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Evaluation of Mechanical Properties and Microstructural Study of AlSi Alloy Developed by Horizontal Centrifugal Casting Technique

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Abstract: ***Mechanical characteristics of Al-Si alloys can be optimized for the specific application depending upon the demands in various engineering sectors by the combinations of relevant material constituents and processing parameters. In recent years, many manufacturing techniques have been proposed, among them centrifugal casting technique is one of the attractive method for producing cylindrical component of Al-Si alloys with higher density. In this paper, Al-10wt%Si, Al-20wt%Si and Al-30wt%Si alloy were cast by varying mold rotational speed. In this method, mold rotational speed and fluid flow plays a major role and understanding the flow process is important for the production of defect-free castings. The effect of various processing parameters to form a uniform cylinder during horizontal centrifugal casting process has been discussed. The microstructure, tensile strength, impact strength and hardness of cylindrical component have been discussed. The uniform cylindrical component was formed above 600RPM of mold rotational speed. At 800RPM better mechanical properties were observed. Also, fine structured grain size with high hardness values were observed when compared with other rotational speed.***

Key words – rotational speed, fluid flow, centrifugal casting, tensile strength, hardness, microstructure,

I. INTRODUCTION

The centrifugal casting method is one of the most straightforward and economical methods to produce functionally graded materials (FGMs) with continuous gradients among all manufacturing techniques [1]. It is a special type of casting process used for making hollow parts by rotating the mold at a predefinedRPM and pouring the molten metal at a uniform rate from a pouring basin. In the revolving mold, the molten metal solidifies and conforms to the cylindrical shape. In centrifugal casting process, the mechanical properties of material are considered as more critical than the dimensional characteristics.

Factors that influence centrifugal casting are metal pouring temperature, mold temperature prior to pour, mold rotational speed, rate of solidification, pouring time, centrifugal force, fluid flow. Centrifugal force and rapid solidification rate lead to the development of finer equi-axed grain structures. The crystals will grow when the liquid is in contact with the mold wall and will grow up to the rest of the molten metal freezes uniformly toward the interior of the casting, and the casting produces a smooth surface without any shrinkage defects [2]. Equiaxed grain helps to obtain homogeneous and isotropic mechanical properties.

The mold rotational speed has a significant impact on the mechanical properties of the alloy and influences the grain size [3][4]. At lower rotational speeds and higher cooling rates, better particle distribution and fine microstructure can be obtained [5][6][7]. The centrifugal effect is alloy-dependent and well correlated with the eutectic volume fraction of the alloy. And also, strain to failure and ultimate tensile strength can be satisfactorily correlated with the eutectic volume fraction [8].

Different flows were observed in the centrifugal casting process before a full length cylinder was formed (e.g., Couette Flow, Ekmann Flow, and Taylor Flow). Among those flows, Ekmann Flow disturbs the fluid flow at a lower aspect ratio (decrease in mold length). The Couette Flow, Ekmann Flow, and Taylor Flow will be more prominent at lower rotational speeds, resulting in castings with uneven inner surfaces. With the increase inRPM, the liquid metal forms a uniform cylinder avoiding all types of disturbing flows. Viscosity plays a vital role in the formation of uniform cylinders. For low viscosity fluids, the formation of uniform cylinders occurs at higher rotational speeds, and for high viscosity fluids, the uniform cylinders are formed at lower rotational speeds [9][10]. High initial pouring and mold temperatures, increase the effect of viscosity variation on particle segregation [11].

Fluid flow inside the rotating mold depends on its viscosity, which is driven at higher mold speed and at its lower value. Low viscous melt teem the mold upper surface and reduces the melt weight [12]. The most common interior flaw is shrinking caused by the solidification process beneath the smaller sections. The microstructure changed from a fine grain on the surface to a relatively coarse grain in the interior. Because of the shift in microstructure, microhardness profiles on the cross-section showed a decreasing trend from the surface to the inner area [13]. The centrifugal force and rapid cooling of molten metal in contact with the mold's inner surface prevents the migration of particles towards the inner wall of the component [14][15].

Aluminum alloys are commonly employed in engineering structures and components that require low weight and corrosion resistance. Copper, magnesium, manganese, silicon, and zinc, etc, are most commonly used as an alloying element in aluminum alloys. The 7000 series of aluminum has the highest strength of any metal currently available on the market. Due to these, several literatures were found in the last few years. Silicon has a low density that can aid in reducing the overall weight of the cast component. Although silicon has minimal solubility in aluminum alloys, it precipitates as nearly pure silicon, which is hard and enhances abrasion resistance. At 12.6 wt% silicon, aluminum-silicon alloys form a eutectic with a temperature of 577°C. Since it has the lowest melting temperature, this indicates a typical casting alloy composition [16]. Al-Si alloys with greater than 12% Si have a hypereutectic microstructure, which indicates it contain primary silicon phase in the eutectic matrix [17].

From literature reviews, it has been observed that there are various parameters that influence the properties of centrifugally-cast Al-Si alloys. But still there is a gray area to improve mechanical properties of centrifugal cast. The present article is an attempt to develop and characterize the mechanical properties of Al-Si alloys. The rapid growth in the application of Al-Si alloys in various industries made to reduce the literature review to a feasible level by concentrating on the fluid flow and microstructure study of Al-Si alloy. The work carried out here, is concerned with effects of mold rotational speed and fluid flow on development and microstructure study of Al-Si alloy. Important observations from the work are outlined in the conclusions.

A. Centrifugal Casting Process

Centrifugal casting is a unique form of casting technique for metals. The casting process occurs inside the hollow shaped mold that spins rapidly. Schematic illustration of centrifugal casting process is shown in Fig. 1. Centrifugally cast specimens show higher densities in the outermost regions. The centrifugal casting process uses a permanent mold that is rotated about its axis at a predefined speed as the molten metal is poured.

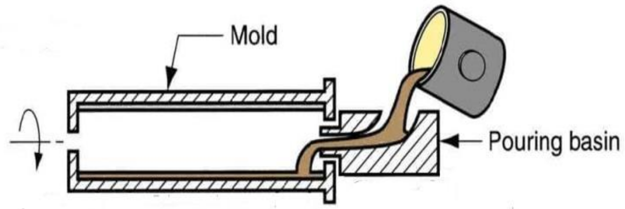

Fig.1. Schematic representation of centrifugal casting process

Centrifugal force causes the melt to be pushed out towards the mold walls, where it solidifies after cooling. Centrifugally cast specimens have a fine grain microstructure, which is resistant to atmospheric corrosion; hence this method has been used to manufacture cylindrical components. Since metal is heavier than impurities, most of the impurities and inclusions are moved closer to the inner diameter and can be machined away.

II. EXPERIMENTAL DETAILS

The experimental setup of the horizontal centrifugal casting machine is shown in Fig. 2. A cylindrical mold is mounted to a driving flange in a horizontal centrifugal casting machine. The driving flange is connected to the 2HP DC motor through a shaft, the DC motor speed can be varied from 10 to 2000RPM with the speed controller. The temperature of the electrical furnace is controlled by thermocouple activated controlling unit. Mass required for the casting of cylindrical specimen having thickness 6mm is calculated as follows.

Mass, $m = \rho \times V$

Where, density $\rho = 2710\ kg/m^3$ for Al-Si alloy

Volume, $V = \pi (R^2 - r^2)$ for hollow cylinder

R = Outer radius of cylindrical specimen

r = Inner radius of cylindrical specimen

The calculated mass of Al-Si alloy to be melted is placed inside the graphite crucible, which in-turn is kept inside the electrical heating furnace. The temperature of the electrical furnace is pre-set to 8500C in the control unit. The mold is preheated to temperature 200^0C with the help of a blow torch before liquid metal is poured into the rotating mold.

The crucible containing melt is taken out of the electrical furnace and the melt alloy is then poured into the rotating mold of the horizontal centrifugal casting machine through a pouring basin. The molten metal conforms to the shape of the mold and the cast cylinder is taken out. Specimens having ϕ80mm outer diameter, 110mm length and 6mm thickness are centrifugally cast by varying mold rotational speeds of 400RPM, 600RPM, 800RPM, 1000RPM, and 1200RPM. The rotating mold speed is set and adjusted to ±5RPM before pouring the melt and continued to rotate for at-least 2 minutes after liquid metal poured and allowed for adequate solidification.

Further, the cast specimens were subjected to tensile test, hardness test, impact test in order to evaluate their mechanical characteristics and to study the microstructure of centrifugally cast specimens.

TABLE I. CHEMICAL COMPOSITION OF AL-10WT%SI ALLOY

Al	%Si	%Fe	%Cu	%Mn	others
Base	10.04	0.25	0.027	0.03	< 0.01

TABLE II. CHEMICAL COMPOSITION OF AL-20WT%SI ALLOY

Al	%Si	%Fe	%Cu	%Mn	others
Base	20.07	0.29	0.021	0.02	< 0.01

TABLE III. CHEMICAL COMPOSITION OF AL-30WT%SI ALLOY

Al	%Si	%Fe	%Cu	%Mn	others
Base	30.11	0.31	0.020	0.05	< 0.01

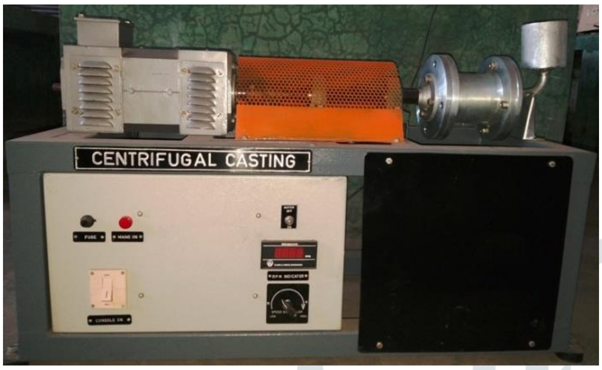

Fig.2. Centrifugal casting setup

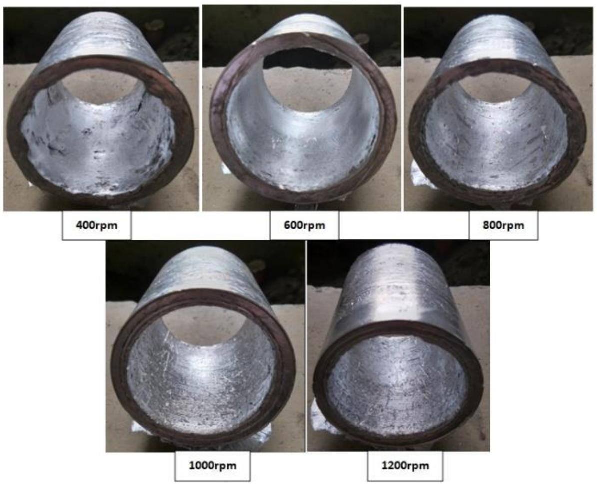

Fig.3. Pictorial view of Al-10wt%Si cast specimens obtained at various rotational speeds

The chemical composition of Al-Si alloys with varying wt% of silicon is shown in the tables. Also, Fig. 3 to Fig. 5 shows the pictorial view of cast specimens produced by varying mold rotational speed.

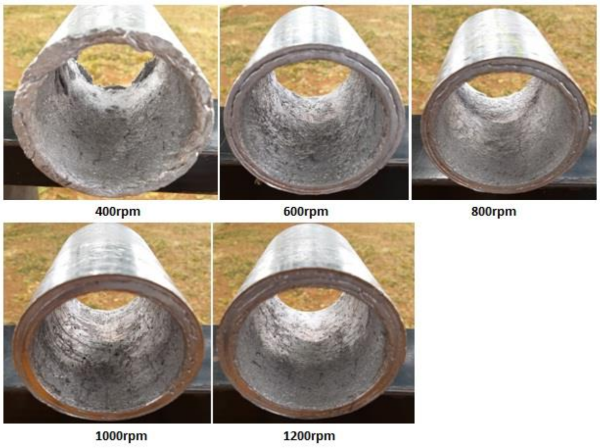

Fig.4. Pictorial view of Al-20wt%Si cast specimens obtained at various rotational speeds

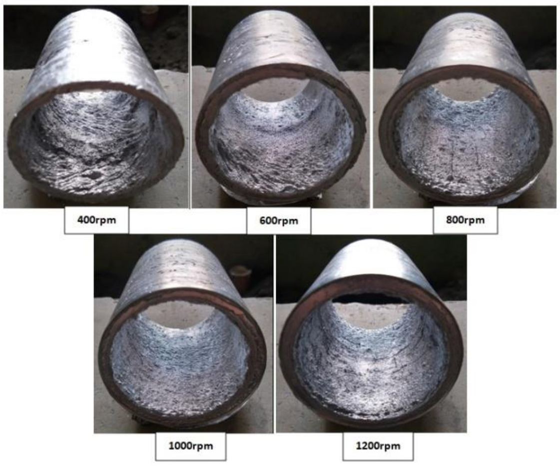

Fig.5. Pictorial view of Al-20wt%Si cast specimens obtained at various rotational speeds

III. RESULTS AND DISCUSSION

In the centrifugal casting process, mold rotational speed plays a major role in moving the melt Al-Si alloy along the mold inner circumference. At a lower rotational speed, formation of uniform cylinders throughout the length of the mold is not possible. At an optimum rotational speed, a full length cylinder is formed and prevents raining of molten metal, when the melt flows through the upper half section of the rotating mold. Centrifugal force pushes the molten metal towards the inner wall of the rotating mold and overcomes the slip between liquid metal and mold wall. The following test has been carried out in order to evaluate mechanical properties.

A. Tensile strength of as-cast Al-Si alloys

Tensile test were conducted at room temperature on centrifugally cast specimens to assess mechanical properties of Al-10wt%Si alloy, Al-20wt%Si alloy, and Al-30wt%Si alloy. Cast specimens were prepared for tensile testing as per the standards of ASTM E8M-16a. Fig. 6 shows the specimen prepared for tensile testing. The prepared specimens were subjected to tensile loads by a universal testing machine. The load versus displacement graph was plotted for each specimen, which was centrifugally cast at rotational speeds of 400RPM, 600RPM, 800RPM, 1000RPM, and 1200RPM. From the graph, it clearly depicts that, there are rapid changes in the curve with the applied load for the corresponding deflection. The maximum load taken by the specimen, ultimate tensile strength and the corresponding deflection were recorded.

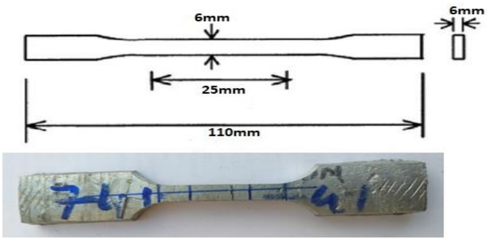

Fig.6. Tensile test specimen

The Fig.7 (a) (load v/s displacement) shows the mechanical behavior of Al-10wt%Si alloy cast at mold rotational speed 400RPM. It is observed from the graph that the maximum load taken by the specimen is 3.59KN with the corresponding elongation of 3.72% and ultimate tensile strength 105.03MPa.

From the graph, it is found that material is unable to take up further increases in load so that fracture of the specimen takes place immediately when the load is applied beyond this peak load. Similarly, for mold rotational speeds 600RPM, 800RPM, 1000RPM, 1200RPM the maximum loads taken by the specimens are 4.75KN, 5.65KN, 5.23KN, 4.69KN and the corresponding elongations are 3.68%, 6.10%, 4.65%, 2.30% and the corresponding ultimate tensile strength are 129.85MPa, 148.30MPa, 139.55MPa, 123.61MPa. From the observation of graphs, it is clearly depict that at mold rotational speed 800RPM, specimen experience maximum ultimate tensile strength among all other rotational speeds.

The Fig.8 (a) (load v/s displacement) shows the mechanical behavior of Al-20wt%Si alloy cast at mold rotational speed 400RPM. It is observed from the graph that the maximum load taken by the specimen is 2.40KN with the corresponding elongation of 1.21% and the ultimate tensile strength 49.92MPa.

When the load is applied beyond the peak load, the material is found to be unable to withstand further increases in load, causing the specimen to shatter instantaneously. Similarly, for mold rotational speeds 600RPM, 800RPM, 1000RPM, 1200RPM the maximum loads taken by the specimens are 3.25KN, 4.20KN, 3.80KN, 2.66KN and the corresponding elongations are 1.52%, 2.43%, 2.81%, 2.63% and the corresponding ultimate tensile strength are 81.24MPa, 104.52MPa, 87.06MPa, 68.87MPa. From the observation of graphs, it is clearly depict that at mold rotational speed 800RPM, specimen experience maximum ultimate tensile strength among all other rotational speeds

The Fig.9 (a) (load v/s displacement) shows the mechanical behavior of Al-30wt%Si alloy cast at mold rotational speed 400RPM. It is observed from the graph that the maximum load taken by the specimen is 0.59KN with the corresponding elongation of 1.56% and ultimate tensile strength 18.33MPa.

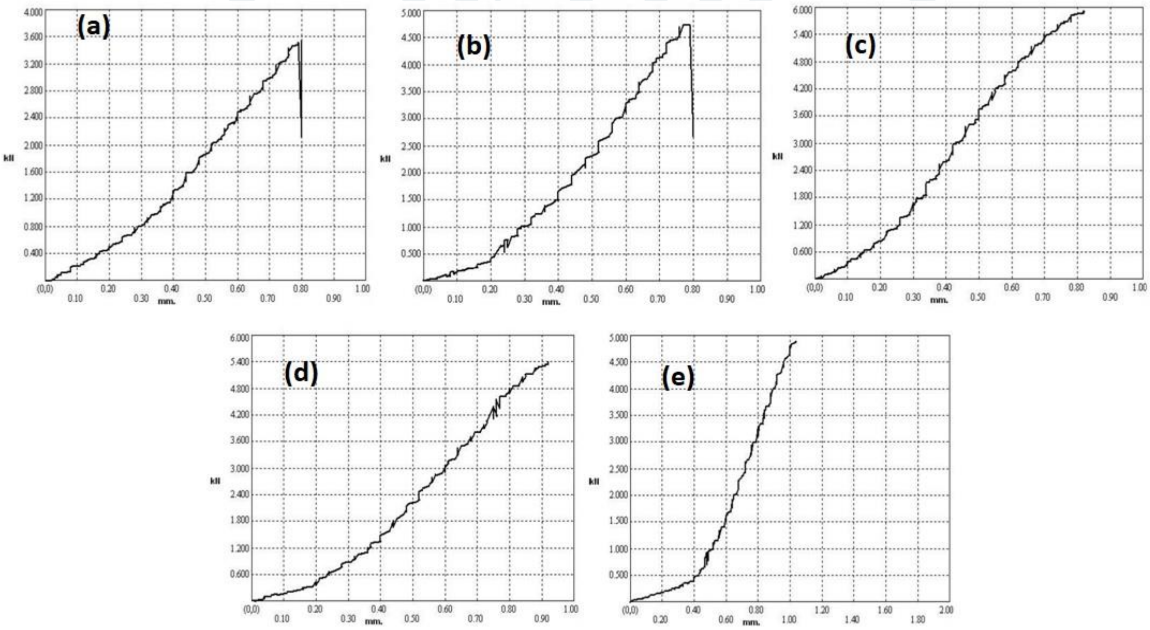

Fig.7. Load v/s displacement for Al-10wt%Si alloy at rotational speed (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM and (e) 1200RPM

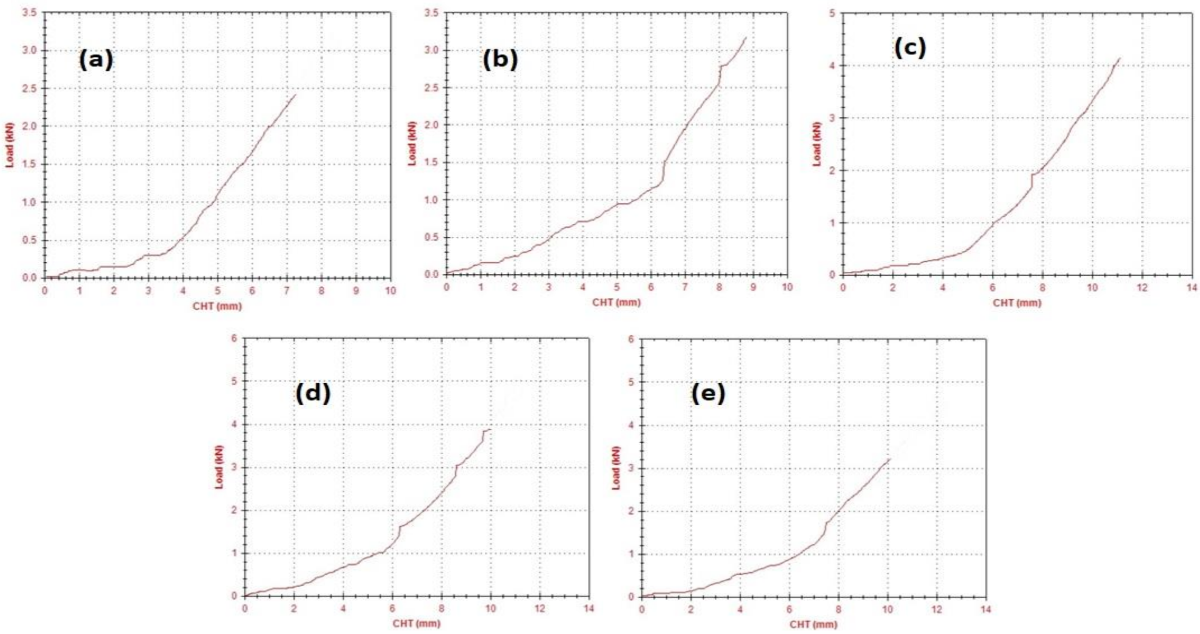

Fig.8. Load v/s displacement for Al-20wt%Si alloy at rotational speed (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM and (e) 1200RPM

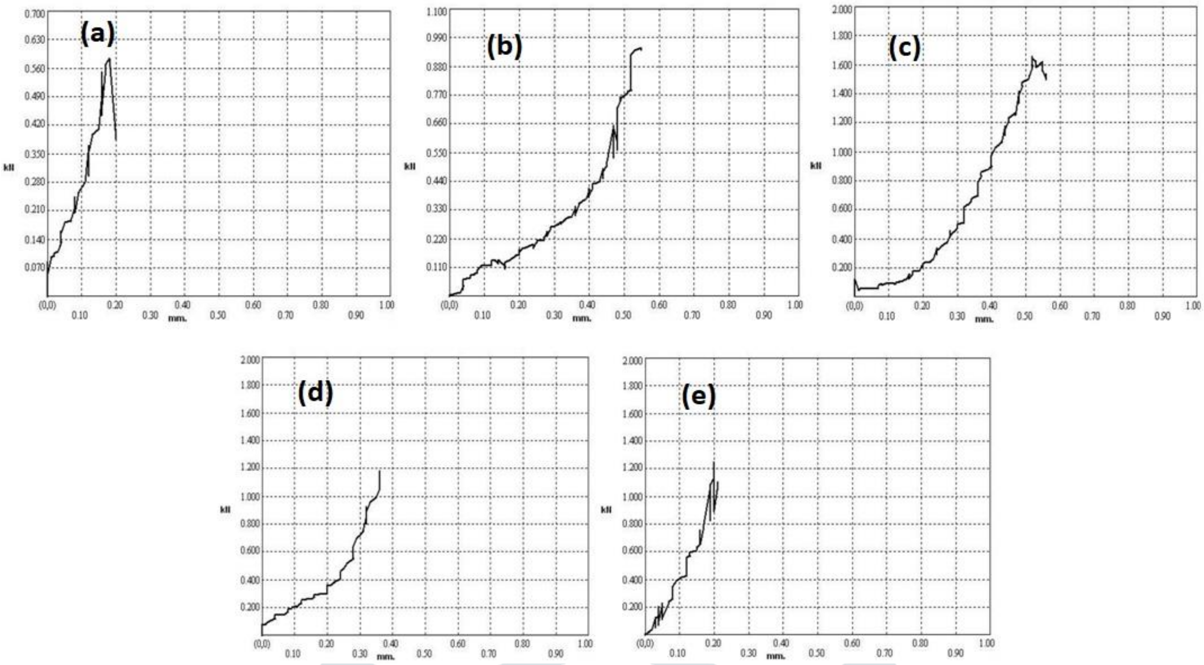

Fig.9. Load v/s displacement for Al-30wt%Si alloy at rotational speed (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM and (e) 1200RPM

When the load is applied beyond the peak load, the material is found to be unable to withstand further increases in load, causing the specimen to shatter instantaneously. Similarly, for mold rotational speeds 600RPM, 800RPM, 1000RPM, 1200RPM the maximum loads taken by the specimens are 0.96KN, 1.69KN, 1.19KN, 1.22KN and the corresponding elongations are 1.69%, 2.12%, 1.65%, 1.63% and the corresponding ultimate tensile strength are 29.45MPa, 47.37MPa, 35.73MPa, 34.69MPa. From the observation of graphs, it is clearly depict that at mold rotational speed 800RPM, specimen experience maximum ultimate tensile strength among all other rotational speeds.

The full length cylindrical specimen was formed at 800RPM due to uniform spreading of the molten metal after teeming into the mold. It had a low viscosity during its upward motion, spread across, uniformly forming good casting. The solidification rate is more due to uniform spreading of the melt and forming fine grain structure.

B. Microstructure of as cast Al-Si alloys

The cylindrical specimens were prepared as per IS: 7739 part-III - 1975 RA 2018, An OYMPUS Microscope BX51M with Clemex Image analyzer equipment was used to study the microstructure of all cylindrical specimens.

Sequential steps have been carried out to prepare cylindrical specimens of Al-Si alloy for microstructural investigations. The metallographic specimen preparation process for microstructural investigations of Al-Si alloy specimen usually consists of five stages - sampling, cold or hot mounting, grinding, polishing, and etching with suitable etchant to reveal the microstructure each cylindrical specimens.

Fig.10. Al-Si alloy specimen prepared for the study of microstructure

The graded distribution of aluminum and silicon alloy along the radial direction is observed in all the centrifugally cast cylindrical specimens. It can be seen that the microstructure consists of eutectic silicon dispersed in the interdendritic region and fine precipitates of alloying elements in the matrix of aluminum solid solution were observed. Also, small quantities of coarse primary Si phase and needle-like eutectic microstructure with coarse alpha-aluminum dendrite were observed.

Fig.11 shows the microstructure of Al-10wt%Si specimens which were centrifugally cast at (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM, and (e) 1200RPM. Specimens were observed under microscope and it was found that there is a partial modification in the eutectic silicon for specimens obtained at mold rotational speeds of 400RPM, 600RPM, 1000RPM, and 1200RPM. Whereas in the specimen obtained at 800RPM there is no partial modification in the eutectic silicon was observed.

The microstructure of Al-20wt% Si specimens centrifugally cast at (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM, and (e) 1200RPM is shown in Fig.12. Primary silicon blocks and eutectic silicon crystals are embedded in an alpha-aluminum phase matrix. For specimens developed at mold rotating speeds of 400RPM and 600RPM, partial fibrous morphology of eutectic silicon was found. For specimens acquired at mold rotating speeds of 800RPM, 1000RPM, and 1200RPM, both fibrous and acicular morphologies of eutectic silicon were found.

The microstructure of Al-30wt% Si specimens centrifugally cast at (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM, and (e) 1200RPM is shown in Fig. 13. Primary silicon blocks, eutectic silicon, and fine precipitates of alloying elements are dispersed in the alpha-aluminum phase matrix. It was observed that specimens developed at mold rotating speeds of 800RPM, 1000RPM, and 1200RPM have a partial modification in the eutectic silicon. There was no partial alteration in the eutectic silicon in the specimens produced at 400RPM and 600RPM.

From microstructural investigations, it has been observed that there is a variation in Si content from the outer surface to the inner surface in all specimens. More Si particles were observed at the outer surface than inner surface; this is due to centrifugal force pushing the particle at the outer periphery of the centrifugally cast specimens. More casting defects were observed in specimens that were centrifugally cast at a rotational speed of 400RPM; this was due to an insufficient rotational speed. When the mold rotational speed increased, the outer periphery containing Si particles increased. Uniform cylinder with fewer defects was observed above 600RPM.

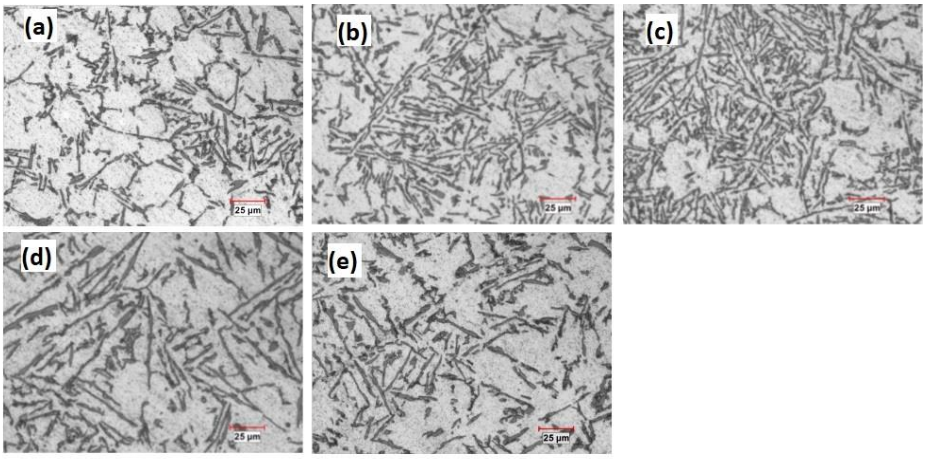

Fig.11. Microstructure of Al-10wt%Si cylindrical specimen developed at (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM, (e) 1200RPM

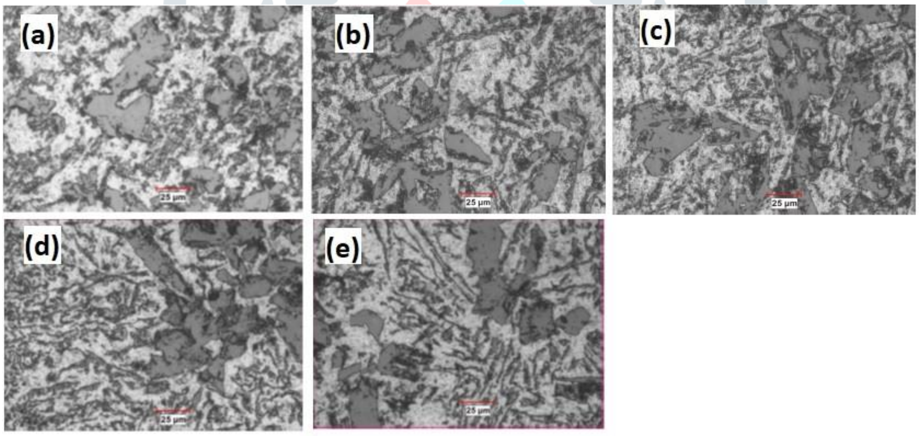

Fig.12. Microstructure of Al-20wt%Si cylindrical specimen developed at (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM, (e) 1200RPM

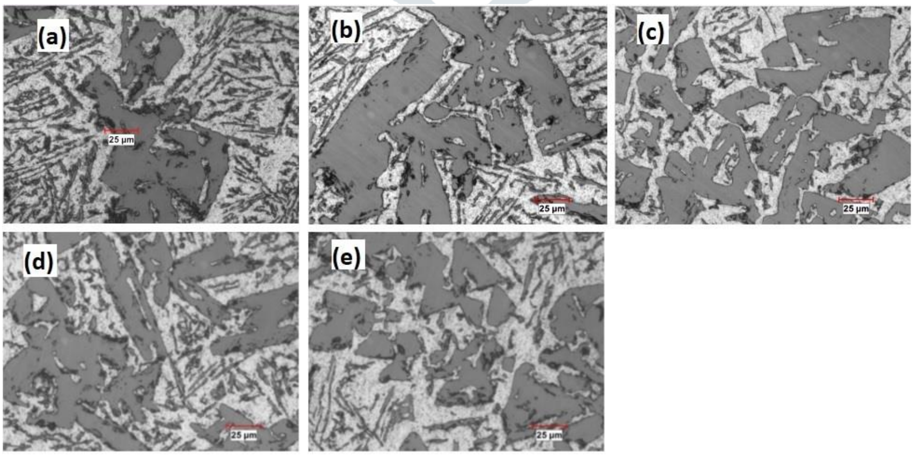

Fig.13. Microstructure of Al-30wt%Si cylindrical specimen developed at (a) 400RPM, (b) 600RPM, (c) 800RPM, (d) 1000RPM, (e) 1200RPM

C. Hardness values for as cast Al-Si alloys

The hardness value for the cast specimen is determined using the Vickers hardness tester. The hardness test is carried out with the load of 100 Kgf at 3 points having equal distance along the axis for all the cast specimens. It is observed that higher values of hardness are seen in cast specimens produced at 800RPM. Due to the non-uniform distribution of the melt, variation in the hardness value is observed for below and above 800RPM.

The graph plotted (Fig. 14) shows the vickers hardness numbers for Al-10wt%Si, Al-20wt%Si, and Al-30wt%Si alloys. The cast cylindrical specimens were subjected to Vickers hardness testing machine at mold rotational speeds of 400RPM, 600RPM, 800RPM, 1000RPM, and 1200RPM. It was found that at 800RPM cylindrical specimen has the highest hardness number when compared to other mold rotational speeds. Al-10wt%Si and Al-20wt%Si, due to higher silicon content in Aluminum alloy.

The cylindrical specimen of Al-30wt%Si has higher hardness value of 78.67HV compared to Al-10wt%Si and Al-20wt%Si, this is due to higher silicon content in Aluminum alloy.

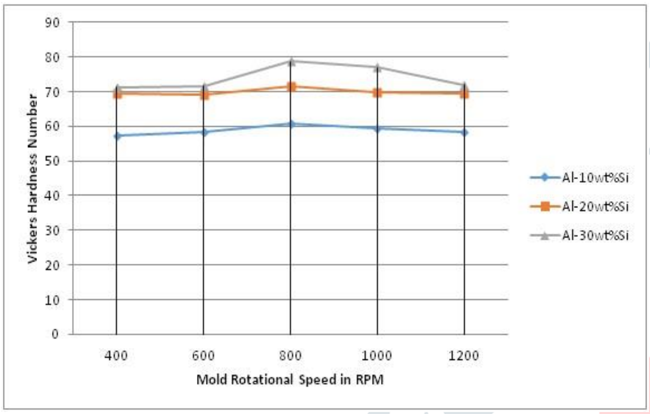

Fig.14. Graph plotted for VHN v/s Mold rotational speed

D. Impact Strength of Al-Si alloys

The results obtained from the charpy impact tester are shown in table 4. The test was conducted at room temperature 26oC for all the specimens of Al-10wt%Si, Al-20wt%Si and Al-30wt%Si alloy, which were developed at mold rotational speed of 400RPM, 600RPM, 800RPM, 1000RPM and 1200RPM.

TABLE IV. IMPACT TEST RESULTS

Material	Mold Rotational Speed (RPM)	Absorbed energy (J)
Al-10wt%Si	400	3.6
	600	3.9
	800	4.2
	1000	4.0
	1200	3.7
Al-20wt%Si	400	1.7
	600	2.0
	800	2.4
	1000	2.2
	1200	2.1
Al-30wt%Si	400	1.6
	600	1.8
	800	2.3
	1000	2.1
	1200	2.0

The specimen developed at 800RPM shows a remarkable increase in toughness value. Cast specimen of Al-10wt%Si alloy absorbs more energy (J) when compared to Al-20wt%Si alloy and Al-30wt%Si alloy.

IV. CONCLUSIONS

The following conclusions were made based on the results of cast specimens developed by varying mold rotational speed and wt% of Si content in the aluminum alloy.
At an optimum rotational speed, a uniform cylinder is formed and metallurgical investigation shows a better gradient in the outer region. Above 600RPM, melt flows throughout the length of the mold and forms a uniform cylindrical specimen. Specimen formed at 800RPM have better mechanical properties when compared with other mold rotational speeds. The ultimate tensile strength and impact strength of Al-10wt%Si alloy was more compared to Al-20wt%Si alloy and Al-30wt%Si alloy. Hardness number increases with increase in Si content of Al-Si alloys. Partial fibrous morphology of eutectic silicon was observed for specimens developed at mold rotational speeds of 400RPM and 600RPM. Both fibrous morphology as well as acicular morphology of eutectic silicon were observed for specimens obtained at mold rotational speeds 800RPM, 1000RPM and 1200RPM. Si content of the Al-Si alloys varies along the radial direction of the cylindrical specimen.

REFERENCES

[1] G. Chirita, D. Soares, F.S. Silva, Advantages of the centrifugal casting technique for the production of structural components with Al-Si alloys, Mater. Des. 2008, Volume 29, pp 20–27.

[2] Roni Kusnowo1, Sophiadi Gunara "Engineering Design of Centrifugal Casting Machine" AIP Conf. Proc. 1855, 030026 (2017), pp 1–7; doi: 10.1063/1.4985496

[3] L. Sankara Rao, K. Raju, A. K. Jha, S. N. Ojha "Microstructural and Tribological Characteristics of Al–10Cu–Fe alloy Produced by Vertical Centrifugal Casting process" Transactions of the Indian Institute of Metals, January 2018, Volume 71, Issue 6, pp.1427-1438.

[4] Mahantesh Tattimani, Shailesh Rao Agari Effect of Rotational Speed in Vertical Centrifugal Casting on the Wear Properties of Obtained Aluminum Tubes" Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, May 2018, Volume 43, pp 587–592.

[5] Jian Zhang, Zhongyun Fan, Yuqing Wang, Benlian Zhou "Hypereutectic aluminium alloy tubes with graded distribution of Mg2Si particles prepared by centrifugal casting" Materials & Design, June 2000, Volume 21, Issue 3, pp 149-15.

[6] Jeong-Wook Park, Heon-Joo Kim "Melt Filling Behaviors and Primary Si Particle Distribution on Horizontal Centrifugal Casting in B390 Aluminum Alloy" International Journal of Metalcasting, January 2017, Volume 11, Issue 4, pp 802-811.

[7] L. Yang, L.H. Chai, Y.F. Liang, Y.W. Zhang, C.L. Bao, S.B. Liu, J.P. Lin "Numerical simulation and experimental verification of gravity and centrifugal investment casting low pressure turbine blades for high NbeTiAl alloy" Intermetallics, Volume 66, July 2015, pp.149-155.

[8] G. Chirita, D. Soares, F.S. Silva "Advantages of the centrifugal casting technique for the production of structural components with Al–Si alloys" Materials & Design, 2008, Volume 29, Issue 1, pp 20-27.

[9] Kestur Sadashivaiah Keerthiprasad, Mysore Seetharam Murali, Pudukottah Gopaliengar Mukunda, Sekhar Majumdar "Numerical Simulation and Cold Modeling experiments on Centrifugal Casting" Metallurgical and Materials Transactions B, Volume 42B, Feb. 2011, pp 144-155.

[10] K. S. Keerthi Prasad, M. S. Murali, P. G. Mukunda "Analysis of fluid flow in centrifugal casting" Frontiers of Materials Science China, January 2010, Volume 4, Issue 1, pp 103–110.

[11] B. Balout and J. Litwin "Mathematical Modeling of Particle Segregation During Centrifugal Casting of Metal Matrix Composites" Journal of Materials Engineering and Performance, April 2012, Volume 21, Issue 4, pp 450-462.

[12] A. Shailesh Rao, Mahantesh S. Tattimani, and Shrikantha S. Rao "Effect of Rotational Speeds on the Cast Tube During Vertical Centrifugal Casting Process on Appearance, Microstructure, and Hardness Behavior for Al-2Si Alloy" Metallurgical and Materials Transactions B, December, Volume 46, Issue 2, pp 793-799.

[13] Benidiktus Tulung Prayoga, Rini Dharmastiti, Fahrurozi Akbar and Suyitno "Microstructural characterization, defect and hardness of titanium femoral knee joint produced using vertical centrifugal investment casting" Journal of Mechanical Science and Technology, September 2018, Volume 32, Issue 1, pp 149-156.

[14] Chester Contatori, Antonio Augusto Couto, Jan Vatavuk, Arnaldo A. Ciquielo Borges, Nelson Batista de Lima, Renato Baldan "Effect of Copper and Magnesium on the Microstructure of Centrifugally Cast Al-19%Si Alloys" Materials Science Forum, January 2018, Volume 930, pp 484-488.

[15] N. Radhika, R. Raghu "Effect of Centrifugal Speed in Abrasive Wear Behavior of Al-Si5Cu3/SiC Functionally Graded Composite Fabricated by Centrifugal Casting" Transactions of the Indian Institute of Metals volume, September 2017, Volume 71, pp 715-726.

[16] Prashantha Kumar H.G, Mohan Kumar.S, Keerthiprasad K.S "Synthesis and Characterisation of Al-Si Alloy" Global Journal of Researches in Engineering Mechanical and Mechanics Engineering, 2013, Volume 13, Issue 6.

[17] Kori S, Murty B, Chakraborty M "Development of an efficient grain refiner for Al- 65 7% Si alloy, Mater. Sci. Eng.: A, Volume 280, Issue 1 (2000), pp 58-61.