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THE EFFECT OF QUENCHING AND HOLDING TIME ON WHITE CAST IRON MATERIAL PROPERTIES APPLIED TO GRINDING BALLS ON BALL MILLS FOR CEMENT PRODUCTION

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Abstract

Indonesia has several cement factories to meet domestic needs and for export. Until the last decade, cement demand has continued to increase but also cement prices have continued to increase. One of the reasons is that all cement factories in Indonesia still use imported grinding balls, causing the procurement costs to be still expensive. Every cement factory requires a large number of grinding balls. If the grinding ball can be made in Indonesia, it is expected that the price will be cheaper so that the cement production cost can be reduced. A grinding ball is one of the media for grinding minerals/ore in a ball mill. The grinding ball is made of white cast iron which has the characteristics of high hardness, wear resistance, toughness, corrosion resistance, and high-temperature resistance to withstand the load and the environment during the rock grinding process. To have a lower price, low-chromium White Cast Iron material for the manufacture of grinding balls is heat-treated with the quenching method at 850ºC with 15 minutes of holding time to obtain the same hardness as imported grinding balls. As a result, the hardness value is 636 HB with an Impact test result of 2.3 J/mm^2.

Keywords: Grinding ball, Hardness, Holding time, Low-cost, Quenching, White cast iron.

1. Introduction

Cement is one of the main materials for civil construction [1, 2]. Indonesia's cement production is not only to meet domestic cement needs but also to meet export demands. The increasing demand for cement must be anticipated by the cement industry in line with the continuous increase in production costs due to the increase in the electricity consumption cost and domestic fuel prices which are not comparable to the increase in the selling price of cement in the market. The relatively high increase in production costs has a direct impact on the increase in cement prices in the market, so it is necessary to increase efficiency in all lines, especially in the production process so that the selling price of cement can remain affordable for domestic consumers and can compete with cement products from abroad. Efficiency can be done, among others, by increasing local components in the cement manufacturing process, including the use of Ball Mills in various equipment in cement factories, such as Crushers and Cement Mills [3]. Indonesia has several cement factories to meet domestic cement needs and for export. Cement exports are one of the sectors that provide large non-oil and gas foreign exchange. Until the last decade, the demand for cement by the market has continued to increase but also the price of cement has continued to rise. This is partly because all cement factories in Indonesia still use imported grinding balls, including from the United Kingdom, Japan, and Belgium, causing the procurement costs to be still expensive. Each cement factory requires grinding balls in large quantities, so it requires a large amount of money to procure.

Grinding ball is one of the mineral grinding media in the ball mill which aims to grind the ore into a fine powder so that the valuable minerals can be liberated. The replacement volume of grinding balls by cement factories in Indonesia reaches thousands of tons a year. Data on the use of grinding balls installed in one of the cement factories in Indonesia reached 5,700 tons with a turnover volume of 1,700 tons per year. The very large volumes all come from imports at relatively high prices, thus requiring a very large price to purchase these products. If the grinding ball can be made in Indonesia, it is hoped that the price will be cheaper so that cement production costs can be lowered, cement prices are more affordable, and people's welfare can be improved [4]. Until now, the cement industry's needs for grinding balls are still completely dependent on imported grinding ball products. To overcome this, there is a need for a breakthrough by researching one type of material that meets the standards to be used as grinding ball material, which is expected to later obtain local grinding ball products that have a better quality than imported products. The quality of grinding balls is important in the cement industry because if there is an early failure it will have an impact on reducing production capacity due to the non-operation of the ball mill machine due to the grinding ball replacement process, and this causes the operating costs to be very expensive [5].

Generally, grinding balls are made of white cast iron which is required to have the characteristics of being hard, wear-resistant as well as tough and corrosion-resistant, and resistant to high temperatures to bear the load and the environment during the rock grinding process [6]. Improvements to the quality of grinding ball products can be done through the selection of appropriate materials and the use of several alloying elements that can improve the mechanical properties of the grinding balls, such as Chromium (Cr), Molybdenum (Mo), Vanadium (V), and Boron (B), in which these elements are very strong carbide-forming alloying elements (primary, eutectic, and secondary carbide), to increase the hardness and frictional resistance of iron/steel materials. In addition, the improvement of mechanical properties in the form of a combination of good toughness and hardness of the grinding ball material can also be carried out through a series of heat treatment methods to obtain a martensite structure, secondary carbide, and a little amount of residual austenite [6].

Almost all high chromium cast irons used for abrasion resistance are hypo-eutectic alloys containing 10-30% Cr and 2-3.5% Carbon (C). Alloys containing 12% Cr are the cheapest, but 18-22% is the most popular range, for general abrasion resistance such as rollers and tables in grinding balls. Alloys containing 27-30% Cr and 2.0-2.7% C have been specifically developed for a combination of abrasion and corrosion resistance in wear applications, with 30-35% Cr used to resist oxidation and corrosion at high temperatures in applications such as furnaces and burner parts. The microstructure of this alloy consists of ferrite and eutectic carbide [7].

Most cement producers in Indonesia use imported grinding balls because most cement producers have not been able to make grinding balls according to the required technical specifications. Ball mill is one of the important techniques in the industry [8]. This study is follow-up research that aims to meet the needs of grinding balls in the country, and in the long term can export grinding balls abroad. This research was conducted to determine the characteristics of the grinding ball prototype that has been used by cement factories in Indonesia, which was previously made by a casting process and carried out a heat treatment process to get the same quality as imported grinding balls. Thus, it can meet the needs of grinding balls for the cement industry in Indonesia [9].

The objective of this study is to determine the characteristics of the grinding ball prototype that has been used by cement factories in Indonesia after the quenching process with a temperature of 850℃ and 15 minutes of holding time. The heat treatment process in the form of thermal hardening of cast iron aims to improve the mechanical properties of the material, including the value of hardness and wear resistance [10]. Thermal hardening is carried out by heating the material to the austenitizing temperature and followed by the quenching process. High hardness values are obtained from the hardening process which changes the microstructure of ferrite or austenite into a hard martensite structure. In this study, the effect of heat treatment in the form of subcritical and hardening (austenitization and quenching) will be carried out [11]. The microstructure contains a network of eutectic carbides and an austenite matrix which is partially converted into martensite blades during cooling in the mold i.e. around the eutectic carbide. The unstable structure consists of a network of eutectic carbides and secondary carbides deposited in a previously austenite matrix that has largely been converted to martensite. The eutectic carbide in high chromium cast iron depends on the chemical composition and cooling rate [12]. The effect of holding time, thickness, and heat treatment can affect the mechanical properties [13]. Meanwhile, the pearlite percentage depends on the casting time and a longer casting time will result in greater pearlite formation.

2. Methodology

There are process steps carried out in this study (Fig. 1), starting from taking samples of cast iron during the casting process to the microstructural analysis process. The following is the flow of the research process carried out.

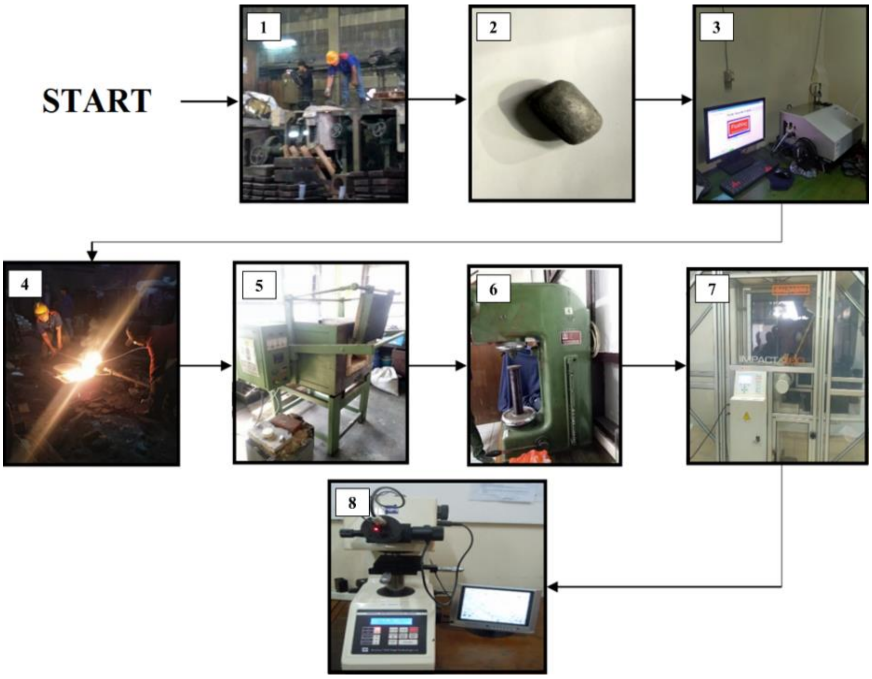

Fig. 1. Research process steps.

The study started with taking a sample of white cast iron (step 1) and making a specimen (step 2) for spectrometric testing. Spectrometric testing is carried out to determine the chemical composition of the sample and ensure that the carbon (C) content in white cast iron is above 2.1% (step 3). The results of the spectrometer test are shown in Table 1. The next stage is the casting of low-chromium white cast iron (step 4). After the low-chromium white cast iron specimen was finished, heat treatment was carried out using the quenching method with a temperature parameter of 850°C and a holding time parameter of 15 minutes (step 5). Then the final test was carried out, hardness test (step 6), impact test (step 7), and microstructural analysis of the specimen (step 8). This was done to determine the mechanical characteristics of the low-chromium white cast iron.

3. Results and Discussion

3.1. Hardness test result

A hardness test was carried out to determine the hardness value of the casting specimens before and after the heat treatment process was carried out by the quenching method with a temperature of 850°C and a holding time of 15 minutes with oil cooling media. The following are the results of the hardness testing of the specimen.

Based on the data in Fig. 2, there is a difference in the hardness value before and after the heat treatment process. The test results showed that the hardness of the specimen before heat treatment had an average hardness value of 382 HB. Meanwhile, after heat treatment, the average hardness value of the specimen increased to 636 HB. This is due to the formation of a martensite phase after heat treatment as a result of the quenching process.

Table 1. Elements contained in low-chromium white cast iron.

Elements	Amount (%)
C	2.30
Si	1.30
P	0.50
Mn	1.00
Ni	1.50
Cr	2.50
Mo	3.00
Cu	1.50

As a comparison, the imported grinding ball used in one of the cement factories in Indonesia [3] had an average hardness value of 467.53 HV, or equal to 444 HB. But another research [4] shows that another imported grinding ball from a different maker had an average hardness value of 687.74 HV or far higher.

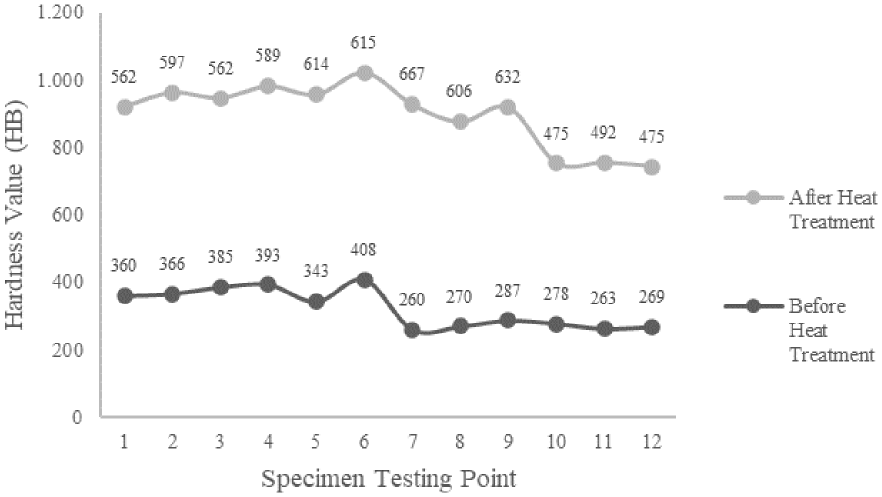

Fig. 2. Comparison of specimen hardness values before and after heat treatment.

3.2. Impact test results

The impact test was carried out to determine the impact value on low chromium white cast iron specimens before and after the heat treatment process was carried out with the quenching method at a temperature of 850°C and a holding time of 15 minutes with oil cooling media. The following are the results of the impact testing of the specimen.

Based on the data in Fig. 3, there is a difference in the Impact value before and after the heat treatment process. The test results showed that the Impact value of the specimen before heat treatment is 3.1 J/mm^2. Meanwhile, after heat treatment, the Impact value of the specimen decreased to 2.3 J/mm^2.

This is because there are many martensite phases formed during rapid cooling after the quenching process on the oil medium, thereby increasing the hardness of the material and causing the material to be hard and brittle which reduces the impact value.

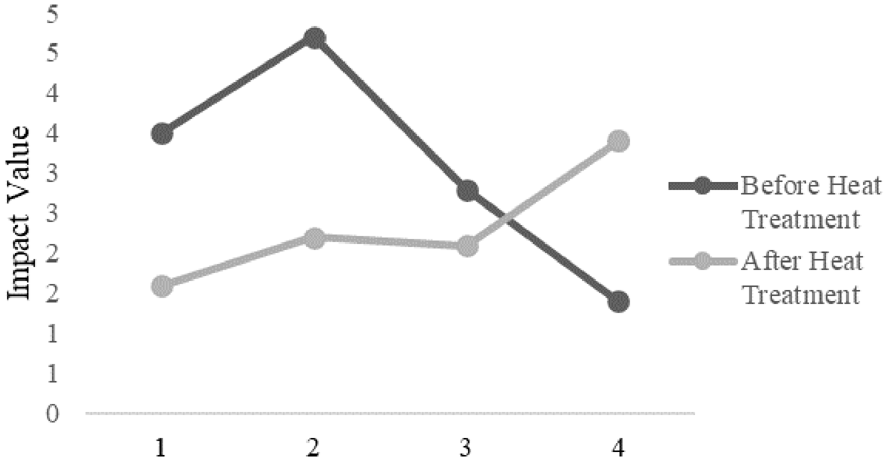

Fig. 3. Comparison of specimen impact values before and after the heat treatment process.

3.3. Microstructure analysis

Microstructure analysis was carried out after the hardness testing and impact testing processes. The microstructure analysis process begins with an etching or polishing process by chemical liquids on the surface to produce clearer results from the microstructure itself. The following are the results of the metallographic analysis of specimens before and after the quenching process proses.

Figures 4 and 5 show the image of the specimen before and after the quenching process. Figure 6 is the microscopic image of nickel-chrome alloy white cast iron material based on ASTM A532 Type I standard. The Red circle indicates the chrome carbide, and the yellow circle indicates the martensite. In the specimen image, the white colour indicates the presence of carbide, while the black colour indicates the presence of austenite. Austenite will turn into martensite as the abrasive process occurs. As a comparison, the following is the image of Nickel-Chrome Alloy White Cast Iron Material based on ASTM A532 Type I standard.

(i) This study shows the effect of heat treatment on the mechanical properties of low-chromium white cast iron. Quenching heat treatment with oil media can increase the hardness and can decrease the toughness value. Based on the results of the study and analysis that has been done, the discussion on the quenching process with oil media on white cast iron on mechanical properties (hardness and toughness) are as follows:

(ii) From the hardness test of low-chromium white cast iron, the results of the quenching process with oil media obtained a high hardness value. This is due to the formation of the martensite phase during the quenching process.

(iii) From the Impact test of low-chromium white cast iron, the results of the quenching process with oil media obtained a low Impact value. This happens because, after heat treatment with the quenching method, a lot of martensite phase is formed during rapid cooling. Thus increasing the hardness of the material causes the material to be hard and brittle and reduces its toughness.

(iv) From the Microstructure analysis of low-chromium white cast iron, it can be seen the difference in the shape of the graphite before and after heat treatment. This is a supporting factor in why the value of material hardness can increase. It can be seen in the results of microstructure analysis that the form of graphite which is denser after quenching with oil cooling media and there is a lot of martensite phase which causes hardness to increase.

This study demonstrates the need for material preparation for making ball mills. This is because the ball mill itself is one of the important processes in industry and is well-applied in many sectors [14].

Fig. 4. Before the Quenching process.

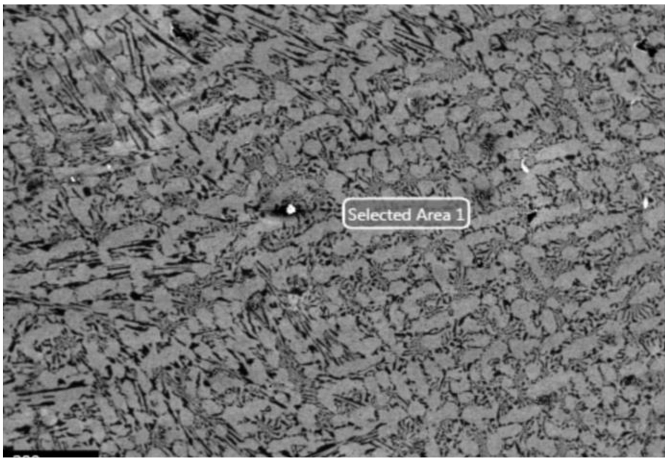

Fig. 5. After the Quenching process.

Fig. 6. A microscopic image of nickel-chrome alloy white cast iron material based on ASTM A532 Type I standard. The Red circle indicates the chrome carbide, and the yellow circle indicates the martensite.

4. Conclusion

The results of this study of low-chromium white cast iron show an increase in hardness when heat treatment is carried out at a temperature of 850ºC. These specimens were quenched in oil to obtain good hardness and meet the hardness standards for grinding balls in grinding mills in cement factories in Indonesia. With the production of grinding ball, it is expected that the quantity and quality of domestic cement production will be higher with more efficient production costs.

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