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# Investigating the Influence of Casting Parameters on the Mechanical and Microstructural Characteristics of Grade Al6063 Alloy

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**ABSTRACT:** Influence of casting parameters on the mechanical properties and microstructure of alloys is gaining more prominent research concerns. The main aim of this work is to investigate the effect of three main casting parameters (Pouring temperature, pouring speed and pouring height) on the mechanical and microstructural characteristics of Al6063. The Al6063 obtained in billet form, was processed into cylindrical shape of length 20 cm and diameter 2 cm by casting. Fifteen cast samples were obtained at varying pouring temperatures, pouring speeds and pouring heights. Tensile, impact and hardness tests were performed. The samples were thereafter examined using optical metallurgical microscope. Results showed that enhanced mechanical and microstructural characteristics were obtained at the pouring temperature of 730$^{o}$C, pouring speed of 1.75 cm/s, and at pouring height of 15 cm relative to the as-received Al6063 aluminium alloy. This can be attributed to the effect of grain refinement during recrystallization and solidification as there was increase in the total grain boundary area capable of impeding to certain extent dislocation motion. In addition, it can be inferred that there exist also grain growth occurrences and the emergence of precipitates $Mg_2Si$ in the alloy and this perhaps was responsible for the observed considerable increase in hardness.

**Keywords:** Al6063, Pouring temperature, Pouring speed, Pouring height and Mechanical properties

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## I. INTRODUCTION

The 6xxx-group aluminium alloys are well known for its immense excellent properties and this has been responsible for its widespread applications (especially in the automobile, building services and aircraft industries). The 6xxx series contain silicon (Si) and magnesium (Mg) as main alloying elements (Aluminium Standard and Data, 1988). These alloying elements are partly dissolved in the primary $\alpha$-Al matrix, and partly present in the form of inter-metallic phases. As reported by Siddiqui *et al*. (2000), a range of different inter-metallic phases may be formed during solidification, depending on alloy composition and solidification condition. The authors emphasised that the relative volume fraction, chemical composition, and structural morphology of this alloy series exert significant influence on their engineering properties. Aluminium alloy Al6063 is a member of the 6xxx group in which the prominent alloying elements are magnesium and silicon at different percentages.

The distinct properties of Al6063 and other similar nonferrous alloys have been well reported to be affected by casting parameters such as mould temperature, moisture content, sand and type of binders used, pouring temperature, pouring speed, pouring height, runner size, casting size, fluidity and composition of metals among others (Li and Li, 2001;Sadrossadat and Johansson, 2009;Turbalioglu and Sun, 2011; Lus, 2012; Datau *et al.*, 2012; Ayoola *et al.*, 2012; Adeosun *et al*., 2013 ;Singh *et al*., 2013; Mohandass *et al.*, 2014; Changizi *et al.*, 2014, Souissi *et al.*,2014 and Kumar *et al.*, 2016). Attempt made by Turbalioglu and Sun (2011) was based on the desire to enhance mechanical properties of AA6063 alloy using vertical continuous method. This method has been found beneficial as it provides opportunity for maximizing time and energy during billet production. This in turn reduces the overall manufacturing cost in no small measure. The authors found that high potential exists for improving the alloy's mechanical properties at casting temperature of 690ºC and speed range of 100-110 mm/min. Singh *et al.* (2013) studied the influence of pouring temperature and permeability of sand on the behavioural response of aluminium alloy. It was shown that increase in temperature and permeability of sand mould promotes the grain structure finess. This in turn improved the impact strength and hardness of the cast alloy. A research work that focused on the influence of pouring temperature on microstructural evolution, mechanical and electrical properties response of aluminium 6063 cast alloy was carried out by Adeosun *et al.*, 2013. It was reported that maximum tensile strength and electrical resistance were achieved at pouring temperature of 740ºC. The impact of casting parameters such as cooling rate on the mechanical properties of the A380 aluminium alloy was examined by Mohandass *et al.* (2014). Although with a slight disparity, the outcome of the study revealed that an increase in cooling rate generally enhanced the mechanical properties of the cast aluminium alloy.

It is imperative to choose the right and the best materials for engineering applications and often in terms of high mechanical characteristics which has enormous effect on quality, cost effectiveness, and service performance of the materials. Over the years, various manufacturing processes such as casting, rolling and extrusion have been developed with the aim of improving the mechanical and microstructural properties of several aluminium alloys (Datau *et al.*, 2012).

Casting is a manufacturing process of heating to the melting point of metal and then pouring the liquid (molten) metal into a prepared mould, which contains a hollow cavity of the desired shape, and then allowed to solidify (Sanders, 2011). The solidified part is also known as a casting, which is ejected or broken out of the mould to complete the process. Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other manufacturing methods. Once the mould is cured, the pattern is removed, leaving a hollow space in the sand in the shape of the desired part. The pattern is intentionally made larger than the cast part to allow for shrinkage during cooling. Cores can be inserted into the mould to create holes and improve the casting's net shape (James *et al.*, 1909). The pouring temperature of the material should be a few hundred degrees Celsius higher than the melting point of the material to assure good fluidity, thereby avoiding premature cooling, which can create voids and porosity (Lindberg, 1997). Different casting processes have been employed over the years to produce cast ranging from simple to intricate parts of machines, equipments, structures, etc and these include; die casting, squeeze casting, gravity casting, chill casting and sand casting to mention just a few (Degarmo et *al*, 1988, Jatau et *al*, 2002 and Callister, 2007).

This research work is within the framework of carrying out a study on the influence of pouring temperature, pouring speed, and pouring height on the mechanical and microstructure characteristics of Al6063 using sand casting process. The melting points of aluminium alloys have been found to be in 615-660$^{o}$C range (Lindberg, 1997; Mohammed et al., 2000). Based on this data, pouring temperature was varied between 700 and 740$^{o}$C. The pouring speed was however varied between 1.4 and 7 cm/s while other parameters were kept constant and pouring height varied in the range 15 to 35 cm.

## II. MATERIALS AND METHODS

Aluminium alloy Al6063 in billet form was procured from Nigeria Aluminium Extrusion Company (NIGALEX), Oshodi, Lagos. A total of fifteen (15) cast specimens were produced in accordance with specified casting parameters described in subsection 2.1.

### 2.1 Casting Parameters

*Pouring Temperature*

Pouring temperature of Al6063 was varied between 700 and 740$^{o}$C at an interval of 10$^{o}$C. This was achieved with the aid of a thermocouple. The alloy began to melt at a temperature of 670$^{o}$C. It was superheated to a temperature of 700$^{o}$C and a temperature rise of 10$^{o}$C was allowed to cater for temperature drop during transferring and pouring. The pouring height was maintained at 35 cm and the aforementioned process was however repeated for temperatures 710, 720, 730 and 740$^{o}$C.

*Pouring Height*

For the variation of the pouring height, pouring temperature was maintained at 700$^{o}$C and this was carried out for 15, 20, 25, 30 and 35 cm.

*Pouring Speed*

This is the flow of the molten metal per unit time. As illustrated in eq.1, this can be expressed as the ratio of the pouring height to the time of pouring of the molten metal.

$$\boldsymbol{V = \frac{H}{T}} \qquad (1)$$

Where V= pouring speed (cm/s); H= pouring height (cm); T= time for pouring the molten metal (s).

The molten metal was poured into the mould and the pouring time for each mould to be filled up was varied for five specimens vis-a-vis 5, 10, 15, 20 and 25 s, so as to obtain different pouring speeds for the castings. The pouring temperature was maintained at 700°C and the pouring height at 35 cm. The time readings were obtained by a stop watch. The process was repeated for five times to obtain castings at different pouring speed while keeping pouring temperature and height unchanged.

### 2.2 Mechanical Tests

The castings were machined to the required specifications (Fig.1). The equipment used for the tensile test is automated universal testing machine with a capacity of 25 kN. The 'dogbone' test specimen was introduced into the holding grips of the testing machine and was subjected to tension gradually until the specimen experienced necking and finally fractured. Corresponding applied load and elongation were recorded. This process was repeated for the remaining specimens.

Impact test was performed using the pendulum type impact machine. The specimens were machined to a standard test piece size. They were then notched on the vice with the use of file to form a groove of 2 mm on the specimen. The diameter of the specimen is 10 mm and the length 120 mm as shown in the Fig.2.

The notched part of the machine helped to fit the specimen to the machine. The specimen was fixed to the machine and the pendulum was allowed to fall from a fixed starting point to fracture or deform the specimen. When the pendulum was released from the maximum height position, the pointer on the scale also moved along with the pendulum and stopped at a particular point to give the readings and the results after the specimen experienced fracture. The aforementioned process was repeated for each of the specimen.

Brinell hardness test was conducted for the specimens. In this test, the specimen was placed in between a standard steel ball of diameter 10 mm inside the machine. The hardened steel ball of diameter D is then pressed for about 10 – 15 s into the surface of the specimen by a gradually applied load which was powered mechanically. The diameter of the indentation on the specimen was then measured after the load and ball were removed. The Brinell number was obtained using eq. 2.

$$HB = {}^{P}\Big/\left(\frac{\pi D}{2}\right)\left(D - \sqrt{D^2 - d^2}\right) \qquad (2)$$

Where HB is the Brinell hardness number; *P*, the imposed load, =500 kg,
*D*, the diameter of the spherical indenter, =10mm, *d is* the diameter of the resulting impression, (mm).
The size of the specimen were sufficient to ensure that no part of the plastic flow around the impression reaches a free surface, and the load were applied steadily and lasted for at least 15 s.

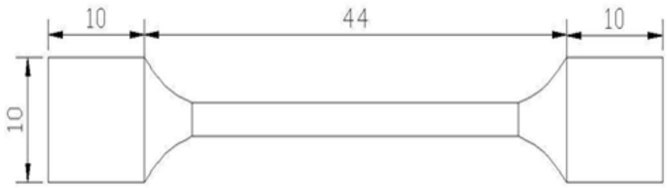



**Fig 1:** Specimen configuration in mm for tensile test

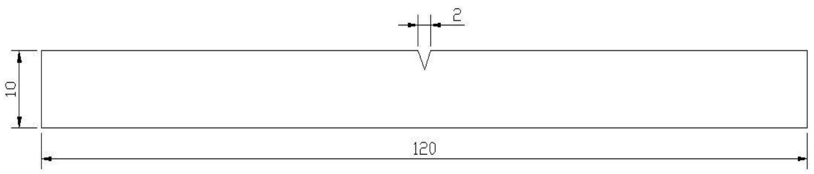



**Fig 2:** Specimen configuration in mm for impact test

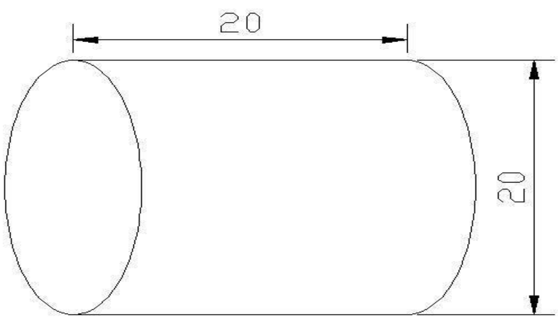



**Fig 3:** Specimen configuration in mm for Hardness test

## III. RESULTS AND DISCUSSION

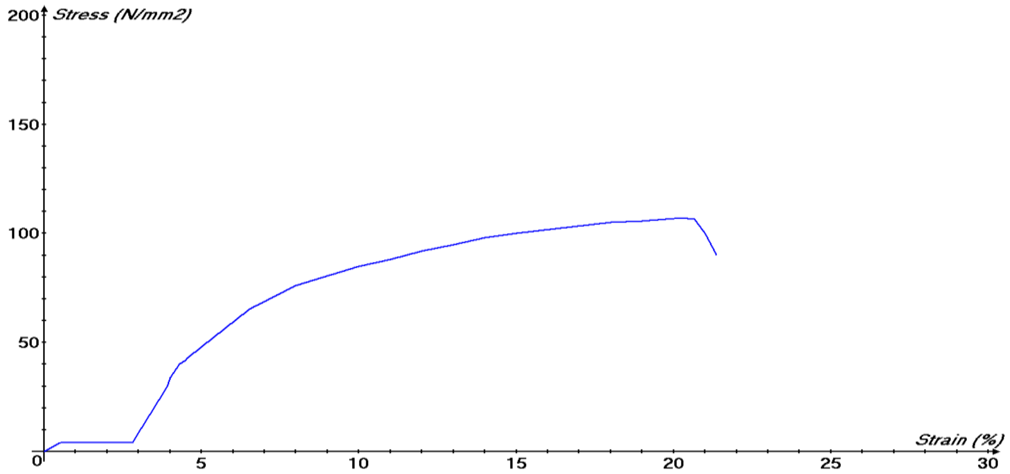
The percentage chemical composition by weight of aluminium alloy Al6063 is presented in Table 1. Tensile test results were obtained from the stress-strain curves at varying pouring speeds, pouring temperatures, and pouring heights. The representative stress-strain curves are presented in Figs. 4, 5, and 6 respectively. Fig. 7 shows the impact test results at varying pouring heights, pouring temperatures, and pouring speeds, respectively. Hardness test results at varying pouring temperature, pouring height, and pouring speed are presented in Fig. 8. The results of the influence of pouring temperature, pouring speed, and pouring height on the mechanical properties are presented in Figs. 9, 10 and 11. The optical micrographs of the process parameters influences are shown in Figs. 12, 13, 14, 15, 16, and 17.

**Table 1: Percentage Chemical composition of aluminium alloy Al6063**

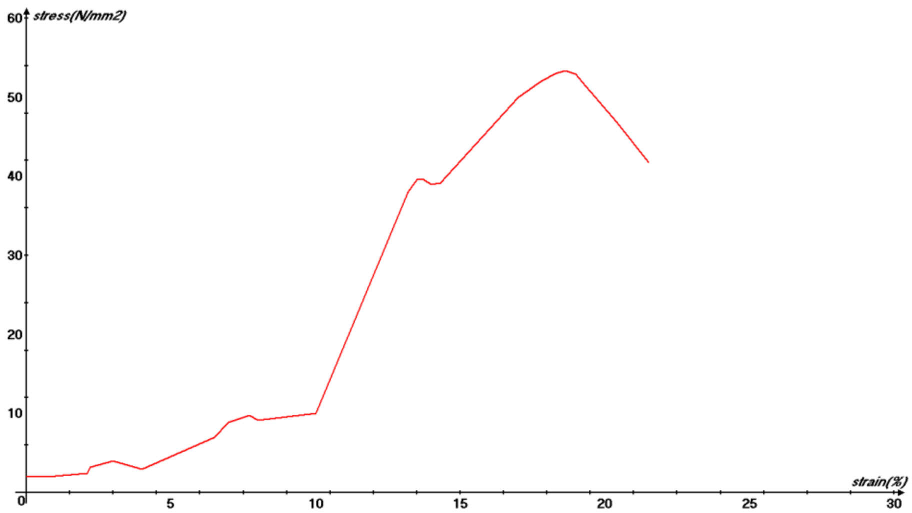
| Si | Fe | Cu | Mn | Mg | Zn | Ti | Cr | Al |
|---|---|---|---|---|---|---|---|---|
| 0.48 | 0.29 | <0.008 | 0.017 | 0.47 | <0.001 | <0.003 | <0.008 | Balance |

### 3.1 Tensile Test Results

(I) Casting Parameter: Pouring Speed




**(a) 1.75 cm/s**




**(b) 3.5 cm/s**

**Fig. 4:** Stress-Strain curve at varying pouring speeds (a=1.75 cm/s, b=3.5 cm/s)

(II) Casting Parameter: Pouring Temperature

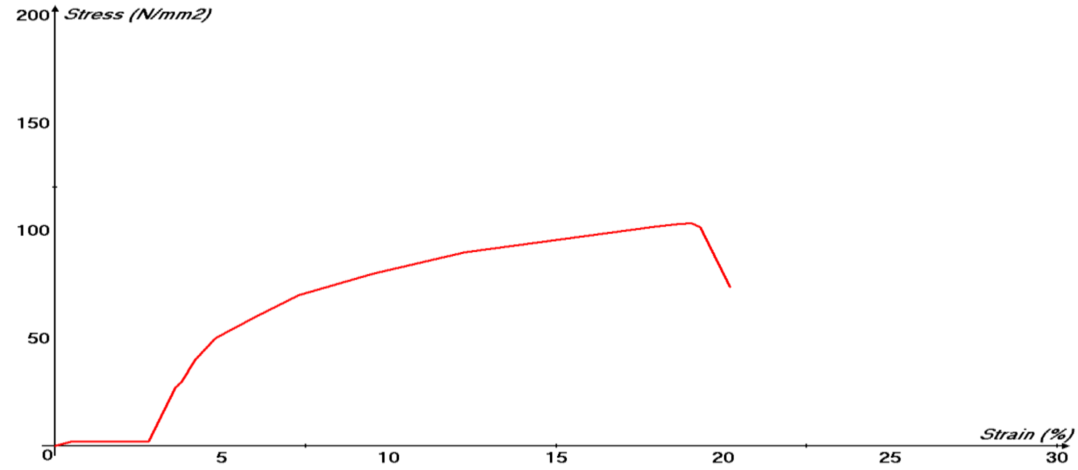



**Fig. 5:** Stress-Strain curves at pouring temperature of 730$^{o}$C

(III) Casting Parameter: Pouring Height

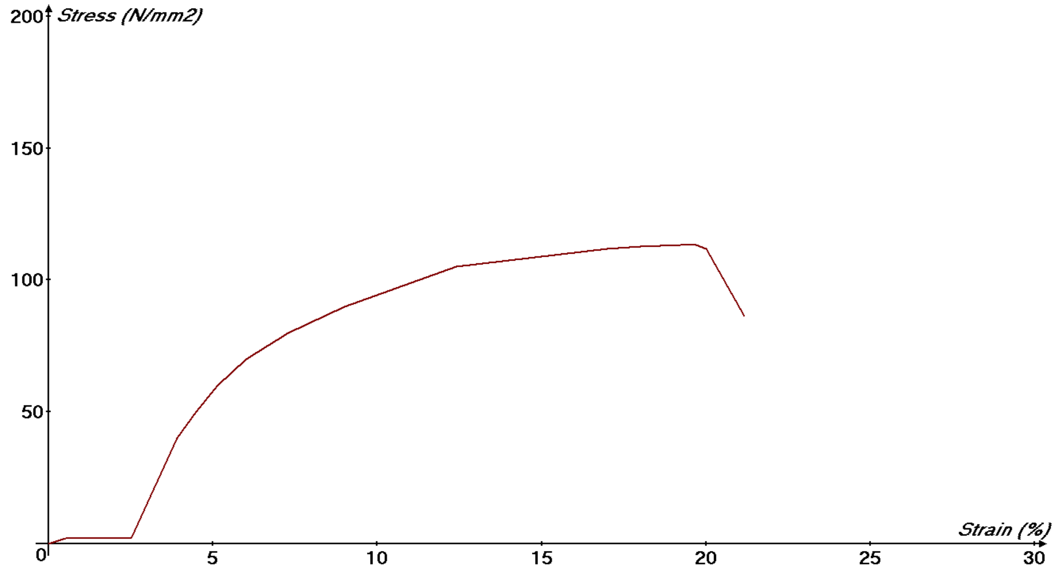
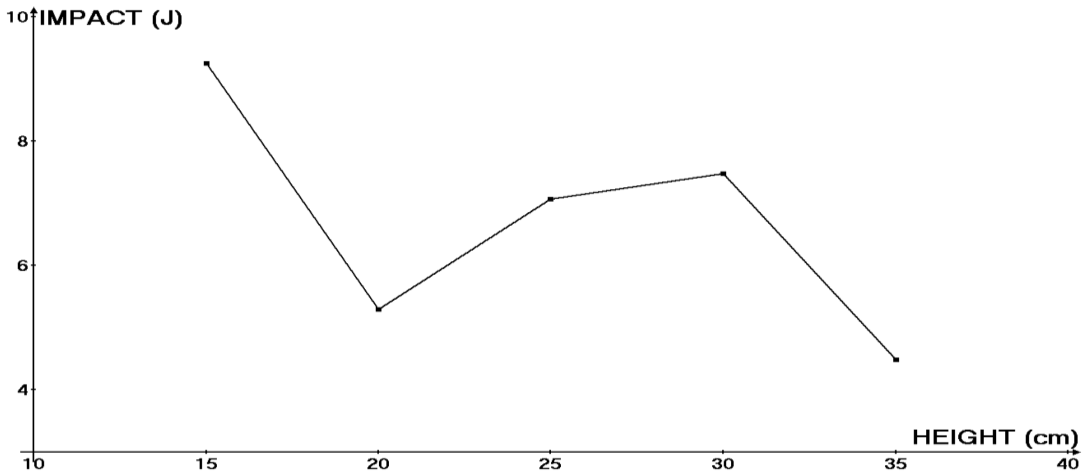
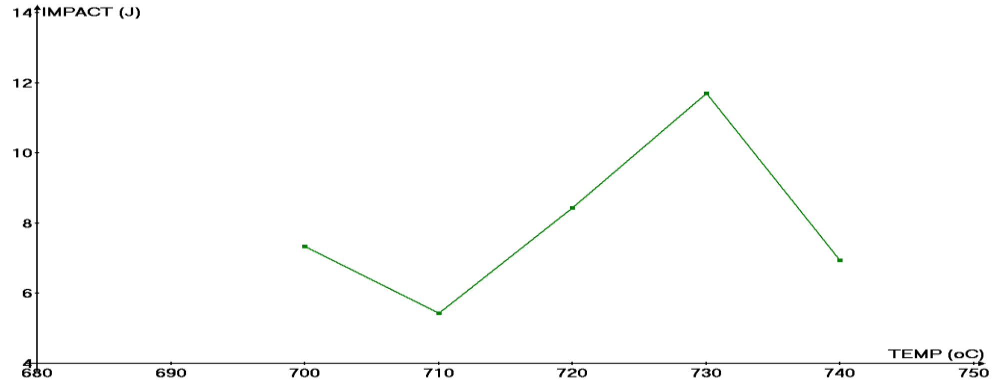



**Fig. 6:** Stress-Strain curve at pouring height of 15 cm

**3.2 Impact Test Results**




**(a) Variation of pouring height with Impact strength**

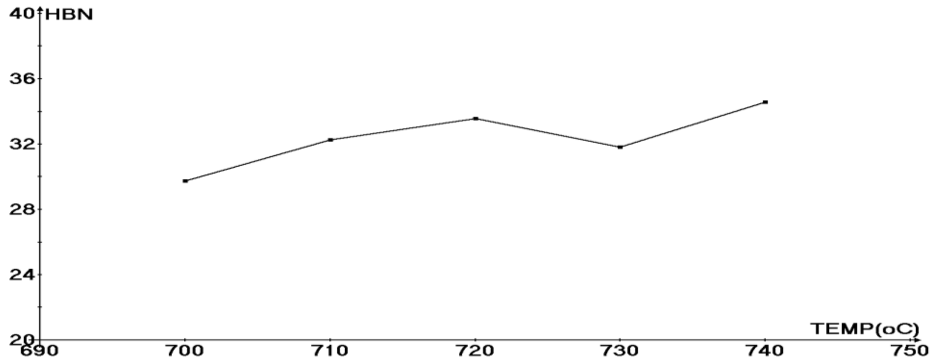



**(b)** **Variation of pouring temperature with Impact strength**

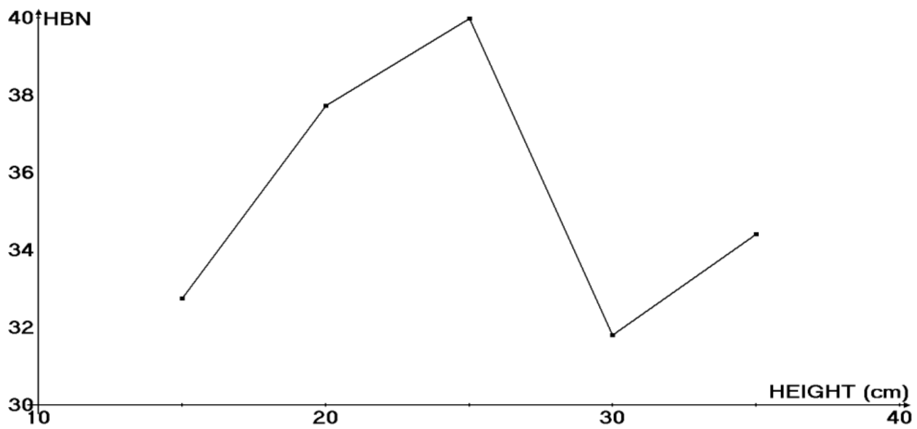

**(c)** **Variation of pouring speed with Impact strength**

**Fig.7:** Impact test results at varying casting parameters

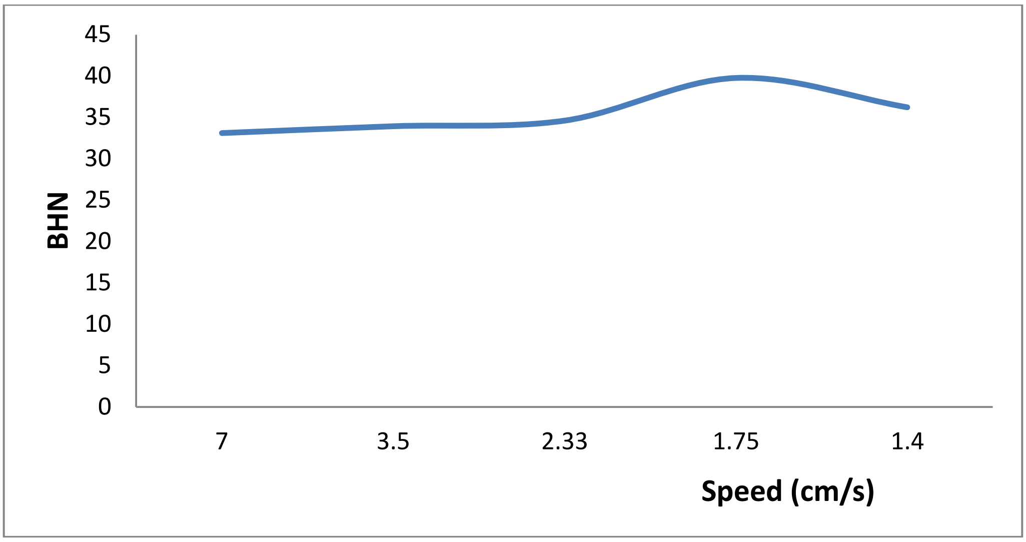
### 3.3 Hardness Test Results




**(a)** **Variation of pouring temperature with hardness number**




**(b)** **Variation of pouring height with hardness number**




**(c) Variation of pouring speed with hardness number**

**Fig. 8:** Hardness Test results at varying casting parameters

### 1.4 Summary of Casting Parameters Effects on Mechanical Properties

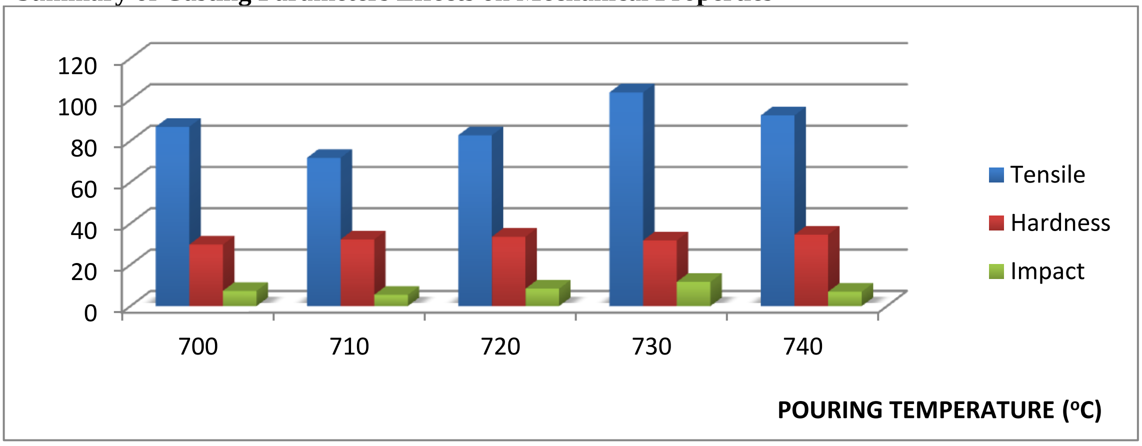



**Fig. 9:** Influence of pouring temperature on mechanical properties

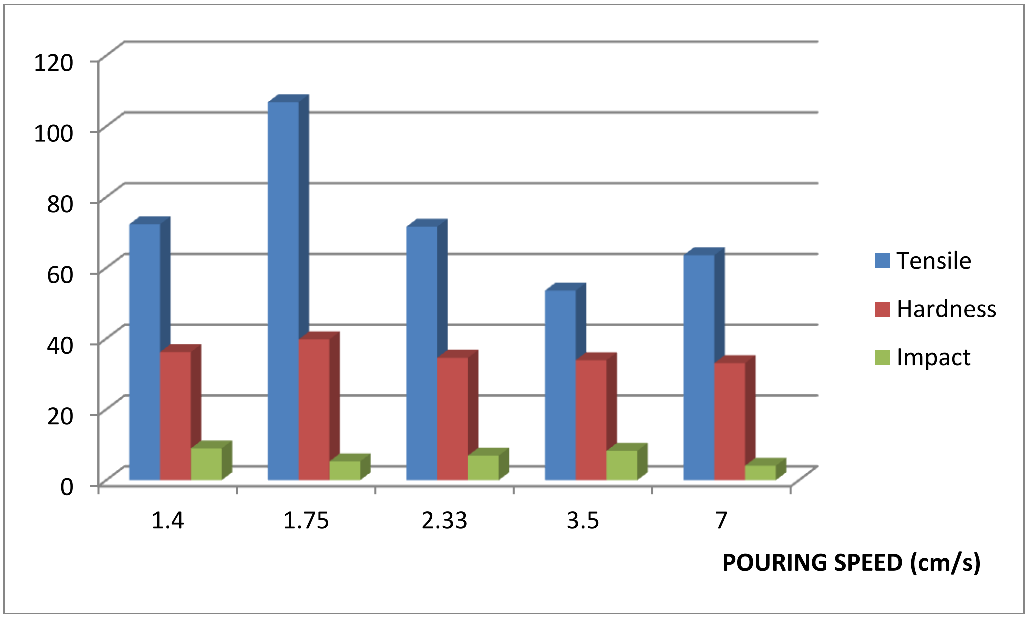



**Fig.10:** Influence of pouring speed on mechanical properties

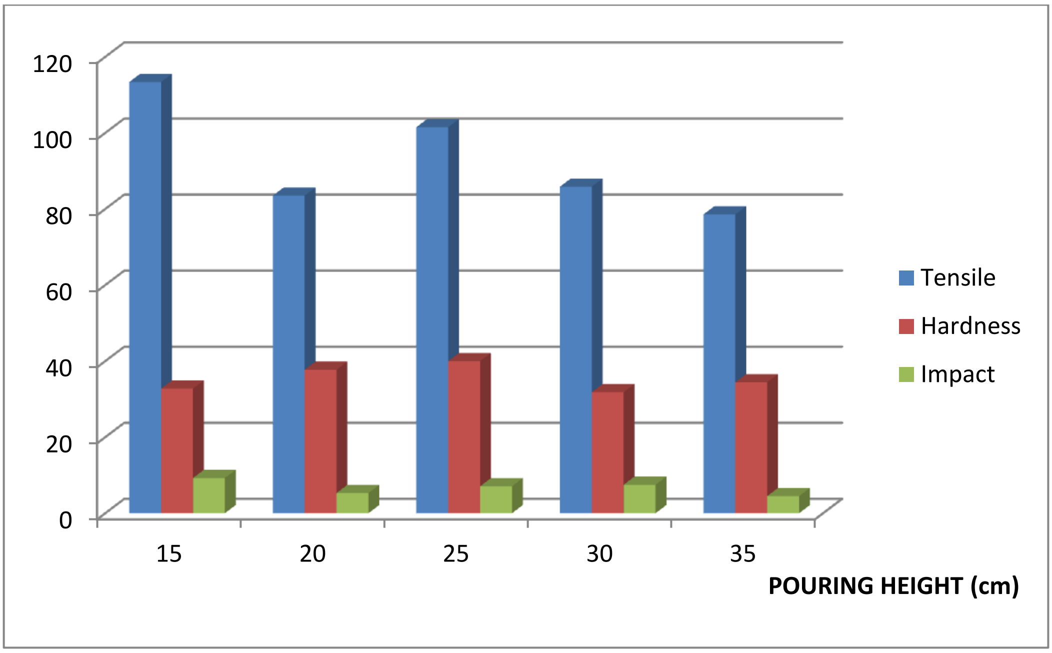



**Fig. 11:** Influence of pouring height on mechanical properties

**3.5 Summary of Casting Parameters Effects on Microstructural Evolution**

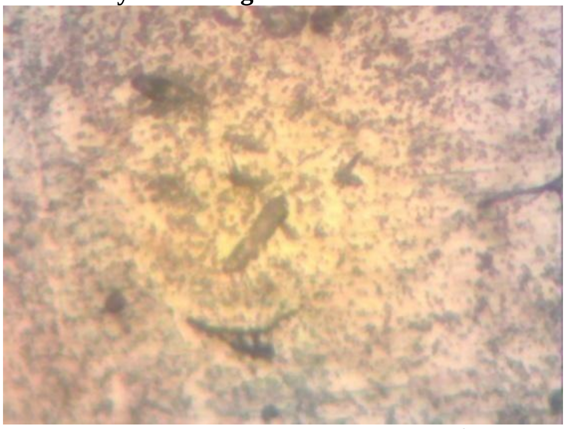


**Fig. 12: Pouring temperature 730$^o$C**

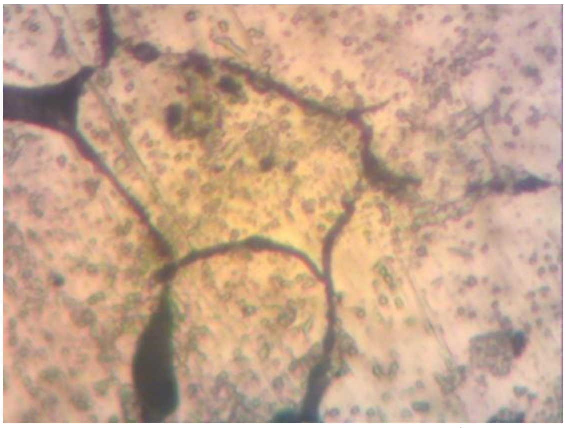


**Fig. 13: Pouring temperature 710$^o$C**

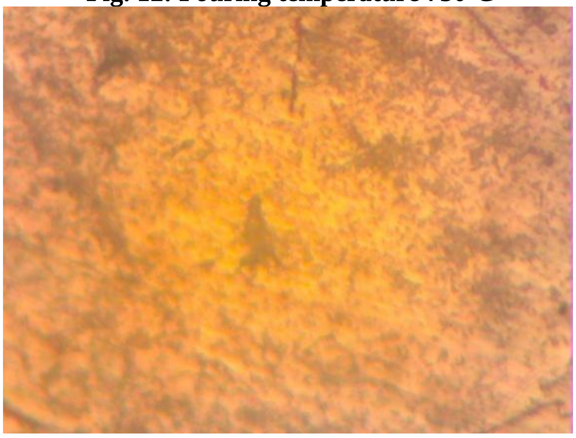


**Fig. 14: Pouring height 15 cm**

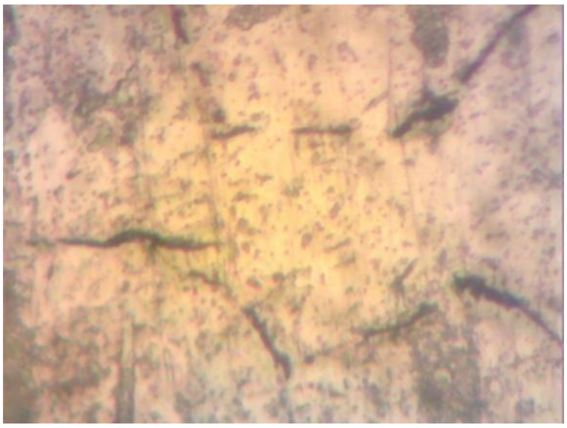


**Fig. 15: Pouring height 35 cm**

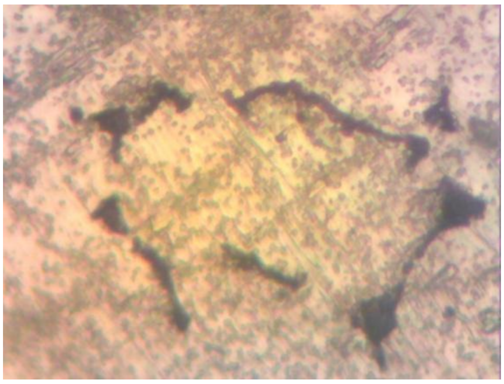


Fig. 16: Pouring speed 7cm/s

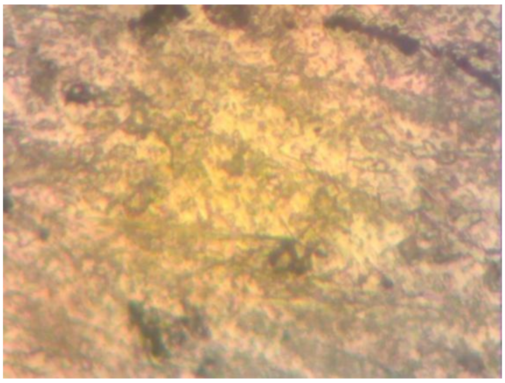


Fig. 17: Pouring speed 1.75 cm/s

**3.6. Discussion of Results**

Figs. 4, 5, and 6 shows representative responses of Al6063 specimen at varying casting parameters under linearly increasing load up to the point of failure where necking and eventually breakage occurred. As pouring speed was varied from 7.0 to 1.4 cm/s, it was observed that the tensile strength decreases initially with increasing pouring speed from 63.396 N/mm$^2$ to 53.57 N/mm$^2$. It reached a maximum value of 106.82 N/mm$^2$ at a pouring speed of 1.75 cm/s as shown in Fig. 4(a). Subsequent increase in pouring speed reduces the tensile strength with the lowest tensile strength value obtained at a pouring speed of 3.5 cm/s as shown in Fig. 4(b). It was found that the tensile strength decreases with increasing pouring temperature at first and later increased up to a point where a maximum value of 103.48 N/mm$^2$ was obtained at 730$^o$C as illustrated in Fig. 5. Subsequently, the tensile strength decreases. The maximum tensile strength value of 113.37 N/mm$^2$ was attained at a pouring height of 15 cm (Fig. 6).

In Fig. 7a, the Impact test results shows an initial increase in value as pouring speed decreases from 7 cm/s to 3.5 cm/s. This however increased to a maximum value of 8.976 J at a pouring speed of 1.4 cm/s. Also from Fig. 7b, as pouring temperature increases from 700$^o$C to 740$^o$C, impact value reduces from 7.344 to 5.44 J. This later increased to its maximum value of 11.696 J at a pouring temperature of 730$^o$C before subsequent decrease. Same trend as observed in Fig. 7b occurred in Fig.7c as the maximum value of 9.25 J was obtained at a pouring height of 15 cm. From Fig. 8a, the hardness value increases initially from a value of 29.76 to 33.58 with pouring temperature at 700$^o$C to 720$^o$C respectively. After the sharp fall of the hardness value, it attained maximum value of 34.59 at the temperature of 740$^o$C. Fig. 8b shows an increase in hardness value up to the maximum point of 39.98 at pouring height of 25 cm before a sharp fall to the minimum value of 31.31 at 30 cm from where it finally increased. From Fig. 8c, there was a slight but uniform increase in hardness value up to its maximum with value of 39.77 at a pouring speed of 1.75 cm/s. It later reduced to a value of 36.21 at speed of 1.4 cm/s.

From Figs. 9, 10 and 11, it was observed that as pouring temperature increases, impact strength, tensile strength and hardness increases. For instance, when pouring temperature increased from 700 to 730$^o$C, tensile strength increased from 86.8 N/mm$^2$ to 103.5 N/mm$^2$, hardness increased from 29.76 to 31.81 kg/mm$^2$, and impact strength increased from 7.34 to 11.6 J. It can be inferred that as pouring temperature increases, the mould cavity was filled uniformly and this resulted in the formation of uniform and fine grain structure during recrystallization. Thus eliminating some of the casting defects such as shrinkage, blow holes which could have caused decrease in the mechanical properties. Further observation indicated that as pouring speed decreases, there was increase in impact strength, hardness, as well as tensile strength. This suggests uniform solidification of the molten metal in the mould cavity thereby forming uniform grain structure.

Fig. 12 shows the micrograph of cast sample at pouring temperature of 730$^o$C. This indicated the presence of closely packed grain size with grain having a low dislocation density. Fig. 13 shows the micrograph at a pouring temperature of 710$^o$C. It can be deduced that there exist a coarse grain structure having a high dislocation density and an increased boundary area. Fig. 14 shows a fine grain structure of a cast sample at a pouring height of 15 cm with an indication of a grain growth occurrence at grain boundaries and a reduction in total boundary area. Fig. 15 gives an indication of a thick grain boundary lines with unequiaxed grains.

Fig. 16 revealed formations of some thick boundary lines at some points and this suggest occurrence of microscopic pinholes. Fig. 17 indicated a fine grain structure and a decrease in total boundary area due to grain growth and boundary motion. A cross examination of the metallographs (Figs.12, 13, 14, 15, 16, and 17) revealed that at a pouring temperature of 730$^o$C, pouring speed of 1.75 cm/s and pouring height of 15 cm, the grain structures are closely packed having a fine grain with large total grain boundary area capable of impeding dislocation motion. This perhaps resulted in the attainment of optimum mechanical properties. The microstructures at pouring temperature of 710$^o$C, pouring speed 7 cm/s, and pouring height 35 cm revealed that there exist a non-uniform microstructure formation within the solidified casting and thus coarse grain structures of larger diameters are formed. This however resulted to its poor mechanical properties when compared to those with fine grain structure having enhanced mechanical properties.

## IV. CONCLUSIONS

The following major conclusions can be drawn from this study:

- A good quality Al6063 cast characterised with fine grain microstructures and enhanced mechanical yield are achievable at the pouring temperature, speed and height of 730$^{o}$C, 1.75 cm/s and 15 cm.
- There are grain growth occurrences and the emergence of precipitates $Mg_2Si$ in the alloy which perhaps were responsible for the observed significant increase in hardness.

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