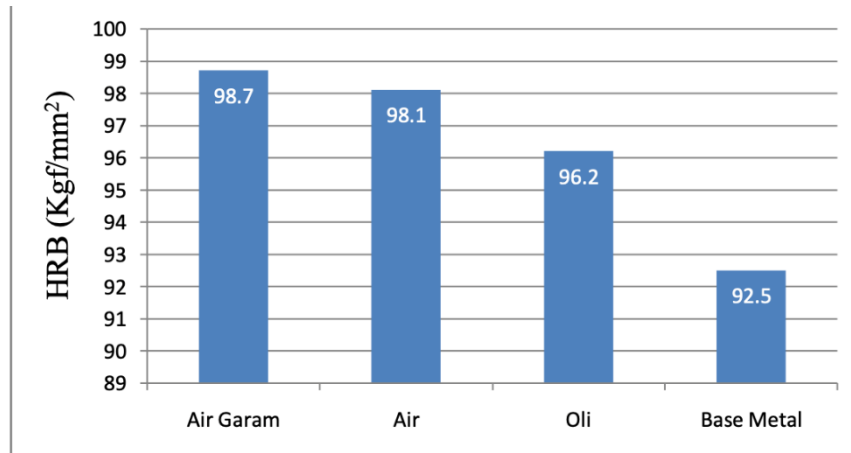


Figure 1. Violence Comparison Chart

In comparison, specimens that did not undergo hardening showed an average hardness of 92.5 kgf/mm², which was lower than that of specimens that had undergone hardening using cooling media. This shows that the hardening process with a variety of refrigerant media can significantly increase the hardness of the steel, especially with the use of salt water which has the fastest cooling rate.

DISCUSSION

Based on the results of the tests carried out, the cooling medium affects the hardness of the steel processed by the hardening method. The brine cooling medium produces the highest hardness compared to ordinary water and oil. Brine-cooled specimens have an average hardness of 98.7 kgf/mm², while plain water produces a hardness of 98.1 kgf/mm², and oil yields only 96.2 kgf/mm². This is in accordance with the theory that a cooling medium with a faster cooling rate will produce more martensitic structure, which in turn increases the hardness of the steel (Brandt, 2020) The hardness of the oil medium can be explained by the slower cooling rate. Oil, as a refrigerant medium, cannot cool steel as quickly as water or brine, so less martensite is formed and the microstructure is more stable but with lower hardness. In addition to providing additional protection on the steel surface which can reduce the cooling rate. The same thing is also in line with the previous article which stated that the variety of refrigerant media has a significant influence on the microstructure and hardness of steel. In their study, the use of salt water as a cooling medium

resulted in higher hardness due to the faster cooling rate compared to other media (Surdiya, 2015).

Meanwhile, the lower in the non-hardening comparator specimens, i.e. a hardness of 92.5 kgf/mm², indicates that without the hardening process, the steel cannot achieve the optimal level of hardness. This indicates the importance of heat treatment in improving the mechanical properties of steel, particularly in applications that require high hardness.

Overall, this study confirms that the refrigerant media used in the hardening process plays an important role in determining the hardness of steel. Therefore, the selection of the right refrigerant media depends largely on the application needs and the desired steel specifications. Further research can be conducted to see how these refrigerant media affect other mechanical properties such as the toughness and ductility of steel, as well as to explore more efficient refrigerant alternatives.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study on the influence of refrigerant media variations on steel hardness in the hardening process, it can be concluded that the refrigerant media plays an important role in determining the level of steel hardness produced. The results showed that the specimen cooled with brine medium gave the highest hardness, which was 98.7 kgf/mm², followed by ordinary water which had an average hardness of 98.1 kgf/mm², and oil with an average hardness of 96.2 kgf/mm². The brine medium has a faster cooling rate compared with ordinary water and oil, which produces more martensitic structure and improves the hardness of the steel. In contrast, oil provides a slower cooling rate, resulting in a more stable microstructure but with lower hardness. The specimen that was not processed through hardening had a hardness of 92.5 kgf/mm², which indicates that the hardening process through a variety of refrigerant media significantly increases the hardness of the steel.

Based on the results of this study, it is recommended that industries that require high-hardness steel consider the use of brine as a cooling medium in the hardening process. This is because salt water has a faster cooling rate compared to ordinary water and oil, resulting in higher hardness. However, it should be noted that the use of brine can increase the corrosion potential of steel, so corrosion prevention measures need to be applied to steels processed using this medium.

ADVANCED RESEARCH

In addition, it is recommended to conduct further research involving variations of other refrigerant media, such as mixtures of water and certain chemicals or special oils, to obtain more optimal results in terms of steel hardness. Further research should also pay attention to other mechanical properties, such as toughness and ductility, to obtain steel materials with more balanced and reliable properties for various industrial applications.

For a more effective hardening process, it is recommended that the heating temperature and cooling time be adjusted to the thickness and composition of

the steel, so that the desired microstructure, especially martensitic, can be optimally formed. This will improve the quality and durability of steel, especially in heavy equipment, automotive, and mining industry applications that require high hardness and wear resistance.

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