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Parametric Investigation on the Hardness of an Al-Si Alloy in newly invented setup of Centrifugal Casting (CC)

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Abstract: The current study focuses on how process variables affect aluminum-silicon alloy's hardness in newly invented setup of Centrifugal Casting. Due to a newly created centrifugal casting setup, the qualities of a part can be enhanced at different inclination within 0^0 and 90^0. A hitherto unstudied feature of centrifugal casting, the casting intermediate between vertical and horizontal centrifugal casting is examined here. Hardness acquired during intermediate phases has also been compared to the hardness attained of casting using conventional centrifugal techniques. Here it is comprehended that how process variables like mold inclination angle, RPM, and preheat temp. of mold affect the hardness. Hardness specimens from cylinders were taken to determine the hardness of the cast components. The hardness of each specimen has been determined, and the effects of each control parameter have also been studied. Through experimental research, the optimal values of control parameters have been identified.

Keywords - Casting, Hardness, Mold inclination angle, Mechanical Properties, Preheat Temp, RPM

I. INTRODUCTION

The industrial sector with the fastest global growth right now is casting. [1] Centrifugal process is appropriate for material that has the potential to liquidate. [2] Based on the mold axis direction, centrifugal process is categorized in to horizontal axis and second vertical axis. In horizontal axis m/c, the mold's axis of rotation is parallel to earth surface, and in vertical axis m/c, the mold's axis is perpendicular to earth surface. [3]–[7] Numerous studies have examined the impact of controlling variables like mold's RPM and product solidification rate in centrifugal casting. [8],[9]–[11]. Process variables such as pouring temperature, mold preheating, rotating speed, particle size, shape, and composition influence product's quality. [3],[12], [13] The castings have a large concentration of particles and excellent characteristics because of the close grain structure. [14], [15]. To improve mechanical properties, centrifugal casting controlling parameters can be adjusted. [16]

A technician transfer liquid metal to middle of the mold during the centrifugal casting operation. Bulky particles flow outward from the mold's core due to centrifugal force, while lighter particles stay back at their center. The castings are absolutely free of any porosity flaw, have high densities, and are extremely strong because of the centrifugal action. These castings have shown to be just as important as comparable forgings. The approach is less expensive because it does not require large gates, feeders, or cores. [17].

Researchers have tried several things to enhance the material's properties, including modifying the controlling parameters for the CC process. This article aimed to examine a previously unexplored aspect, inclined mold axis CC technique, and corelate its outcomes to conventional casting process. Examine inclined CC within 0^0 to 90^0 in newly developed CC setup is one of the goals of this study. Current study also evaluates and compares the results obtained using intermediate stages with conventional CC process.

II. MATERIALS AND METHODS

The material for the studies was an Al-Si alloy of the near-eutectic type. Applications of Al-Si alloy is found in automobile industries, military, marine applications, space components, and many more engineering fields due to its excellent resistance to corrosion and outstanding casting capabilities. [18]–[22]

Table 1, displays Al-Si (LM6) alloy contents

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Table 1: Al-Si (LM6) alloy contents

Component	%	Component	%
Silicon	11.7	Nickle	0.01
Iron	0.15	Zink	0.07
Copper	0.09	Titanium	0.001
Manganese	0.23	Tin	0.001
Magnesium	0.09	Lead	0.008
Chromium	0.02	Al	Remaining

Figure 1 illustrates the newly created centrifugal casting setup, which was created to alleviate the drawbacks of earlier centrifugal casting techniques.

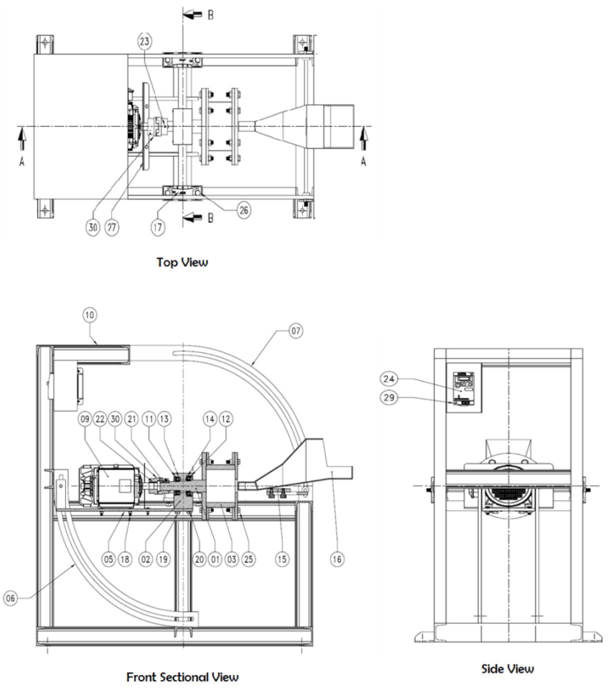

Fig 1: Newly invented setup of Centrifugal Casting [23]

The recently developed setup, illustrated as figure-1 is revolutionary invention for symmetric components. This system produces hollow cylinders without the requirement for a core. The current novel invention, the newly invented setup of Centrifugal Casting, is intended to minimize the disadvantages of conventional centrifugal casting processes while providing users with the benefits of a range of inclination angle for rotary motion of mold in a single machine. [23]

III. EXPERIMENTAL PROCEDURE

Figure 1 shows a newly created centrifugal casting setup. This setup may also carry out intermediate casting between 0° and 90°. The mold for this system was made of mild steel. The mold dimensions are 124 mm length, 20 mm thickness, and 129 mm diameter. The following process variables and their levels were chosen to investigate the impacts of mold inclination, RPM, and also pre-heat temp of mold on casting's mechanical characteristics (hardness), as indicated in table 2.

Table 2: Controlling Parameters with different levels

Controlling Parameter	L1	L2	L3	L4
Mold Inclination Angle	0	30	60	90
Mold RPM	600	800	1000	1200
Pre-heat Temp. of Mold (^{o}C)	180	200	220	240

An experimental table was created using the aforementioned parameters with levels, as shown in table 3.

Table 3: Design of Experiments

Sr. No.	Mold Inclination Angle (θ)	Mold RPM	Preheat Temp. of Mold (°C)
1	0°	900	210
2	30°	900	210
3	60°	900	210
4	90°	900	210
5	45°	600	210
6	45°	800	210
7	45°	1000	210
8	45°	1200	210
9	45°	900	180
10	45°	900	200
11	45°	900	220
12	45°	900	240

A few pre-stages must be followed before centrifugal casting to ensure flawless casting. A thermoelectric voltage comes in to picture due to vast temperature variation among liquid metal as well as the mold walls, which might potentially shorten the mold's life and damage the coating on the mold walls. As shown in figures 2(A) and (B), a mold is preheated and its temperature is measured in order to reduce the detrimental thermoelectric voltage's effect. Pre-heating a mold is dominant factor impacting centrifugal casting quality [24]. In order to avoid chilling, porosity, segregation, and to compensate for shrinkage throughout casting, the first mold is heated to around 200 ^{0}C [25]. Figure 2(C) shows how the graphite coating was applied to the internal wall of the mold in this investigation after preheating it.

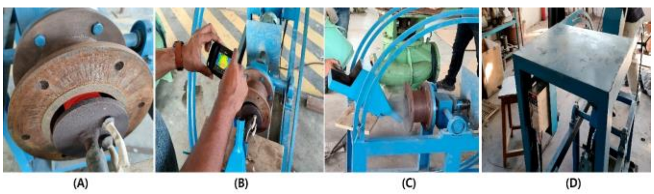

Fig-2: (A) Heating of the mold (B) Temp. measurement after heating (C) Mold coating (C) VFD to control RPM

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At 730 °C, an aluminium silicon alloy that was nearly eutectic melted. As seen in figure 3, thermocouple was used to determine the pouring temp. In CC process, RPM of mold must be adjusted before transferring liquid metal to the mold. RPM of the mold is responsible for sound casting [26]. RPM of the mold was managed using a variable frequency drive, as seen in Figure 2. (C)

Fig 3: Temperature measurement of Metal (Converted in to liquid phase)

The centrifugal casting is typically divided into two categories: horizontal casting and vertical casting. However, this study also investigates casting at intermediate angles between 0° and 90°. In figure 4, various pouring positions are displayed. The flow of molten metal has a considerable impact on the completed cast product's quality [27]. Compared to other casting methods, the centrifugal casting process cools more quickly. This setup has a unique hopper shape that allows it to quickly fill whole mold to avoid erroneous mold filling.

Fig 4: Position of Pouring at (A). Horizontal, (B). Inclined, (C). Vertical

The casted cylinder's removal is seen in Figure 5(A). The coating used before transferring the liquid state metal to the mold makes it straightforward to remove the casting from the mold. Figure 5 (B) shows a cylinder just after machining, and it is evident from the DP Test that the surface is not porous. The cylinder is clearly devoid of surface flaws, as seen in figure 5. (C).

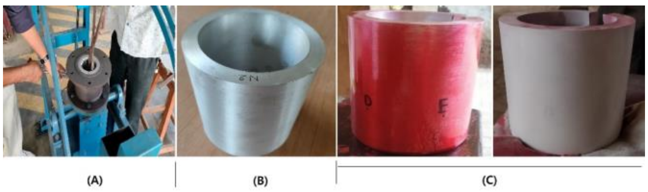

Fig 5:(A) Cylinder extracting from mold (B) Secondary machining (C) DPT

As illustrated in figure 6, three hardness specimens from the top and bottom of each cylinder were made to measure the hardness of the casting from each cylinder. Also, as per figure-7, hardness specimen prepared from the upper portion and bottom portion of the cylinder. After the hardness specimens were prepared, a Vickers Hardness Tester with method (IS 1501 (P1):2013 Ra.2018) was used to measure the hardness at mentioned sections of each specimen prepared, as shown in figure-6. With the use of equation (i) and the final hardness value summarized in table 4, an average of three measurements (Vickers hardness) was calculated.

$$Average\ Hardness\ Value\ (HV5) = \frac{(HV5-1+HV5-2+HV5-3)}{3} \ldots\ldots(i)$$

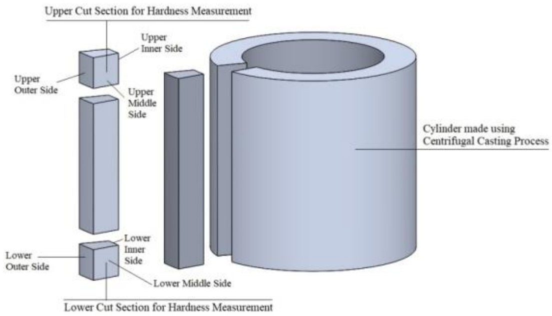

Fig 6: Diagram of the hardness specimen

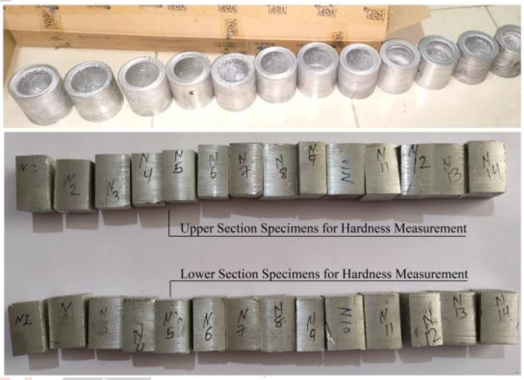

Fig 7: Casted Cylinders and Hardness specimen cut from the cylinders

Table 4: Hardness Value at upper section

Sr No.	Mold Inclination Angle (θ)	Mold RPM	Preheat Temp. of Mold (°C)	Vickers hardness (HV5) (Upper Section)		
				O*	M*	I*
1	0°	900	210	65	62	59
2	30°	900	210	69	68	65
3	60°	900	210	69	68	65
4	90°	900	210	68	65	63
5	45°	600	210	67	62	60
6	45°	800	210	72	68	66
7	45°	1000	210	63	59	59
8	45°	1200	210	65	63	61
9	45°	900	180	64	64	63
10	45°	900	200	68	64	60
11	45°	900	220	68	68	64
12	45°	900	240	67	65	63

O-Outer, M-Middle and I-Inner

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Table 5: Hardness value at lower section

Sr No.	Mold Inclination Angle (θ)	Mold RPM	Preheat Temp. of Mold (°C)	Vickers hardness (HV5) (Lower Section)		
				O*	M*	I*
1	0°	900	210	65	62	59
2	30°	900	210	67	66	64
3	60°	900	210	67	66	65
4	90°	900	210	67	65	60
5	45°	600	210	65	61	60
6	45°	800	210	69	67	66
7	45°	1000	210	61	60	65
8	45°	1200	210	65	63	61
9	45°	900	180	64	64	63
10	45°	900	200	67	64	59
11	45°	900	220	66	66	63
12	45°	900	240	66	66	64

O-Outer, M-Middle and I-Inner

The hardness of an Al-Si alloy centrifugally produced is depicted in Figures 8, 9, and 10 at various mold inclination angles, mold RPMs, and mold preheating temp.

Impact of Mold inclination angle on hardness:

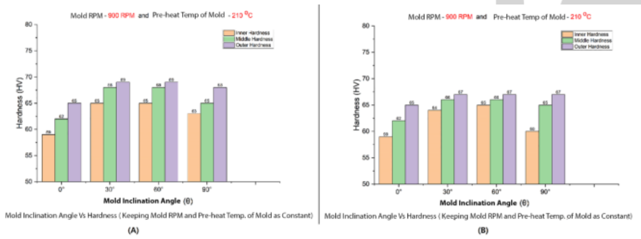

Fig 8: Impact of Mold inclination angle on hardness (A) Upper Section (B) Lower Section

According to figure-8, Vickers hardness increases for each inclination angle (at mold inclination angle 0^o to 90^o) from inner to outer section. It is because the particles feel the centrifugal force. Heavy particles are forced toward inner surface of mold, and impurities as well as light particles feel less centrifugal force than heavy particles. Additionally, it is evident that at intermediate angles (mold inclination angle 30^o as well as 60^o) in both upper cut section (figure-8 (A)) and lower cut section (figure-8 (B)), compared to conventional centrifugal casting methods, the value of hardness is higher It might be because centrifugal casting has a length-to-diameter ratio restriction. Conforming to figure 9, inclination angles of mold help to overcome length and diameter constraint.

Impact of Mold RPM on Hardness:

As shown in figure-9 (A) and (B), the hardness values increase up to 800 RPM of the mold; after that, hardness has been reduced. It can be seen that hardness values are lesser at 1000 RPM and 1200 RPM than at 800 RPM. It is also clear that the hardness value mostly shows an increasing pattern from the inner to the outer section

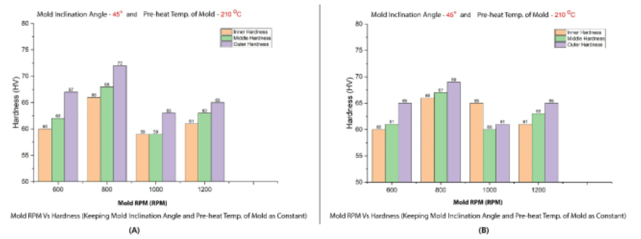

Fig 9: Impact of Mold RPM on Hardness (A) Upper Section (B) Lower Section

At lower RPM, centrifugal force is less, so the molten metal does not feel sufficient force to have a higher hardness value. Also, molten metal does not have force in the proper pattern at higher centrifugal force to have a higher hardness value. The optimized rotational speed is 800 RPM, where the highest hardness value is achieved.

Impact of Preheat Temp. of Mold on the Hardness:

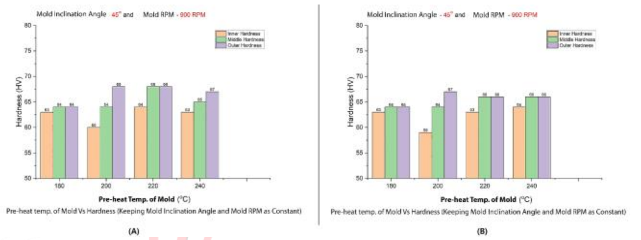

Fig 10: Impact of Preheat Temp. of Mold on the Hardness (A) Upper Section (B) Lower Section

Mold lifespan and mold coating degradation both avoided mostly by preheat temp. of mold. A significant difference in temp. will result from the interaction of high-temp. liquid metal with a mold that is held at ambient temperature. If difference in temperature is not properly managed, it can decrease the mold's lifespan and damage its covering. Therefore, it's indeed shown in figure 10 that hardness rises to 220 ^{o}C. Following that, it displays a descending trend, indicating that 220 ^{o}C seems to be the ideal pre - heating temp for mold in this configuration and material.

IV. Conclusion

The newly developed centrifugal casting technique was designed to investigate the feasibility of interim casting between 0^0 and 90^0. The hardness of a near-eutectic aluminum-silicon alloy cylinder was investigated the use of many process parameters such as mold inclination angle, mold RPM, and mold Preheat temp. To generate cylindrical specimens, typical centrifugal casting and different mold inclination angles between 0^0 and 90^0 were used. The following conclusions were derived after comparing the hardness of specimens formed using intermediate stages to those made using the traditional centrifugal casting technique.

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1. Compared to conventional centrifugal casting techniques, the hardness at intermediary mold inclination was examined and determined to be superior because it has the advantages of mold inclination. Due to this, it can minimize the demerits of horizontal and vertical centrifugal casting processes.
2. Hardness increases up to 800 RPM. After 800 RPM, the declining graph was observed because 800 RPM is the optimum speed for hardness for Al-Si alloy.
3. The mold's Preheat temp is 220 0C to offer an appropriate Preheat temp for enhanced component hardness. It is a critical factor that must be carefully evaluated and addressed.

According to research work, the optimal mold inclination angle value is 60, the mold RPM value is 800, and the mold's preheat temperature is 220 0C. Because both conventional centrifugal casting techniques have Length to diameter ratio restrictions, intermediate stages often exhibit better hardness values than conventional centrifugal casting methods. Also, intermediate stages counter the adverse effect of low RPM in vertical centrifugal casting.

Future Scope:

To fully comprehend the precise impacts of various controlling parameters at each mold inclination angle in centrifugal casting, In-depth investigation between 0^0 and 90^0 is necessary.

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Declaration:

The author states having no conflicts of interest to disclose.

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