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# Impact of Mould Material on Microstructure and Mechanical Properties of Aluminium Castings: A Comparative Study with Aluminium Matrix Composites

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**_Abstract_**

*Casting has a wide industrial usage because it allows manufacturing complicated forms even at a comparatively low cost. Issues like transfer of heat through the interface of the mould and the metals, the rate of solidification, and the characteristics of the mould material have a powerful impact on the quality of cast products. This study measures the influence of various mould substances on the mechanical characteristics of aluminium castings. Sand, metal and plaster of paris were used to prepare moulds with a steel rod of about 25 mm diameter being used as a casting pattern. The scraps of aluminium were melted and cast into the moulds made available. A specimen that was taken out of every casting was machined and tested in tensile, hardness, and impact tests as well as microstructural analysis. These findings revealed that Sample A (prepared through metal mould) registered the highest value of hardness of 38.00 BHN and Sample C (prepared through plaster of parismould), the second best registered 36.50 BHN. Contrastingly, Sample B (prepared through sand-cast) was the most ductile and the least hard. The observed increase in hardness of metal and plaster of parismould castings is explained by the faster cooling rates and the refinement of the microstructure, and slower cooling in sand moulds led to larger microstructures and higher ducilities. Sand moulds are more applicable in high ductility and metal and plaster of paris moulds are more applicable where more hardness is required. Finally, a detailed comparative analysis has carried out based on fabricated products with available aluminium metal matrix composites.*

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**Keywords:** Casting, aluminium, mould, sand, plaster of paris, aluminium matrix composite

## INTRODUCTION

Casting is one of the basic processes of metalworking when molten metal becomes poured into a mould cavity, solidifies, and is removed as a solid casting. It is most popular in different industrial fields due to the complex shapes that it can form at a comparatively low price [1]. Some of the main aspects that influence the quality of casting are the heat exchange in castings between the mould-metal contact, solidification speed, and the character of mould content [2]. Strength, permeability and hardness are the characteristics that are especially crucial in determining the end result of the casting in green sand moulds [3].

 

Generally speaking, casting processes can be divided into expendable and non-expendable mould. Expendable mould casting makes use of temporary moulds - sand, shell, plaster, and so on, which are destroyed after use. Among them, sand casting is used the most as it is flexible, it is cheap, and it can be used in a wide range of alloys [4, 5]. Studies show that mechanical strength of alloys of aluminium is directly influenced by such factors as size of the runners, temperature of the mould, and pouring conditions [6]. Plaster mould casting is more costly but provides a better surface finish and dimensional accuracy in complex shapes and is, therefore, appropriate [7]. Shell mould casting also increases accuracy and surface finish and is commonly employed in aerospace and art making [8–10]. Other methods Moulds are sometimes made in one-step in lost-wax (investment) casting by refractory clay applied to the wax model [11], and this method is often used together with vacuum casting [12]. The techniques of evaporative pattern like lost-foam [14] and full-mould casting [15] come into play in the production of complicated parts, since they employ the use of polystyrene patterns that vaporize during pouring, thus making mould preparation a simpler task [13]. With permanent metallic moulds, non-expendable mould casting techniques have better repeatability and dimensional accuracy. These processes are die casting, semi-solid metals casting, centrifugal casting and continuous casting. Die casting Die casting In die casting, molten metal is pressurized into the cavity of a reusable steel mould (die) and is therefore especially appropriate in the manufacture of near-net-shape parts with high dimensional accuracy and high surface finish [16]. The semi solid metal casting methods can be used to minimize porosity and can be heat treated to produce castings that are stronger and ductile [17–18]. Centrifugal casting is capable of being poured and then allowed to solidify by centrifugal action in a rotating mould and is mostly used to produce cylindrical parts with a central axis of rotation [19–20]. During the process of continuous casting, molten metal is cast into a mould, it is cooled by water and continuously removed when it is solid [21]. The process can be applied to the production of steel because it is efficient in the production of high-quality products at a relatively low cost [22]. The casting process can never be complete without mechanical testing which offers a reliable method of evaluating cast material performance and integrity [23]. In the case of aluminium castings tensile [24], hardness [25–26] and impact [27] tests, in particular, are the most essential types of tests to assess the mechanical behaviour during various service conditions. Not only do they provide crucial data about strength, ductility, toughness, and deformation resistance, but also assist in the discovery of the impact of natural and process-oriented characteristics, including defects in the castings, moulding materials, and cooling rates [28], on the ultimate characteristics of the material. The data collected during mechanical testing can be used to gain valuable information into the optimisation of casting design and processing parameters that will result in an increase in structural reliability, a reduced number of defects and improved material performance across a broad selection of engineering applications. The process of simulation in casting has become a necessity in manufacturing industries and has been crucial in product design and development of processes aimed at increasing yield and quality of casting. To a great extent, its successful implementation is preconditioned by the presence of accurate input data, especially, thermo-physical and physical characteristics in solidification [29]. Casting simulations enable a careful assessment of the quality of the components through the application of numerical means to assess the process of filling moulds, solidification, and cooling. This gives quantitative forecasts of mechanical properties, thermal loads and deformities, which can offer useful information on the performance of casting before actual production [30]. Consequently, simulation helps in development of casting methods which meet specific purpose hence enhancing the reliability and efficiency. As an example, the Iqbal et al. [31] employed MAGMASOFT software to evaluate three variations of mould design by evaluating how riser and gate position and size affect filling properties, pressure, velocity, rate of cooling, and solidification. Even though the casting is ancient, it still remains relevant in the contemporary engineering. Pouring temperature, gating design and mould type are factors which have a substantial effect on the development of microstructure and mechanical behaviour. Defects, such as, porosity, shrinkage and cavities, may occur due to poor process control and negatively impact performance [32]. The former works have investigated aluminium alloy castings made through $CO_2$ processes, metal moulds, cement-bonded sand moulds, and naturally bonded sand moulds [33–35].

 

But few studies have been done to compare performance of aluminium castings produced with the help of sand, plaster of Paris and metal moulds. The gap is the foundation of the current research, which follows the goal of exploring changes in the mechanical properties of castings made of aluminium using various types of moulds. Parallaly, a comparative study has made between the casted aluminium with aluminium metal matrix composites based on varsatile applications.

## MATERIALS AND METHODS

### Materials

The resources of this research work consist of aluminium scrap, sand, plaster of paris, and a splitable cast iron metal mould.

### Preparation of Plaster of Paris Mould

Scrap aluminium, plaster of paris powder and a hollow cast iron mould were prepared as cylindrical hollow and casting sand was also prepared available. The plaster of paris was powdered and then the right quantity of water was added to the mixture after which talc and silica flour were added to control the time of setting the plaster and to strengthen it. The mixture that was created was then poured on the rod-shaped pattern made of cast iron and the plaster of paris was left to dry, taking approximately 20 minutes, before the pattern was removed. This mould was then fired to a few hours to remove any moisture and harden the mould to suffer the hot metal.

### Preparation of Metal Mould

As the mould a hollow, cast iron hollow cylindrical mould which was split into two halves and clamped firmly was made. It had been preheated at 180–190 deg C to promote the movement of molten metal and limit the thermal damages to the casting. Also, the mould cavity was covered with a refractory to avoid sticking of the casting in the mould and to increase the service life of the mould.

### Preparation of Sand Mould

The sand was pouring into a flask, which consisted of frames or mould boxes. The mould was formed by placing a pattern of the required rod-like form in the sand, and the pattern and the sand were both put into a gating system. This was then peeled off to leave a cavity in which to cast.

### Aluminium Cast Preparation using the Various Mould Techniques

The aluminium scrap was melted in electricity-based furnace, and the lava was cast to the prepared moulds. Castings were left to cool after an hour. The aluminium castings of the sand and plaster of parismoulds were recovered by breaking the mould, and the casting of the metal mould by splitting the cylindrical mould. The castings of the three various mould materials were then cleaned and machined ready to be analyzed microstructurally and subjected to mechanical testing.

### Characterizations

A metallographic microscope was used to examine the microstructural characteristics of the three samples and the following stages make up the systematic preparation process, which included; grinding (rough through fine), polishing and etching. They determined the tensile properties using tensometer, Brinell hardness testing machine being used to determine the resistance to indentation. Besides, the Izod impact test was used to identify the impact strength of the samples, which is the resistance to sudden applied loads.

## RESULTS AND DISCUSSION

### Microstructure Analysis

Figure 1 shows microstructure of Sample A (aluminium casting created with the help of metal mould). This existence of highly fine microstructures indicates that the heat is quickly removed by the aluminium through the metal-mould interface thus resulting in a high rate of solidification and cooling. This led to lack of enough time during which substantial growth of grains occurred leading to development of fine microstructures.

 

The microstructural properties of Sample B (aluminium casting on a sand mould) are shown in Figure 2. The microstructures observed are coarse which means that there was ample time to allow the new grains to grow at the interface between the aluminium casting and the sand mould.

Figure 3 depicts the microstructure of Sample C (plaster of parisaluminium casting). A fine microstructure is visible in the image, which means that the transfer of the heat in the casts of aluminium to the plaster of parismould and the surrounding environment was performed in a short period of time. This was a high rate of heat transfer which restricted the duration of new grains growth and led to a fine microstructure.

**Figure 1.** Microstructure of sample ‘A’ at 200X magnifications.

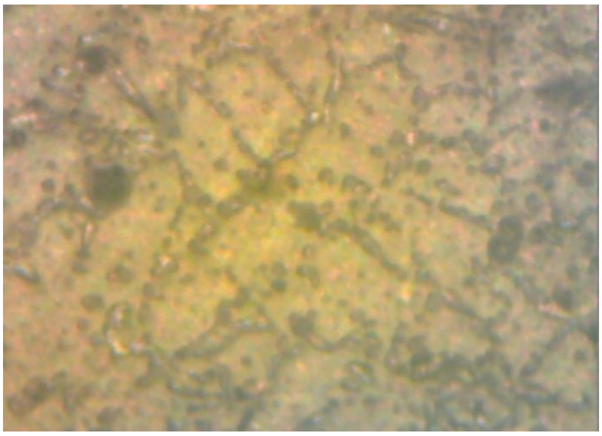

**Figure 2.** Microstructure of sample ‘B’ at 200X magnifications.

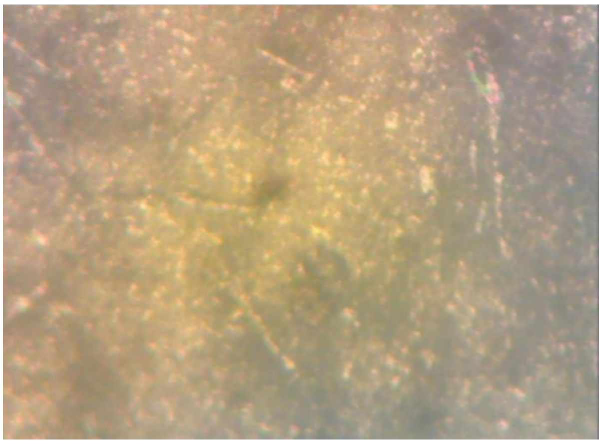

**Figure 3.** Microstructure of sample ‘C’ at 200X magnifications.

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**Tensile Tests Results**

As Figure 4 indicates, the Sample A broke at 90 Mpa while Figure 5 shows that Sample B broke at 100 Mpa. Conversely, Figure 6 shows that Sample C broke at 72 Mpa. These findings imply that Sample B had the highest ductility as it was able to hold the highest load until fracture where Sample A recorded moderate ductility with a correspondingly smaller fracture load. Sample C that experienced the lowest load failure proved to be the least ductile and weakest performing mechanical sample amongst the three samples.

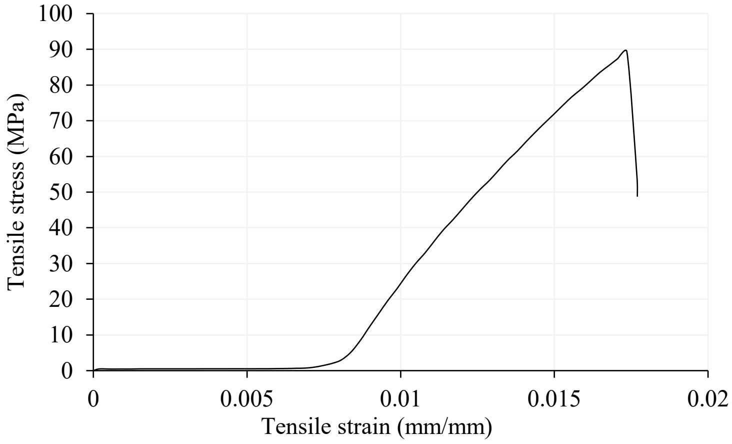


**Figure 4.** Stress- strain curve of sample 'A'.

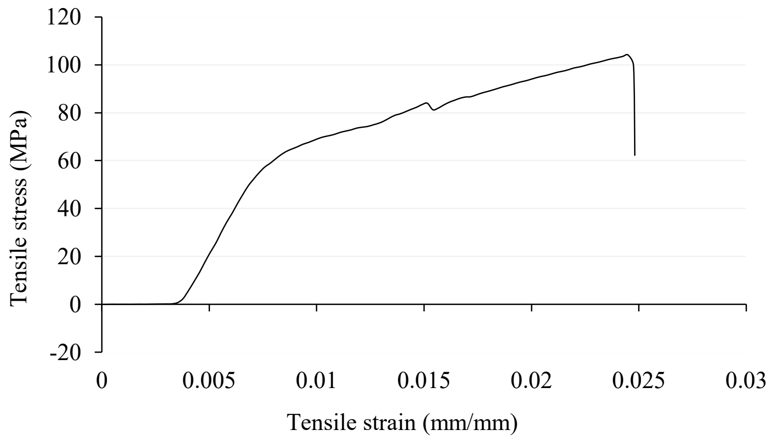


**Figure 5.** Stress-strain curve of sample 'B'.

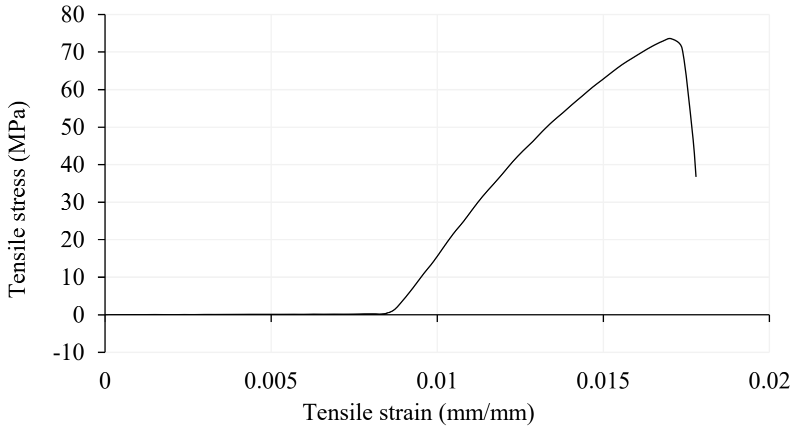


**Figure 6.** Stress-strain curve of sample 'C'.

Sample B has the largest tensile strain at fracture (0.025), as shown in Figure 7, with A and C also failing at lower tensile strain of 0.0175. This implies that Sample B is the most ductile of the three samples.

**Hardness Tests Results**

The hardness test of the three samples is presented in Figure 8. Sample A measured the highest hardness at 38.00 BHN, then Sample C at 36.50 BHN and finally the lowest value of 32.80 BHN in Sample B. It is possible to explain the increased hardness of Sample A by the chilling effect due to the fast extraction of heat at the metal-mould interface that resulted in a more refined microstructure. Similarly, the relative hardness of Sample C could be linked to the fact that the plaster of parismould had additives like talc and silica, thus, limiting the dislocation movement and leading to precipitation hardening. Sample B, on the contrary, cooled more slowly giving the microstructure a coarser form and, therefore, reduced hardness.

**Impact Tests Results**

The graph below (Fig. 9) demonstrates the effects of the three samples. Sample B recorded the highest impact strength of 6.52, then Sample C registered 6.25 and Sample A registered the least impact strength of 5.98. The results indicate that Sample B can withstand instantaneous loading the most, that Sample C has moderate resistance, and Sample A has the least resistance to impact.

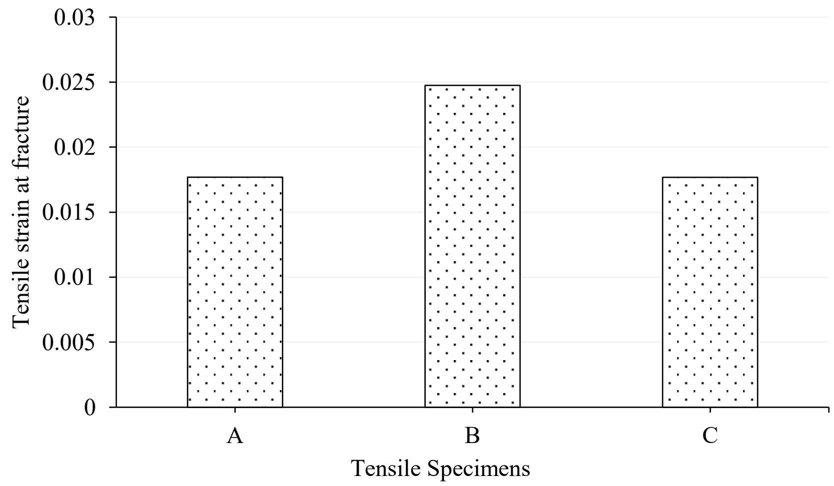


**Figure 7.** Bar chart showing the results of tensile strain at fracture.

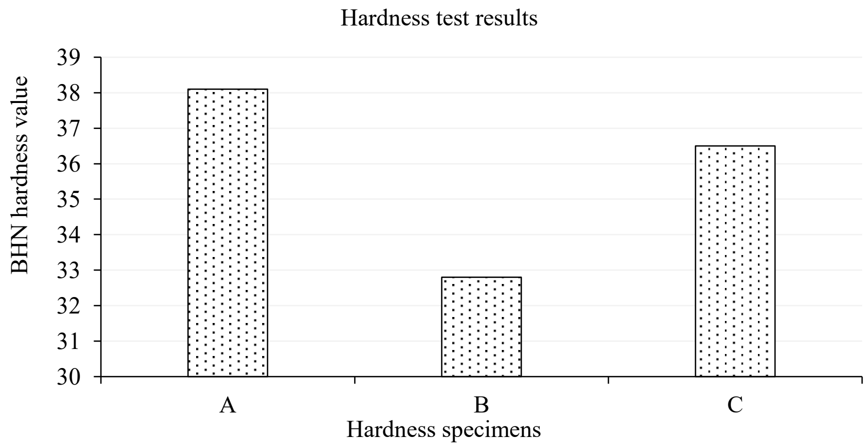


**Figure 8.** Bar chart showing hardness results.

 

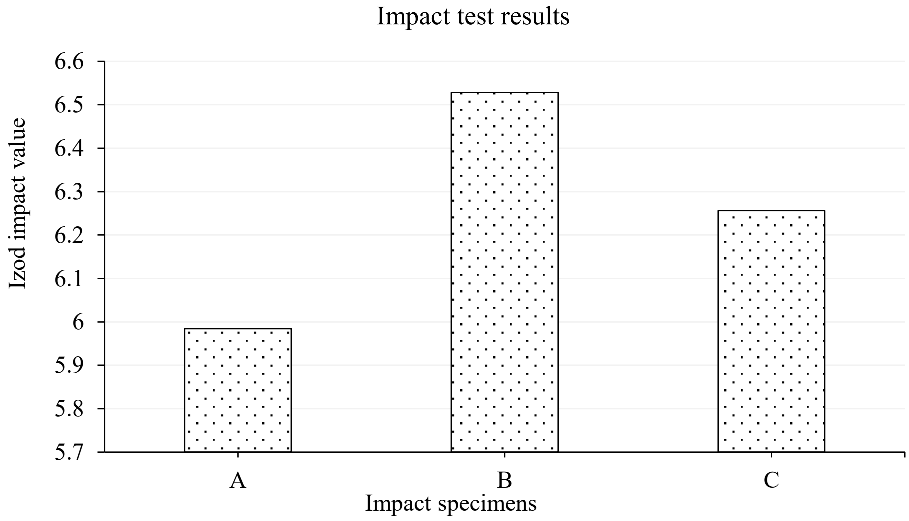


**Figure 9.** Bar chart showing the results of impact test.

**Properties of Aluminium Metal Matrix Composites**

Aluminium metal matrix composites can be fabricated using various methods, among which powder metallurgy technique is universally accepted, as it enables the production of exact final dimentions in a cost-effective way [35–36, 39]. Melting point of the aluminium matrix composites can be incresed with incorporating suitable ceramic particles as reinforcement [35–37, 40]. This will increase the hardness with compromising its strength [36–37, 39–41]. Generally, aluminium matrix composites have insufficient tensile properties [35–36, 41] for using in high load bearing duties while casting aluminium is perfect for such applications. On the otherside, controlled porosity can be present in aluminium matrix composites [35, 40–41] which makes it verymuch perfect for gear arrangements in automotive [36–37, 39], developing implant materials [37–38, 41] in biomedical engineering, various electrical and electronic applications [38–41].

## CONCLUSIONS

Sand moulds reduce the rate of heat removal causing more slow cooling and coarse-grained microstructures. These are formed bodies that enable plastic deformation hence increasing ductility. Metal moulds on the other hand encourage quick heat extraction (chilling effect) whereas plaster of parismoulds enjoy the advantage of precipitation-hardening additives. Both these states produce finer, harder microstructures increasing hardness and decreasing ductility. In general, the results underline inherent trade off between hardness and strength as compared to ductility, with the main control being the nature of the mould employed and the rate of cooling. Such a relationship is essential when designing material selection and casting design since it enables engineers to customize mechanical properties in regards to the requirement of an activity.

Such casted products are able to impose more heavy duties for using in aircraft, automobile applications. Presence of controlled porosity and lightweight makes suitable aluminium matrix composites as sensor design, electronic chip design, biomedical instrumentation and so on.

## AUTHOR CONTRIBUTIONS

The first author and the second author contributed equally to this work and share first authorship.

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