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Effect of Beach Sand and Mountain Sand Types on Aluminum Casting Process Molding Materials with AL_2O_3 Alloy on Hardness and Porosity

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Abstract

Casting is a metal-forming process in which molten metal is poured into a mold and allowed to solidify to produce components of a desired shape. Commonly used natural sand types for mold materials include mountain sand, beach sand, river sand, and silica sand. This study aims to investigate the influence of sand type on the porosity and hardness of Aluminum 6061 castings reinforced with alumina (Al_2O_3). The experiment utilized Aluminum 6061 mixed with 10% Al_2O_3 by weight, melted in a furnace, and cast into molds made from two different sand types: Karoso Beach sand and mountain sand. The hardness of the cast specimens was measured using a Rockwell Hardness Tester on the H scale. Results showed that the average hardness of the specimen using Karoso Beach sand was 117.2 HRH, while the specimen using mountain sand achieved a slightly higher hardness of 119.8 HRH. Porosity was evaluated using Archimedes' principle, comparing the weight of the specimens in air and in water. The results showed that the specimen cast with Karoso Beach sand had a porosity of 3.439%, while the specimen cast with mountain sand had a lower porosity of 3.226%. These findings suggest that mountain sand produces castings with better mechanical properties due to its lower porosity and higher hardness.
Keywords: sand casting, moulding, Al2O3, hardness, porosity.

Introduction

Technological progress in the field of manufacturing has led to significant innovations in how products are designed and produced. Among the foundational processes that support these advancements is metal casting, a method used to create components by pouring molten metal into a mold and allowing it to solidify. Casting has long played a vital role in shaping mechanical parts with intricate geometries and is integral to a variety of industrial sectors, including automotive, construction, aerospace, marine, and heavy machinery [1]. Through casting, industries can produce large quantities of parts with relatively low production costs while still maintaining structural complexity and integrity.

Aluminum casting, particularly when reinforced with ceramic particles such as alumina (Al_2O_3), has emerged as a promising method for producing high-performance components. The addition of alumina enhances mechanical properties such as hardness, wear resistance, and thermal stability, making the resulting metal matrix composite (MMC) suitable for high-stress applications, including engine parts, structural frames, and components exposed to extreme environments [2]. However, the success of this process is not only dependent on the alloy composition but also on the mold material, which plays a crucial role in determining the surface finish, dimensional accuracy, porosity, and overall quality of the final casting [3].

Sand casting remains the most used casting method due to its flexibility, cost-effectiveness, and ability to accommodate various sizes and shapes. The mold, typically composed of sand bonded with a binder, acts as a negative cavity that forms the shape of the desired product. Several types of natural sand are commonly used in this process, including mountain sand, beach sand, river sand, and silica sand [4]. Each type has distinct properties, such as grain shape, particle size distribution, mineral content, and moisture absorption capacity, all of which influence the mold's behavior under thermal and mechanical stress during casting [5], [6].

In practice, the mold must be able to withstand high temperatures and permit adequate gas permeability while maintaining its shape during metal pouring and solidification. Improper mold selection may lead to common casting defects such as porosity, shrinkage cavities, poor surface finish, or insufficient hardness in the final product. Therefore, understanding the relationship between sand type and casting quality is essential in optimizing the process, particularly when casting aluminum alloys with ceramic reinforcements [7].

This research focuses on investigating the influence of different sand types—specifically mountain sand, Pero beach sand, and Karoso beach sand—on the porosity and hardness of Aluminum 6061 alloy castings reinforced with Al_2O_3. Aluminum 6061 is widely known for its good corrosion resistance, strength-to-weight ratio, and weldability, and is commonly used in structural applications. The inclusion of 10% Al_2O_3 by weight aims to enhance its mechanical characteristics further [8].

The casting process was carried out using a melting furnace at a controlled temperature of 770°C, and an open mold casting technique was employed. The mold sands were evaluated based on their physical characteristics before casting, and the cast products were subjected to porosity testing and hardness testing to assess their quality. By comparing the results across different mold types, this study aims to identify the most suitable sand for producing high-quality aluminum-alumina castings [9].

This study investigates how different types of sand used as molding materials—specifically mountain sand, Pero beach sand, and Karoso beach sand—affect the porosity and hardness of Aluminum 6061 castings reinforced with alumina (Al_2O_3). Porosity and hardness are critical indicators of casting quality, influenced by the interaction between molten metal and mold material. By comparing the performance of various sands, the research aims to identify the most suitable molding material to produce aluminum-alumina composites with minimal porosity and optimal hardness.

The scope of this study is limited to the use of three specific types of molding sand: mountain sand, Pero beach sand, and Karoso beach sand. The casting material consists of Aluminum 6061 alloy reinforced with 10% alumina (Al_2O_3) by weight (ratio 10:1), using 500 grams of aluminum and 50 grams of Al_2O_3. The casting process is conducted at a fixed temperature of 770°C using the open mold gravity casting method. The analysis focuses solely on two output parameters—porosity and hardness—without examining other variables such as sand grain size distribution, moisture content, binder type, or particle size of the reinforcement. As such, the conclusions drawn are specifically applicable to the selected materials and controlled experimental conditions.

Experimental Methods

A. *Materials*

This study utilized two types of natural sand as molding materials: mountain sand sourced from Mount Lumajang (East Java) and beach sand collected from Karoso Beach, located in Kodi District, Southwest Sumba, East Nusa Tenggara (NTT), Indonesia. These sands were selected due to their natural abundance and distinctive physical characteristics, which may influence casting quality. The primary metal used for casting was Aluminum 6061, a widely used aluminum alloy known for its good mechanical strength and corrosion resistance. To enhance its mechanical properties, the aluminum was reinforced with alumina (Al_2O_3) particles. The mixture ratio used was 10:1 by weight, consisting of 500 grams of Aluminum 6061 and 50 grams of Al_2O_3.

B. *Mold Preparation*

The molds were prepared using the traditional sand-casting method. Each mold was formed within a rectangular mold box (flask) by packing the selected sand around a physical pattern. The pattern used for mold cavity formation was a motorcycle front gear component, chosen for its complex shape and relevance to real-world applications. The gear was positioned in the mold box, embedded into the compacted sand, and then carefully removed, leaving a negative cavity in the shape of the gear. This cavity served as the mold for molten metal pouring.

C. *Casting Process*

The casting process began by melting the Aluminum 6061 and Al_2O_3 mixture in a crucible using an oxy-acetylene welding torch (carbide welding). The melting temperature was maintained at approximately 770°C, which is within the optimal range for Aluminum 6061 to achieve fluidity while ensuring the dispersion of Al_2O_3 particles. Once fully melted, the molten metal composite was carefully poured into the prepared sand molds. The molds were then allowed to cool under ambient conditions (air cooling) until solidification was complete. After cooling, the cast products were removed from the molds and cleaned of any residual sand or oxides for further analysis.

D. *Testing and Analysis*

Two key performance parameters of the cast products were evaluated: hardness and porosity.

- Hardness Testing was conducted using a Rockwell Hardness Tester (H scale). Ten measurement points were randomly selected on the surface of each casting to obtain an average hardness value for each sample. This method provided insight into the mechanical strength of the material.
- Porosity Analysis was carried out using the Archimedes principle, where the mass of the casting was measured in air and then in water.

The results from both the hardness and porosity tests were used to compare the performance of the aluminium-alumina castings produced using mountain sand and beach sand molds. Statistical analysis and visual data comparisons were conducted to evaluate the impact of the sand type on casting quality.

Result and Discussion

In this study, the evaluation of the casting quality was conducted through two primary tests: hardness testing and porosity analysis. These tests were performed to assess the mechanical strength and internal integrity of the cast products, providing critical insights into the influence of molding sand types on the final material properties.

A. *Hardness Test Result*

In this study, the quality of the cast products was evaluated through hardness testing and porosity analysis, which serve as key indicators of mechanical performance and internal soundness. The hardness test was conducted using a Rockwell Hardness Tester, specifically applying the H scale. Measurements were taken at ten different points on the surface of each sample, labeled T1 - T10, to obtain an accurate and representative average value of surface hardness across the casting. This approach ensures a more reliable assessment of the material's resistance to deformation and surface consistency.

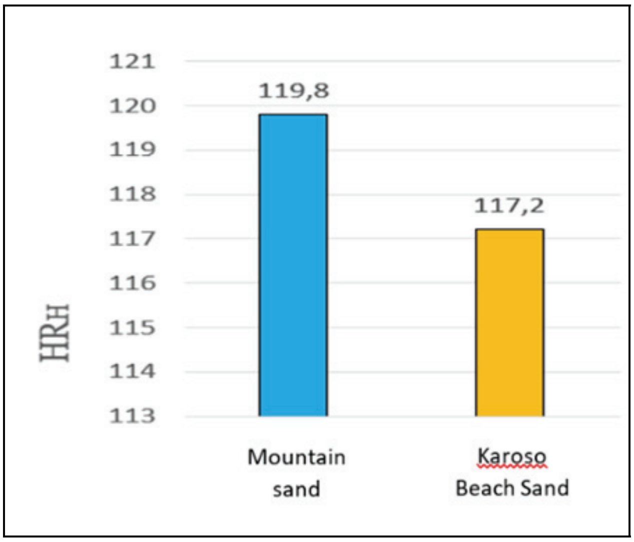

Figure. 1: Hardness test results of casting result.

Based on the results illustrated in Fig. 1, the average hardness of castings produced using Karoso Beach sand (NTT) as the molding material was recorded at 117.2 HRH, equivalent to approximately 80 HRB. In comparison, castings made with mountain sand from Lumajang demonstrated a slightly higher average hardness of 119.8 HRH, or approximately 84 HRB. These findings indicate that mountain sand yields better hardness characteristics in aluminum-alumina (Al 6061 + Al_2O_3) castings than beach sand, suggesting that the physical and thermal properties of mountain sand—such as finer grain structure, higher compaction, and lower moisture content—contribute to improved mold integrity and heat transfer during solidification.

When compared to previous studies, the hardness results of this study appear significantly higher. Study on Al-Si alloy casting using Balikpapan beach sand as the molding material and reported a hardness of only 86 HV, equivalent to approximately 20 HRB [10]. This demonstrates that Aluminum 6061 reinforced with Al_2O_3 and molded using Karoso or Lumajang sand offers superior mechanical performance. Similarly, in aluminum casting using recycled materials with the sand casting method, reported a hardness value of 66.9 HRB, which is significantly lower than the values achieved in the present study [11].

Furthermore, using the lost foam casting method for aluminum, obtained a hardness of 69.357 VHN, or approximately 55 HRB, again highlighting the advantage of combining Al_2O_3 reinforcement with carefully selected molding sands in traditional sand casting [12], [13]. On the other hand, another study using Kelud mountain sand in the casting of Al-Si alloys yielded a hardness of 125.7 HV (approximately 73 HRB) [14], which, while high, still falls slightly below the hardness achieved using Lumajang mountain sand in this study.

Overall, these comparisons underscore the importance of both mold material selection and reinforcement composition in determining the final hardness of cast aluminum products. The findings support the conclusion that mountain sand, particularly from Lumajang, is a more effective molding medium than beach sand for achieving higher hardness in Aluminum 6061–Al_2O_3 castings.

B. *Porosity Test Result*

To evaluate the porosity of the cast specimens, a two-step measurement method based on Archimedes' principle was employed. First, the weight of each specimen in air (Wa) and the weight in water (Ww) were measured using a precision digital balance. These values were then used to calculate the apparent density (Da) of the specimens using the following formula:

$$D_a = \frac{Wa \,.\, Dw}{Wa - Ww}$$

Where:
Da = apparent density of the specimen (g/cm³)
Dw = density of water (typically 1 g/cm³ at room temperature)
Wa = weight of the specimen in air (g)
Ww = weight of the specimen in water (g)

The theoretical density of the Aluminum 6061–Al_2O_3 and the measured (actual) density obtained from experimental data were then used to calculate the porosity percentage of the cast product. This calculation provides a quantitative measure of the internal voids or air pockets present within the material, which can significantly affect the mechanical performance and structural integrity of the casting.

$$P = \left(1 - \frac{Da}{Dth}\right) x\ 100\%$$

Where:
P % : percentage of porosity in the cast products (%)
Da : actual (measured) density of the specimen (g/cm^3)
Dth : theoretical density of the material (g/cm^3), assumed to be 2.70 g/cm^3 for Aluminum 6061.

Based on the formula above, the porosity results can be shown in Fig. 2.

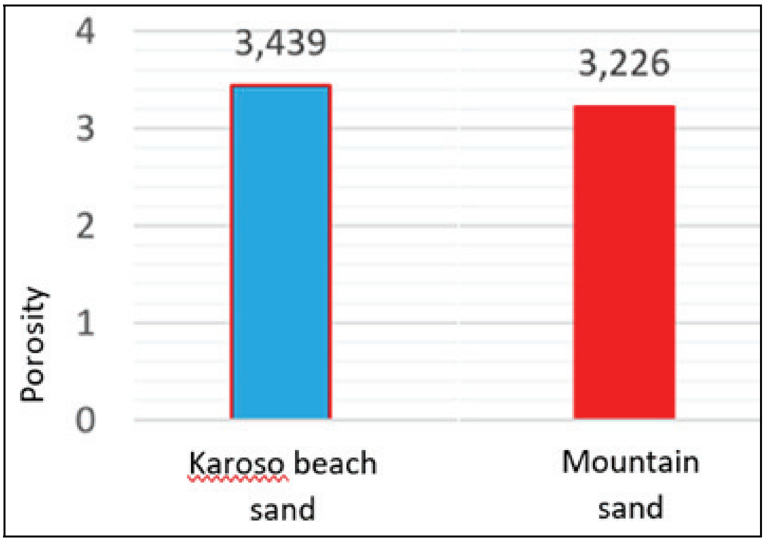

Figure 2: Porosity test results of casting result

Based on the data presented in Fig. 2, the porosity value of aluminum castings using Karoso Beach sand as the molding material was recorded at 3.439%, while castings using Mount Lumajang mountain sand exhibited a slightly lower porosity value of 3.226%. These results indicate that mountain sand yields lower porosity compared to beach sand, suggesting better mold stability and gas permeability during the casting process. Lower porosity levels are generally associated with improved compactness and reduced formation of internal voids during solidification.

This finding aligns with and extends previous research. For instance, another study reported a significantly higher porosity value of 5.84% in aluminum castings produced using river sand from Tanjung Bintang, South Lampung [15]. When compared across all three sand types—mountain, beach, and river sand—it is evident that mountain sand consistently results in lower porosity, followed by beach sand, while river sand produces the highest porosity levels. This variation can be attributed to differences in grain size distribution, moisture content, and compaction properties of each sand type [16], [17].

Porosity plays a critical role in determining the mechanical performance of cast aluminum, particularly in relation to its hardness. Increased porosity introduces micro-voids and discontinuities within the metal structure, leading to decreased material density and reduced resistance to deformation. In this study, it was observed that specimens with lower porosity exhibited higher hardness values, whereas those with higher porosity showed a noticeable reduction in hardness. This inverse relationship underscores the importance of controlling porosity to enhance the mechanical integrity of aluminum castings [18].

Therefore, minimizing porosity through proper selection of molding materials—such as mountain sand—and optimized casting parameters is essential for producing high-quality cast products with improved structural and mechanical properties. This finding is particularly relevant for applications where strength and durability are critical.

Conclusion

The results of this study indicate that mountain sand produces castings with higher hardness values compared to those made with beach sand. This difference in mechanical performance can be attributed to the lower porosity observed in castings using mountain sand. The reduced porosity suggests that mountain sand molds are more effective at containing molten metal, providing better compaction and permeability, which helps to minimize the formation of internal air cavities during the casting process. Consequently, the improved structural integrity of the casting contributes to increased hardness. These findings highlight the importance of selecting appropriate molding materials, such as mountain sand, to enhance the quality and mechanical properties of aluminum alloy castings, particularly when reinforced with ceramic particles like alumina (Al_2O_3).

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