

## CHARACTERIZATION OF CENTRIFUGAL CASTING METHOD FOR PULLEY MANUFACTURING USING VARIABLE ROTATIONAL SPEED

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### ABSTRAK

Seiring perkembangan di dunia industri, aluminium menjadi material yang semakin banyak digunakan di bidang teknik. *Pulley* merupakan komponen yang berfungsi sebagai penghubung atau mentransferkan daya atau putaran mesin kepada beban melalui sabuk v-belt. Penelitian ini bertujuan untuk mengetahui karakterisasi material aluminium dengan metode pengecoran sentrifugal berbahan dasar *brake shoe* bekas dengan variasi kecepatan putar 0 RPM, 100 RPM, 200 RPM. Karakterisasi dari hasil pengecoran pada penelitian ini dianalisis menggunakan pengujian kekerasan metode *Brinell* dan pengujian impak *Charpy*. Hasil dari pengujian kekerasan *Brinell* menunjukkan bahwa coran aluminium untuk pembuatan *pulley* dengan penambahan kecepatan putar cetakan 100 RPM memiliki nilai kekerasan *Brinell* sebesar 53,22 BHN. Hasil pengujian *impact* metode *charpy*, spesimen dengan kecepatan putar cetakan 100 RPM, memiliki nilai *impact* sebesar 0,0135 kg.m/mm<sup>2</sup>. Hasil penelitian ini disimpulkan bahwa variasi kecepatan putar 100 RPM pada pengecoran *pulley* berbahan aluminium bekas dengan metode *centrifugal casting* dapat menghasilkan produk yang memiliki ketangguhan yang baik.

**Kata kunci:** pengecoran sentrifugal, *brake shoe*, *pulley*, karakterisasi material.

### ABSTRACT

*Due to advancements in the industrial sector, aluminum is progressively gaining popularity as a material of choice in the field of engineering. A pulley is a component that functions as a link or transfers power or engine rotation to the load via the V-belt belt. This study aims to determine the characterization of aluminum material made by the centrifugal casting method from used brake shoes with rotational speed variables of 0 RPM, 100 RPM, and 200 RPM. The characterization of the casting results in this study was analyzed using the Brinell hardness test and the Charpy impact test. The results of the Brinell hardness test showed that aluminum castings for making pulleys with an additional 100 RPM die rotation speed had a Brinell hardness value of 53.22 BHN. The results of the impact test with the Charpy method showed that specimens with a mold rotation speed of 100 RPM had an impact value of 0.0135 kg.m/mm<sup>2</sup>. The results of this study concluded that variations in rotational speed of 100 RPM in the casting of pulleys made of used aluminum using the centrifugal casting method can produce products that have good toughness.*

**Keywords:** centrifugal casting, *brake shoe*, *pulley*, characterization material

## 1. INTRODUCTION

Metal casting is one of the oldest and most traditional manufacturing processes. The casting process is divided into several stages. Melting the metal, checking the composition if needed, preparing the mould, pouring the molten metal into the mould, solidified part, finishing process. The metal casting craftsman company stands in line with the current development of metal casting processes and methods and produces various types of casting products that can meet the domestic market [1, 2]. The metal casting products that we often encounter range from household appliances, automotive components, engineering tools, and heavy machine tools. Consumer demand for casting products that are promising and have many enthusiasts is minimally complemented by an increase in the quality of metal casting products [3]. With the current development of the industrial world, aluminum is a material that is widely used in engineering. In addition to its low density, corrosion resistance, light weight, low coefficient of expansion, and good electrical conductivity, aluminum will also have physical and mechanical properties when combined with other elements and processed by certain methods. For example, in industry, aluminum is widely used in household appliances, construction, auto parts, and airplanes (aerospace), along with various components that have complex shapes that must be formed through metal casting processes [4, 5].

Used aluminum is a foundry raw material that Yogyakarta metal casting craftsmen frequently use to produce a variety of kitchen appliances like pans, kettles, cake molds, and automotive parts like wheels, handlebars, and handbrake

handles [6, 7]. Casting imperfections are a common issue for aluminum casters who use metal molds and gravity-based casting processes. These imperfections include cross-flow defects (losses), pores (blowing holes), and shrinkage holes, among which casting defects will affect the poor quality of the casting [8, 9]. Improving the metal casting process will always be carried out in order to obtain quality casting products. Pulley is an important part that most types of machines use and functions as a component for transmitting or connecting engine power or rotation which is transferred using a V-belt belt to the load [10].

One of the casting processes used by the author is the centrifugal casting process. This technique forces trapped air to escape by driving the molten metal into thin trailing edges [11]. However, low superheat is required because casting materials can be very reactive, especially when combined with high turbulent flow and gas trapping caused by high molten metal velocity. In this process, we use rotary rotation on the mold to get the centrifugal force. This force is generated because the mold rotates, resulting in the molten metal being poured being thrown away from the point of rotation and flowing to the farthest radius of the mold so that the cavity in the mold can be filled more completely [12]. Pouring liquid metal into rotating molds produces centrifugal castings. It solidifies under the influence of centrifugal forces, which are directed from the center to the periphery of the mold due to mold rotation, and exhibits directionality in solidification, which aids in the elimination of voids and discontinuities in the resulting casting, which are common in gravity castings [13].

The use of the VCC (Vertical Centrifugal Casting) method of casting liquid metal is encouraged because centrifugal force exerts pressure on the liquid metal during the casting process [14]. The product produced by this method has minimal defects; on the sides of the centrifugal casting product, it has a higher hardness value than the center of the casting, and the temperature in the mold also affects the hardness value of the casting. In a previous study, Chandran *et al.*, said that the centrifugal casting method with a vertical position was very good at making silicon fractions closer together [15]. This was because the vertical position of the mold created a gravitational force. Shomad in his research processed using centrifugal casting at 550 RPM, the casting product has coarser particles when compared to the rest of the rotation, and there is an influence between the combination of speed and rotation on mechanical values and macrostructures [16]. The process parameters chosen in this study have a significant influence on the porosity of centrifugal casting. Material LM24, mold rotation 1500 RPM, pouring temperature 750°C, and preheating temperature 300 °C are the optimal levels for input parameters [17]. The melting rate has the greatest influence on the grain structure of the casting. The grain structure of the casting, on the other hand, governs its mechanical performance and determines its suitability for any specific end-use.

As a result, various processing factors influence the properties of centrifugal casting. In this article, an honest attempt is made to analyze the effect of these factors and to list the role that each of these factors plays in determining the centrifugal casting characteristics [12]. The vertical centrifugal casting technique (VCCT) is the focus of this research because it has several potential advantages over traditional casting methods. Empirical evidence suggests that mold rotation can improve alloy castability because the magnitude of centrifugal force far exceeds that of gravity.

## 2. METHOD

This research used material and equipment: recycled aluminum from brake shoes on motorcycles, crucible furnace, centrifugal casting, hammer, grinder, sandpaper, and calipers. In this research, the variables rotational speeds 0 RPM, 100 RPM, and 200 RPM were used for casting pulleys. Figures 1 (a) and (b) illustrate our method and describe the whole research.

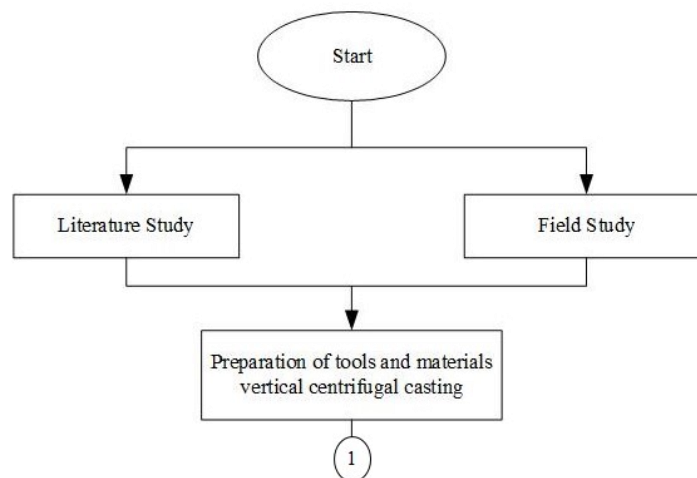


Figure 1 (a). Research Flowchart

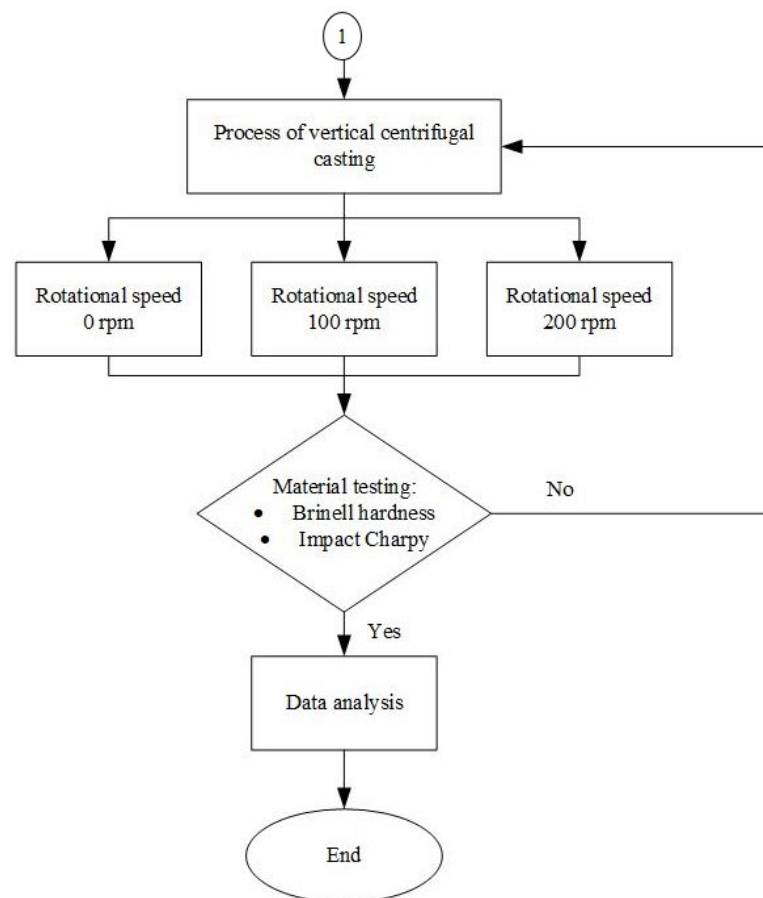


Figure 1 (b). Research Flowchart continued

### 2.1 Casting and Machining Processes of Pulley Materials

In this casting process, solid castings, not tabular forms, are made with the help of centrifugal force. It has a riser in the center for filling the mold with molten metal. Typically used for casting metal alloys for use in the manufacture of pulleys and other components. Figure 2 depicts the vertical centrifugal casting. Used brake shoes are melted with a temperature above 700 °C, the mold must have been heated to a temperature of 200 °C then molten aluminum is poured into a rotating mold with a predetermined rotational speed.

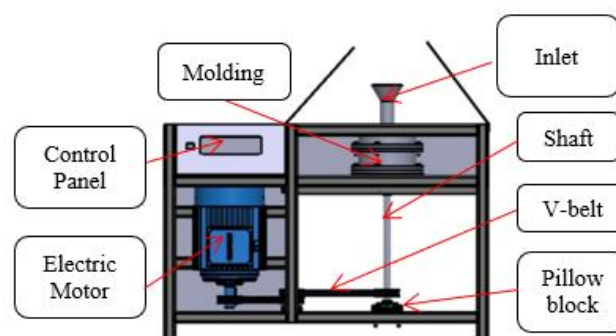


Figure 2. Centrifugal Casting Tool

The centrifugal casting process is carried out by pouring molten metal into a rotating mold. Under the influence of centrifugal force, the casting will have a solid, smooth surface, and the resulting metal structure will have a superior physical structure like the results of the pulley casting in this study. Generally, this method is suitable for symmetrical castings [18, 19]. Under the influence of this centrifugal force, the casting will freeze and solidify. In this centrifugal casting, the molten metal rotates along the horizontal or vertical axis, and in accordance with the application of Newton's

Second Law, the centrifugal force on a rotating object is proportional to the radius of rotation and the square of the rotational speed.

In centrifugal casting there are several parameters, including:

- Rotational Speed: The rotational speed (RPM) in the centrifugal casting process is the number of mold rotations each time. The rotational speed will affect the solidification of the molten metal, which occurs when it is poured into the mold.
- Pouring Temperature: Pouring temperature affects the quality of castings, which will affect their good physical properties. The temperature used in this study was below 750 °C, because if the temperature is too high, the shrinkage in the castings will be even greater, but if the temperature is too low, the aluminum will not melt properly.
- Pouring Speed: The pouring speed aims to adjust the pouring speed when the molten metal enters the mold before the molten metal solidifies. This is because if the process of pouring metal liquid is too slow, it will result in directional solidification, but if the pour is too fast, it will cause turbulence and metal splashing.

## 2.2. Mechanical Properties of The Specimen

The way to determine the Brinell hardness value is to press a metal ball with a specified diameter and load it on the surface of the material to be tested, then measure the diameter of the round mold marks formed on the surface and calculate the hardness value using the specified formula. The formula for the Brinell test is shown in Equation 1. This Brinell test was carried out at five points with three variable rotational speeds.

$$BHN = \frac{P}{\left(\frac{\pi D}{2} (D - \sqrt{D^2 - d^2})\right)} = \frac{2P}{\left((\pi D)(D - \sqrt{D^2 - d^2})\right)} \quad (1)$$

where:

$P$  = Load Used (kg)

$D$  = Steel Ball Indenter (mm)

$d$  = Indentation Diameter (mm)

Hardness testing of casting specimens using the Brinell hardness test method in Figure 3 was carried out to determine the hardness distribution value of the pulley casting specimens. The Brinell test refers to the ASTM E10 handbook [20] with a steel ball indenter of 10 mm, a load of 3000 kg, and a test of 5 points on the specimen.

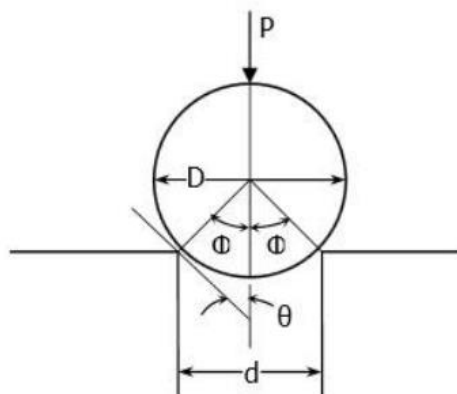


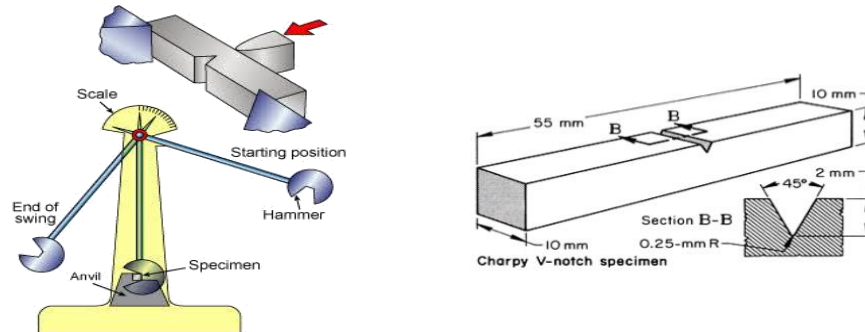
Figure 3. Brinell Test Method

There are two standard impact testing techniques, namely Charpy and Izod. This test aims to test the tendency of a metal to brittle fracture and to measure impact energy or another term called notch toughness (measuring the toughness of a metal against a notch). In this study, the Charpy method was used, which is the most widely used technique [21]. In the method shown in Figure 4, the specimen is placed horizontally and the two ends of the specimen are supported on a platform. The location of the notch is right in the middle of the direction of hitting from behind the notch and the results of the impact value can be known from the following Equation 2.

$$K = \frac{W}{A_0} \quad (2)$$

where:

- $K$  = Impact value ( $kg. m/mm^2$ )
- $W$  = Work that is required to break the test object ( $kg. m$ )
- $A_0$  = Cross-sectional area under the notch ( $mm^2$ )



**Figure 4. Impact Charpy Method [22]**

Impact toughness testing is carried out using an impact testing machine with the Charpy method where this test is carried out to determine the toughness of the pulley specimen. Impact testing with standards following ASTM E23, namely with dimensions of 10x10x55 mm with the notch in the middle of the specimen forming an angle of 45°.

### 3. RESULT AND DISCUSSION

The data obtained from the results of this final project research can be processed and analyzed according to the manufacture of pulleys using aluminum scrap (used brake shoe materials) and reviewed on the graphs obtained from the test results. Calculations are then performed for the results of the Brinell hardness test and impact test, then conclude the experimental results. The centrifugal casting process shown in Figure 5.



**Figure 5. Centrifugal Casting Process**

Metal casting uses a centrifugal casting machine made of aluminum for the manufacture of this pulley; the results are still in the form of raw castings (the pulleys have not yet been formed) and still need to be refined by machining processes. The following is the machining process for the casting of the pulley to completion in Figure 6.

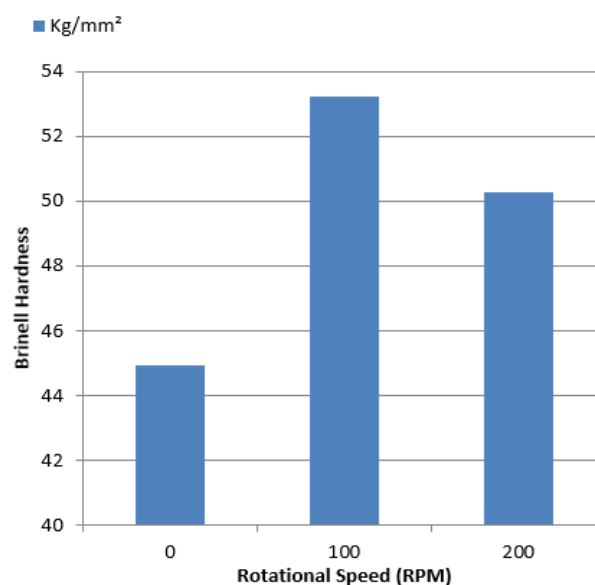


**Figure 6. Machining Process of the As-cast Pulley**

### 3.1. Brinell Hardness testing

Hardness testing is a cost-effective and straightforward nondestructive test (NDT) that can be conducted on the outer surface of materials or welds. NDT testing is carried out to obtain information about the strength and mechanical properties of the materials in pulley manufacturing. The Brinell hardness test data are listed in Figure 7 for each comparison of the variations in the RPM speed of the permanent mold.

The hardness of cast aluminum products in the form of pulleys using variations of the rotational speed of 100 RPM has the highest hardness of 53.32 BHN compared to the hardness using variations of the rotational speed of 200 RPM at 50.29 BHN and 0 RPM at 44.92 BHN. Varying the rotational speed in centrifugal casting from 0 to 200 RPM yields distinct outcomes: at 0 RPM, inadequate centrifugal force may lead to uneven metal distribution and potential defects; at 100 RPM, a balanced centrifugal force enhances metal spreading, resulting in improved casting quality and a finer microstructure; and at 200 RPM, while extremely high speeds refine the microstructure, diminishing returns may occur, emphasizing the need for careful optimization to achieve desired mechanical properties in centrifugally cast components.

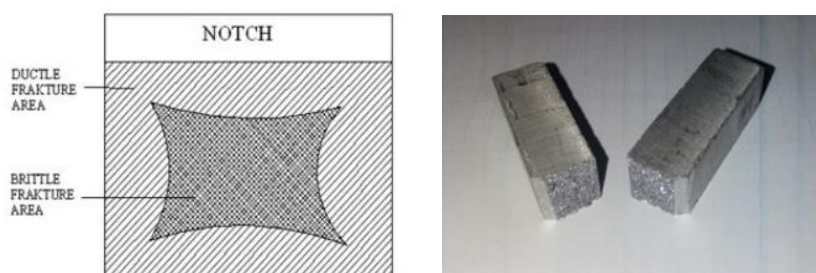


**Figure 7. Average Value of Brinell Hardness Test Results in Variable Rotational Speed**

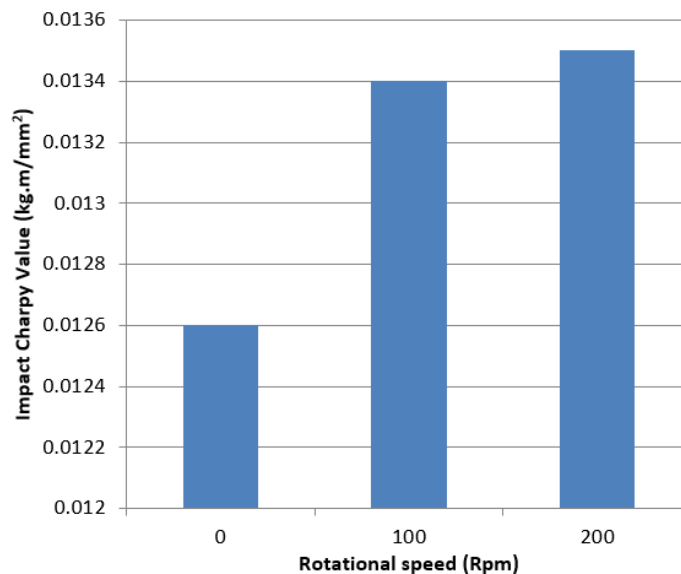
Based on the three hardness testing processes with different rotational speed variables mentioned above, it has been proven to have a significant effect on the results of castings on pulley specimens through the centrifugal casting method. This finding is in line with the results of research conducted by Santoso (2015) where variations in rotational speed changes in the centrifugal casting method can affect casting results, both in terms of external shrinkage defects and increased material strength.

### 3.2. Impact Charpy Testing

The impact test is used to study the fracture pattern of the test specimen, whether brittle fracture or ductile fracture, or a combination of both. Granular fracture or cleavage fracture is a brittle fracture surface shiny and granular while ductile fractures appear opaquer and stringier, also known as fibrous fractures or shear fractures. The surface differences between the two types of faults are shown in the Figure 8:



**Figure 8. Fault Patterns on Impact Test Specimen Cross Sections**



**Figure 9. Impact Charpy Value**

The magnitude of the impact toughness value from the impact test results is shown in Figure 9. From the test results, it was obtained that the average value of the impact toughness of the aluminum pulley castings was greatest in the pulley castings with a mold rotation speed of 100 RPM, which was  $0.0135 \text{ kg.m/mm}^2$ , while the smallest impact strength of the aluminum pulley castings occurred in the result of casting pulley with 0 RPM (gravity casting) is  $0.0126 \text{ kg.m/mm}^2$ . These results indicate that of the three variations of increasing the rotational speed of the mold, the higher the variation of increasing the rotational speed of the mold at the time of casting, the value of the impact toughness on the casting will increase.

#### 4. CONCLUSION

Centrifugal casting is widely used in metal casting processes to produce components such as tubes, pipes, cylinder liners, rolls, aerospace parts, and decorative pieces, leveraging the controlled distribution of molten metal through centrifugal force to achieve uniformity, structural integrity, and precise detailing in various industrial applications. With this centrifugal casting method, it produces castings that are good in terms of external shrinkage defects and can produce good material toughness. Higher rotational speed yields increased hardness due to faster freezing time, greater centrifugal force, and a core growth rate surpassing the grain growth rate, resulting in a fine grain structure. The faster it experiences solidification the more that the atomic structure in it is denser and denser, thus increasing the hardness value. From the research above, it was concluded that the optimal rotational speed for making casting pulley products is 100 RPM. At this rotational speed, the pulley product is very good, with a Brinell hardness value of 53.22 BHN and a Charpy impact value of  $0.0135 \text{ kg.m/mm}^2$ .

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