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Influence of Aspect Ratio on the Mechanical and Tribological Properties of Vertical Centrifugal Cast Aluminium Silicon Alloy

Smrutirekha Sen[1,*], J. Sudheer Reddy[2], B.K. Muralidhara[3]

Abstract

To get a sound cast of precise shape and size in the vertical centrifugal casting process, the flow behavior of the melt and process parameters such as aspect ratio of the mould, rotating speed, volume fraction, etc. must be optimized. The optimal parameters of the vertical centrifugal casting process derived from past cold modelling studies in casting of Al-12%Si alloy are investigated in this paper. Casts were obtained using 7 mm thick mould having l/d ratio of 0.5,1 and 1.5 at 400,500 and 600 rotational speed of mould. Specific Wear Rate (SWR) and Hardness of Vertical Centrifugal Cast Al-12%Si alloy specimens were studied and also microstructure of those specimens was examined. The casts made at 400 and 600 rpm appeared with coarse and fine microstructures respectively. The hardness of the alloy rises with increasing rotational speed for both 0.5 and 1.0 aspect ratio of mould. However, hardness value of casts at 1.5 aspect ratio of mould was found decreased because of insufficient driving force and larger time taken to reach the end of the cylinder. The hardness of the cast specimens was found to be higher for higher l/d ratio. Similarly the hardness at the pouring end is more compared to the mould end of the specimen. It was observed that Specific Wear Rate of cast specimens prepared at 400 rotational speed of mould was higher than those prepared at 600 rpm.

Keywords: Aluminium silicon alloy, vertical centrifugal cast, wear.

INTRODUCTION

The melt is introduced into a revolving mould and allowed to solidify in the centrifugal casting process. As compared to conventional static casting process casts with thinner wall can be obtained by this process due to the effect of centrifugal force [1]. The axis of rotation of mould can be both horizontal or vertical. In horizontal casting the velocity of melt differs from that of the mould, hence molten metal has to be accelerated to compensate the velocity difference, whereas in a vertical centrifugal casting, molten metal quickly approaches the rotational speed of the mould after being introduced into it. Within the realm of functionally graded materials, centrifugal casting serves as a pivotal technique for producing components with a radial variation in material composition and properties. This process harnesses centrifugal force during casting, resulting in a graded distribution of elements or phases. This innovative approach enables the creation of components with distinct material properties, such as heightened wear resistance on the outer surface and increased toughness in the inner regions, facilitating tailored performance for diverse applications [2].

The cast's soundness is determined by the flow behavior of the melt and process parameters such

*Author for Correspondence
Smrutirekha Sen

[1]Professor, Department of Mechanical Engineering, Odisha University of Technology & Research, Bhubaneswar, Odisa, India
[2,3]Professor, Department of Mechanical Engineering,Nitte Meenakshi Institute of Technology, Bangalore, Karnataka, India

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as aspect ratio of the mould, mould thickness, rotational speed, volume fraction, pouring temperature, melt viscosity, and so on [3–7]. The rotational speed of the mould is determined based on the volume fraction and casting thickness as speed is directly proportional to casting thickness [8]. Coarse grains are obtained at low solidification rate and faster solidification rate results in fine equi-axed grains [6]. The solidification rate increases as the mould wall thickness increases because the chilling action helps to reduce the temperature of the melt. According to available literature, [9], the cast microstructure along the thickness of the mould is found to be changed from fine to coarse from outer to inner surface. Silicon's presence in cast iron significantly shapes its microstructure and mechanical properties. Silicon promotes the formation of graphite within the cast iron, influencing its machinability, thermal conductivity, strength, hardness, and wear resistance. The graphite typically manifests in flake or nodular structures, imparting specific characteristics to the material. Moreover, silicon enhances cast iron's resistance to corrosion and oxidation. An in-depth understanding of silicon's role in microstructural development empowers precise control over the mechanical properties of cast iron, allowing for the optimization of its performance tailored to specific applications. The impact of modification procedures on the mechanical characteristics of aluminum-silicon cast alloys is significant. These procedures, encompassing alloying elements and heat treatments, play a crucial role in tailoring properties such as tensile strength, hardness, ductility, and wear resistance. By selectively adjusting the alloy's composition and structure, these modifications enhance its overall mechanical performance, making it better suited for specific industrial applications. Whereas, with increase in mould rotation speed and decrease in melt superheat the formation of equi-axed zone increases [9]. The aspect ratio has the same effect on the mechanical qualities of cast as the rotational speed of the mould. It has been discovered that increasing the aspect ratio results in increased hardness [10]. The melt in the mould becomes more viscous as it solidifies and the results show that larger driving force is needed form a complete cylinder [11–16]. Furthermore, it is known that in the event of a higher viscosity liquid, a lower rotation speed of the mould is necessary to generate a complete cylinder of melt, and vice versa [17–22]. Because of its high strength-to-weight ratio, great wear resistance, low density, and low coefficient of thermal expansion in the current context. Aluminium alloys are better suited to manufacturing industries, particularly vehicle production. The present study attempts to identify the characteristics of Al-12%Si alloy which will enable the alloys to be used in wide range of engineering that involves vertical centrifugal casting.

EXPERIMENTAL SETUP

Based on the size of the cast that is to be obtained, the required quantity of Al-12% Si alloy had been melted in the 110 mm diameter clay graphite crucible. Figure 1 depicts the pit type resistance furnace of capacity 3 kg under the cover flux (45% NaCl +45% KCl + 10% NaF). The slags were removed at regular interval by maintaining the holding temperature as 860°C. As shown in Figure 2, a 1HP DC shunt motor with a speed range of 20 rpm to 2000 rpm rotated a mild steel mould with dimensions of ϕ 80 mm × 88 mm × 5 mm for vertical centrifugal casting.

Figure 1. Preparation of melt.

Figure 2. Vertical centrifugal set up.

(i) 0.5 Aspect Ratio (ii) 1 Aspect Ratio (iii) 1.5 Aspect Ratio

(a) At a Rotating Speed of 400 rpm, an Al-12%Si Cast was Formed for Various Aspect Ratios of the Mould.

(i) 0.5 Aspect Ratio (ii) 1 Aspect Ratio (iii) 1.5 Aspect Ratio

(b) At a Rotating Speed of 500 rpm, an Al-12%Si Cast was Formed for Various Aspect Ratios of the Mould.

(i) 0.5 Aspect Ratio (ii) 1 Aspect Ratio (iii) 1.5 Aspect Ratio

(c) At a Rotating Speed of 600 rpm, an Al-12%Si Cast was Formed for Various Aspect Ratios of the Mould.

Figure 3. Varying cast structures are formed in vertical centrifugal casting at varying aspect ratios and rotational speeds.

As depicted in Figure 3. Al-12%Si casts with mould wall thicknesses of 7 mm were achieved at rotating speeds of 400 rpm, 500 rpm, and 600 rpm for three different aspect ratios of mould, namely 0.5,1.0, and 1.5.

The hardness of the material was determined using a Rockwell hardness tester equipped with a 1/4 ball indenter. Similarly, a Pin on Disc wear tester was utilized to assess the wear rate of the samples. Similarly Pin on Disc wear tester was used to evaluate Wear rate of the samples. The SWR was estimated using the usual wear loss of the test samples at 1N and 2 N normal loads and a constant sliding speed of 400 rpm with a track diameter of 100 mm. A Dewinter inverted optical microscope interfaced with Metalite image analyzer software was used for microstructure characterization.

RESULTS AND DISCUSSION

From the specimens, the Physical appearance of the inner surface of the cast was not found to be smooth and uniform at lower rotational speed. Importantly, the porosity of the specimens cast at 400 rpm was found high. Tables 1 and 2 depict the hardness of specimens measured at pouring and mould end of the mould.

Table 1. R_f of Al-Si(12%) of 7 mm mould wall thickness at different speed (pouring end).

S.N.	L/D ratio	Rotational Speed	RHN Trials			Avg
1	0.5	400 rpm	71	63	63	67
2	1		45	44	44	44
3	1.5		33	32	32	33
4	0.5	500 rpm	76	78	78	77
5	1		56	55	55	56
6	1.5		27	28	28	28
7	0.5	600 pm	79	77	77	78
8	1		61	58	58	59
9	1.5		25	24	24	24

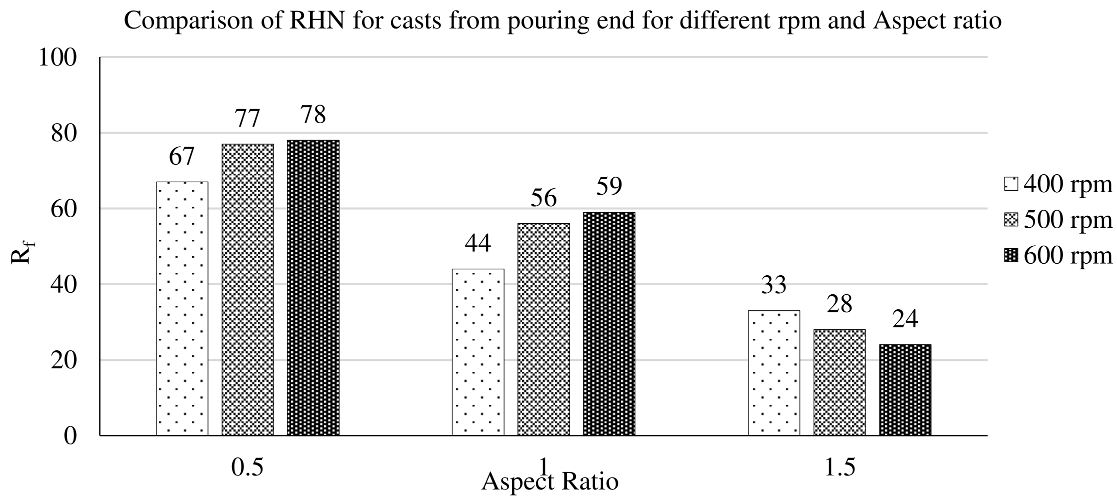


Figure 4. Comparison of RHN, rotational speed and L/D ratio from the pouring end.

The experimental results indicates that with increase in the aspect ratio (L/D) of the mould hardness of specimens decreases. As analyzed in the Figure 4 specimen with (L/D) ratio 0.5 has the highest hardness value of 67 and the one with (L/D) ratio 1.5 has the least hardness value of 33 in R_f scale at rotational speed of 400 rpm. Whereas, specimen with (L/D) ratio equal to 1.0 has an intermediate hardness value of 44. For aspect ratio of mould equal to 0.5 and 1.0, the hardness of Al-12%Si alloy was found high for 600 rpm cast. This might be caused by the molten metal being distributed uniformly throughout the surface. However for the aspect ratio 1.5 due to increase in volume fraction of the melt complete cylinder formation was not possible. Hence hardness value found to decrease with rpm. Hardness of the specimen from the mould end is tabulated in Table 2.

Table 2. R_f of Al-Si (12%) of 7 mm mould wall thickness at different speed (mould end).

S. N.	L/D Ratio	Rotational Speed	RHN Trials			Avg
1	0.5	400 rpm	59	65	61	62
2	1		35	38	36	37
3	1.5		23	22	20	22
4	0.5	500 rpm	71	69	74	71
5	1		50	51	51	51
6	1.5		27	22	19	23
7	0.5	600 rpm	79	74	71	75
8	1		52	56	53	54
9	1.5		27	28	28	28

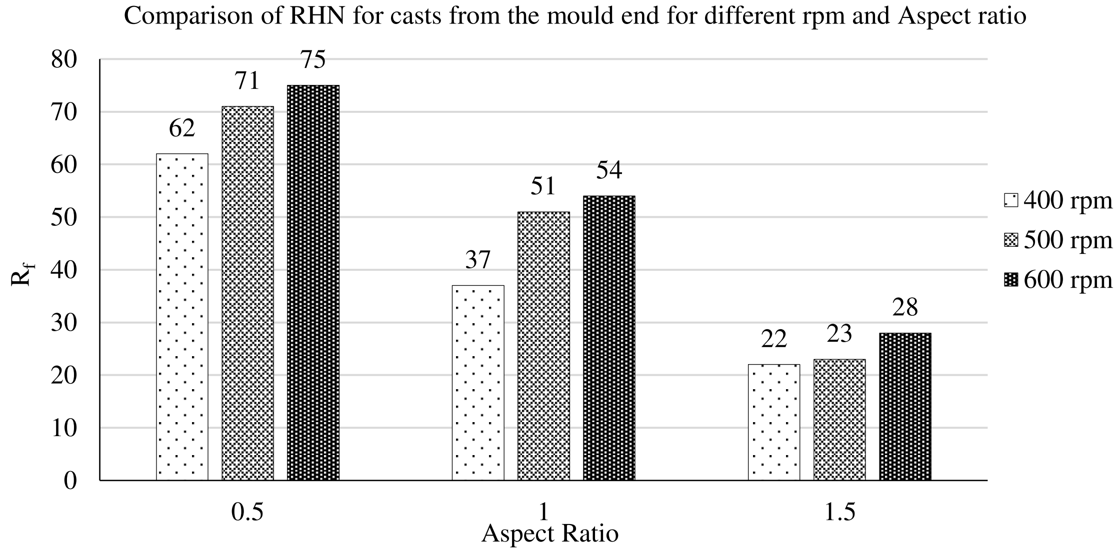


Figure 5. Comparison of RHN, rotational speed and L/D ratio from the mould end.

As shown the Figure 5 it is understood that at the mould end hardness decreases with increase in aspect ratio. Comparing Figure 4 and 5 it is observed that hardness of the specimen is more cast pouring end than the mould end.

Table 3 displays the particular wear rate of the casts' outer wall surface at various rotation speeds and aspect ratios.

Table 3. Specific wear rates for Al-12%Si castings.

S.N.	Cast Speed	Aspect Ratio	Wear in µm	Specific wear rate in $\frac{m^3}{N-M}$
1	400 rpm	0.5	43	$9.85*10^{-14}$
2		1.0	21	$6.552*10^{-14}$
3		1.5	42	$6.46*10^{-14}$
4	500 rpm	0.5	38	$8.711*10^{-14}$
5		1.0	10	$4.29*10^{-14}$
6		1.5	39	$1.589*10^{-14}$
7	600 rpm	0.5	45	$3.838*10^{-14}$
8		1.0	50	$2.037*10^{-14}$
9		1.5	34	$1.06*10^{-14}$

Table 3 and Figure 6 show that the SWR of the Al-12%Si cast decreases with increasing rotational speed, which is due to the deposition of Si grain near the cast's edge Similarly, the cast obtained at high rotational speed has a higher coefficient of friction than the cast obtained at lower rpm. The coefficient of friction is shown to rise as rpm increases.

Grain size was discovered to decrease with increasing rotational speed, i.e. at casting speeds of 400 rpm, 500 rpm, and 600 rpm, the grain size is coarse, fine, and finest, respectively. This may be due to slow solidification rate at less rpm. Coarser aluminium grain boundary with silicon throughout the spread was found in specimen (Figure 7a,7b and 7c). Cast with higher casting speed was found to have finer grains and the rate of cooling is more compared to the aspect ratio. As the cast has a finer structure the hardness increases.

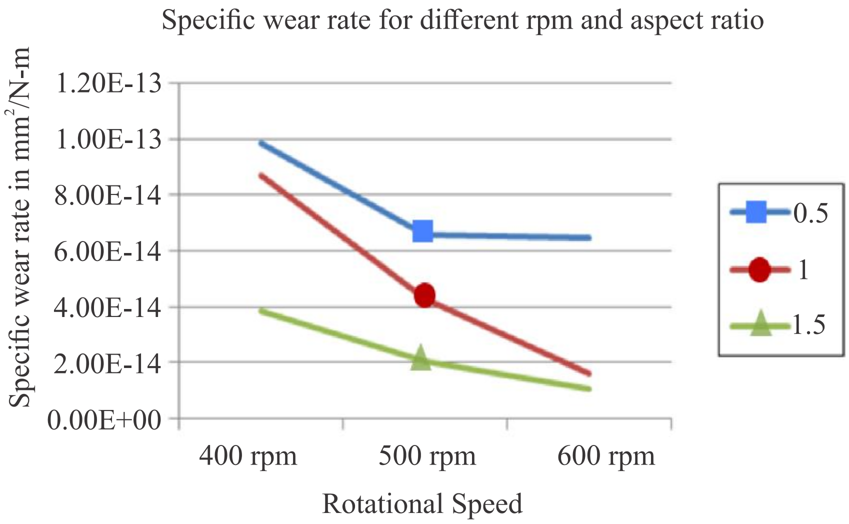
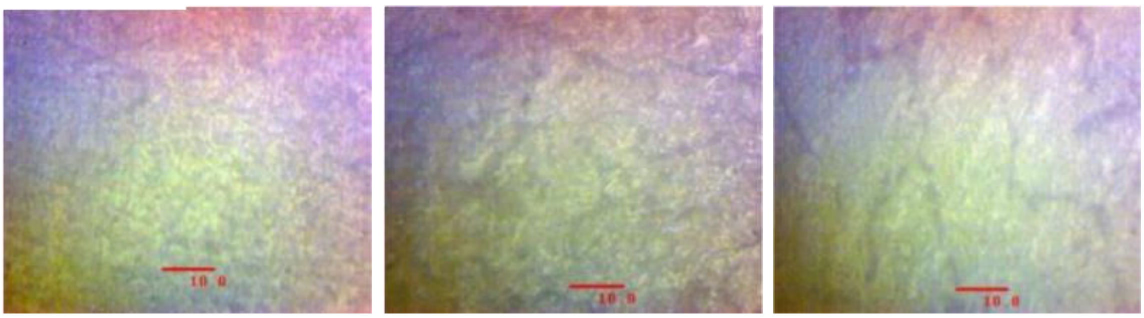
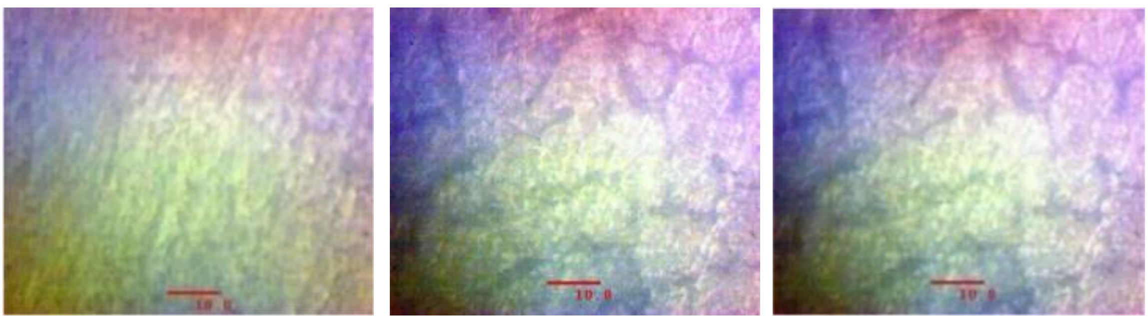


Figure 6. Specific wear rate for different rpm and aspect ratio for cast of Al-12%Si Alloy.



(i) 0.5 Aspect Ratio (ii) 1 Aspect Ratio (iii) 1.5 Aspect Ratio

(a) Micrograph of Cast Al-12% Si at 400 rpm



(i) 0.5 Aspect Ratio (ii) 1 Aspect Ratio (iii) 1.5 Aspect Ratio

(b) Micrograph of Cast Al-12% Si at 500 rpm

(i) 0.5 Aspect Ratio (ii) 1 Aspect Ratio (iii) 1.5 Aspect Ratio

(c) Micrograph of Cast Al-12% Si at 600 rpm

Figure 7. A Micrograph of various cast structures in vertical centrifugal casting at various aspect ratios and rotational speeds.

CONCLUSION

Al-12% Si alloys were centrifugally cast for different aspect ratio with constant mould wall thickness at different rotational speed. The findings from the present investigation are stated below.

The surface finish of the cast achieved at low rotational speed was found to be superior to that obtained at high rotational speed. The microstructure of the cast obtained at greater rotational speed was fine, whereas the microstructure of the cast formed at lower rotational speed was coarse. It was observed that when l/d ratio was more the hardness was less. As rotational speed increases, so does the rate of solidification, which improves mechanical characteristics.. The hardness of the specimen on the mould side is lower than on the pouring side. Most of the cylinders were discovered to be slightly conical, with a smaller inner diameter and a greater outer diameter. SWR of Al-12%Si cast decreased with increasing rotational speed. Grain size has a significant impact on mechanical qualities, the hardness of the cast increased with finer grain structures.

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