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A Study to Determine Optimum Speed to Produce the High-Quality Castings for Al-17%Si Alloy in a Vertical Centrifugal Casting Machine

Mahantesh S. Tattimani[1]*, C. Y. Maheswar[1], Babu Reddy[2] and Shivanand N. Pujar[3]

[1]*Department of Mechanical Engineering, SKSVM Agadi College of Engineering and Technology, Lakshmeshwar, Gadag - 582116, Karnataka, India; mahantesh.s.t@gmail.com*

[2]*Department of Mechanical Engineering, VTU's Centre for Postgraduate Studies, Kalaburagi - 585105, Karnataka, India*

[3]*Department of Mechanical Engineering, Government Polytechnic Gadag, Gadag - 582102, Karnataka, India*

Abstract

The rotational speeds of moulds in a typical vertical centrifugal machine are found to greatly affect the resulting quality of cast tubes as seen through multiple parameters such as finishing texture strength etc. The dependence of the quality of mold on the speed can be attributed to the movement of molten metal, which in turn, is dictated by the speed of rotation. The present work is an effort to experimentally demonstrate this feature. The Alloy used in the work was Al-17%Si. The speeds of interest that were used for experimentation ranged from a minimum of 600 Revolutions Per Minute (RPM) to a maximum of 1200 Revolutions Per Minute (RPM). The results of the experiment were very affirmative towards the fact that the best quality can indeed be obtained for the said range of speeds. Further, a few experiments, beyond this range of speed, showed strikingly low-quality molds characterized by features such as coarse grain, low mechanical strength, and wear properties

Keywords: *Centrifugal Casting, Fractography, Metal Flow, SEM, Wear Characteristics*

1.0 Introduction

The manufacturing sector prefers the low-density material component in order to improve the efficiency of machines and to have a lesser consumption of energy. The Aluminum Silicon alloys best fit the requirements as they have a very high strength-to-weight ratio, quality casting, and high wear resistance. In fact, Aluminum alloys were the most widely used metals before the arrival of the composite materials in the aerospace industry owing to their light weight. Besides, due to economic and environmental constraints, the design of materials has shifted the focus to practice light weight, environmental friendliness, inexpensive, quality, and performance. High mechanical strength and good wear characteristics are vital properties required in important application areas of Al-Si alloy. The properties say of the mechanical nature, of metal alloys in general, and Al-Si casting alloys, in particular, rely mostly on their chemical composition and on microstructural features (namely the morphology of the Al-rich α-phase and of the eutectic phase Si element particles)[1]. A cursory look at the research literature in the field shows that there are a couple of studies made in this direction, especially for metal alloys under varied manufacturing conditions, for example. K Raju *et al.*,[2] studied the mechanical properties in addition to wear properties of the Al-20%Si alloy employing a spray casting and Vertical Centrifugal Casting Process (VCCP). In the paper, they summarized the comparative results of both processes. The distribution of Si is consistent in the Al matrix with its dimension varying from 2 to 10 μm in contrast

*Author for correspondence

to the coarse microstructure of alloy cast by Centrifugal Casting Process (CCP). In the centrifugal casting machine, the uniform distribution of Silicon Carbide (SiC) elements has been seen in aluminum alloy[3]. The adding of the silicon particles and Al oxide to aluminum alloy improved the mechanical and tribological characteristics such as the hardness (multiple forms), the uniaxial tensile strength, and the wear characteristics of the Al alloy[4]. Wang Qudong, *et al.*, [5] also investigated the ramifications that result from the speed of the mould on the castings.

Hence, these are commonly/widely used in the automobile and aerospace industries namely IC engines, bearings, the structure of aircraft, pistons, etc. Even though Al-Si alloys meet several requirements for such applications, these are difficult to be lubricated and exhibit low resistance to damage[6]. The wear rate of components composed of Al-Si alloys relies on parameters namely shape, dimension, chemical composition, and allocation of micro constituents along with load, sliding speed, temperature, and so on[7]. Several studies have revealed the effect of different reinforcements on the wear behavior of alloys of Al-Si. As the load increases the oxide film turns sever more susceptible to bulk failure and changeover to severe wear may occur. Friction stir processing is a valuable process to process the microstructure of Al alloys thereby enhancing the mechanical properties[8,9]. The existence of primary Si particles in hyper eutectic or near eutectic Al-Si alloys offers exceptional wear resistance[10,17]. The fine-grain particle formation affects the tribological properties of the exterior layer[11,12]. Prasada *et al*., revealed that the grain refinement of Al-7Si alloy leads to the improvement in the resistance to wear as well as load-bearing capacity[13,14]. The Al5083, in comparison to the other common aluminum alloys, has one main problem, that is, it has poor wear resistance which puts the limit on their tribological performance[15].

It is evident from the previous studies that the majority of the Al-Si alloys were processed either by centrifuge casting or horizontal centrifugal casting process. Centrifugal and horizontal casting processes have received more attention in the published work than the vertical casting process. Moreover, there is little study on the effect of rotational speed on the quality of the product from the vertical casting process. Furthermore, there is no comparison studies carried out on Al-Si alloy castings produced by both of these casting processes. More so, there aren't enough studies that encompass aspects such as the process of pouring temperature, grain refinement and modification, and varying mould speeds. This work is thus focused on these lacunae. An experimental work is set up to understand these parameters.

1.1 Experimental Details

The samples are prepared in accordance with ASTM standards and processed by 2HP/DC vertical centrifugal casting machine arrangement. A mould with a size of ⌀ 82 X 80 mm is chosen for experimentation. Mould rotational speed with a minimum of 600 rpm to a maximum of 1200 in the steps of 200 rpm is chosen for the process of casting at 800^{0}C temperature. The microstructures are observed by microscope. The wear investigations are accomplished using a Pin-on-disc wear test apparatus as shown in Figure 1. In order to conduct the wear studies, the tube is split into 8X8 mm square samples and glued together with a mild steel spherical flat to grasp the specimen. The SEM (Scanning Electron Microscope) inspections on the wear samples are done by SEM analyzer.

Figure 1. Wear and friction testing machine.

2.0 Results and Discussions

2.1 Appearance of the Cast Tube

Figure 2 indicates the images of the Al-17%Si alloy of casting with a thickness of 8mm. When the mould rotation speed is 600 rpm, the melt is found to be in a

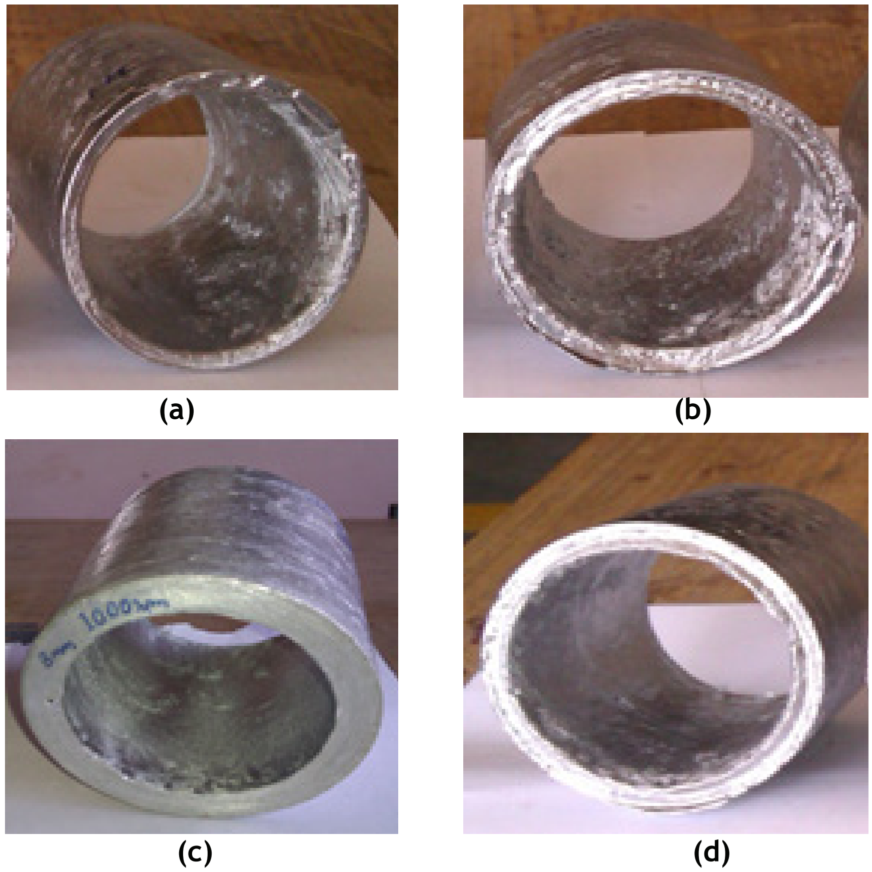
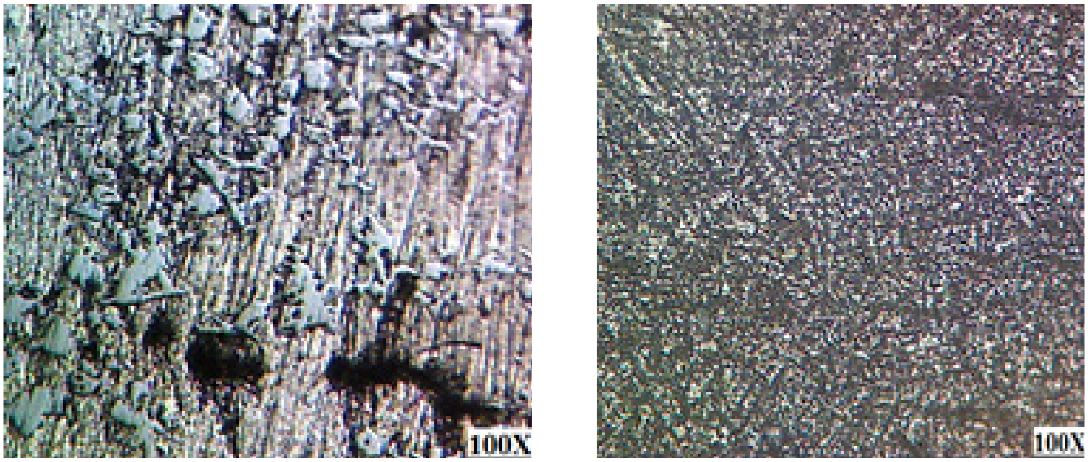


Figure 2. Casting of 8 mm thick Al-17Si rotated at the speeds of, **(a)** 600 rpm **(b)** 800 rpm **(c)** 1000 rpm **(d)** 1200 rpm.

soggy condition for a certain duration. The melt is then transferred, with the help of spruce, to the mould, which is in rotary motion it attempts to rise from the wall of mould. In the course of mould rotation, the melt mounts beside the side wall giving rise to the development of asymmetrically shaped cast tubes because of the inequity of forces as shown in Figure 2 (a). However, at the mould rotational speed of 800 rpm, it is found that the molten metal avoids rising from the mould side wall and perhaps it is in a mushy condition, and its position gets hampered and an inconsistent cast tube is formed as indicated in Figure 2 (b). It is also examined that when the mould is made to rotate at a speed of 1000 rpm, the driving force is adequate for the melt to stretch evenly alongside the axis and the melt gets elevated so as to form an unvarying wall thickness at the topside, middle as well as underneath and to form a full-length cylinder. The gravity downward pull force along with centrifugal force balance one other, so as to create the full-length cylinder as indicated in Figure 2(c). When the rotational speed reaches 1200 rpm, the molten metal travels alongside the mould axis and touches the mould upper flange owing to its huge driving force and then arrives down forming a tapered contour cast tube as indicated in Figure 2 (d).

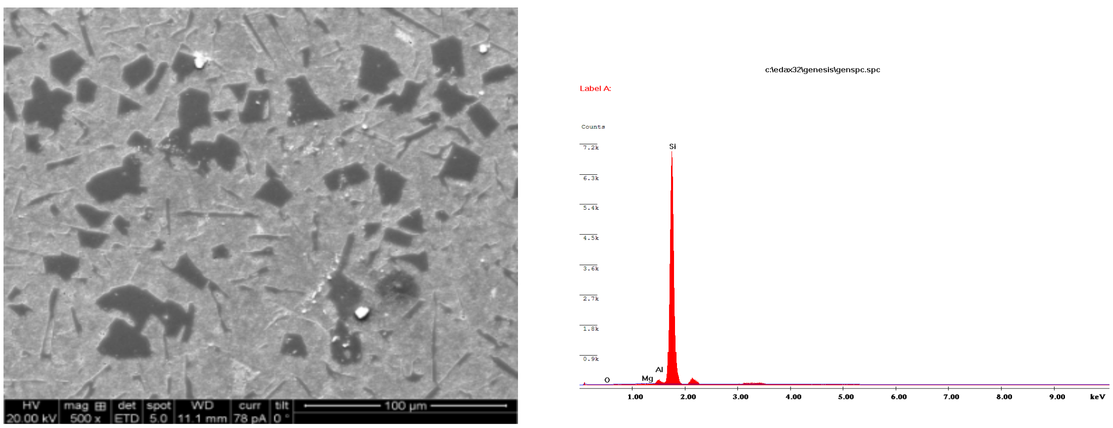
2.2 Microstructure Details

Figures 3 and 4 depict the Al-17Si microstructure throughout the casting section. The flow of liquid metal at different mould speeds results in transforming the alloy microstructure. When the mould rotational speed is 600 between 800 rpm, as indicated in Figures 3 (a) and 4 (a), a comparatively bigger sized primary silicon particle is formed alongside the section. As mould rotation increases, the microstructure transforms from a coarse platelet and uneven primary silicon to tiny and evenly spread particles alongside the section. When the mould rotational speed reaches a value of 1000 rpm, tiny even-sized grains are observed in the castings (Figure

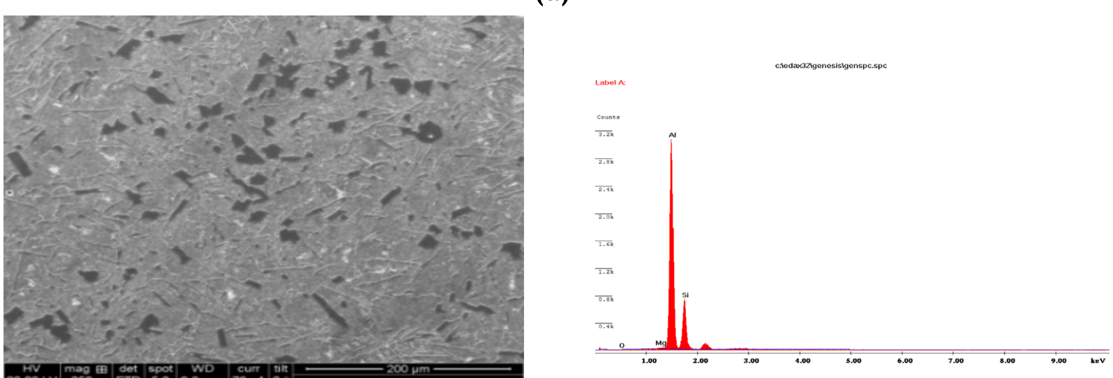


(a) (b)

Figure 3. **(a).** Microstructure of 8mm thick Al-17Si rotated at 600 rpm. **(b).** Microstructure of 8mm thick Al-17Si rotated at 1000 rpm.



(a)



(b)

Figure 4. **(a).** SEM images of 8 mm thick castings at 800 rpm. **(b).** SEM images of 8 mm thick castings at 1200 rpm.

3(b)). When the mould rotational speed reaches a value of 1200 rpm, the solidification rate gets reduced owing to the downward movement of melt, yet again producing primary silicon in the castings as can be seen in Figure 4(b).

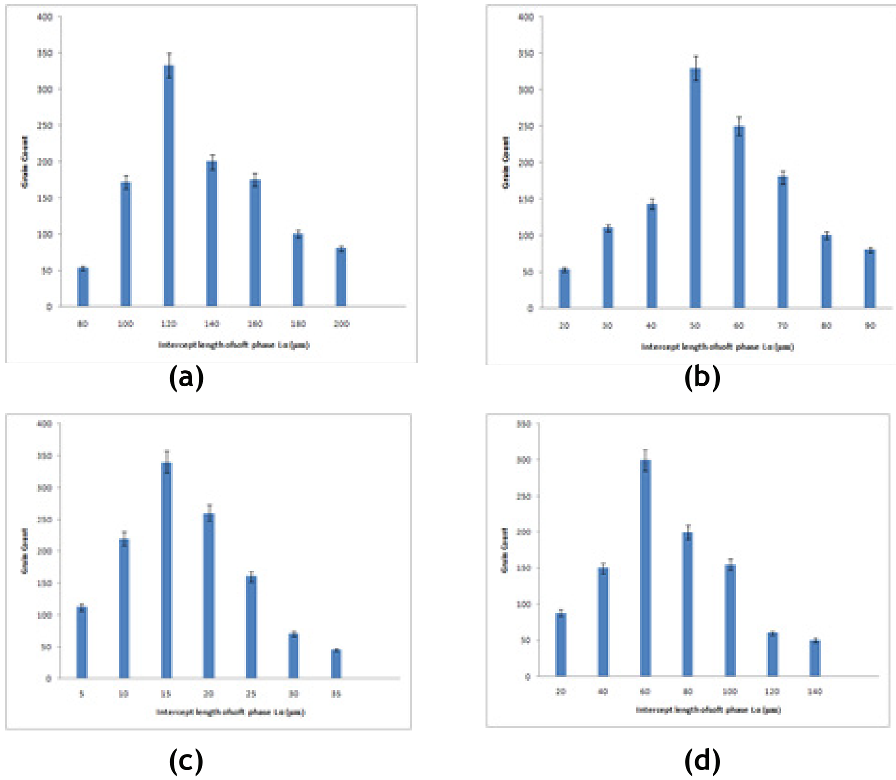


Figure 5. Grain count numbers v/s intercepts lengths of soft phase Lα (Al-17Si Alloy) for **(a)** 600 rpm **(b)** 800 rpm **(c)** 1000 rpm and **(d)** 1200 rpm (respectively from top to bottom).

2.3 Hardness Value and Tensile Tests

Almost 80% of grains are of the size between 100 and 120 µm for the castings produced at a mould speed of 600 rpm which has been graphically depicted in the form of a bar chart of Figure 5(a). When this speed is increased by 200 rpm to reach 800 rpm, it is found that 70% of grains are of size in between 50 and 60 µm and the grain count is revealed in Figure 5(b). On further increasing the speed to 1000 rpm, the cast tube samples consisted of fine grains and 90% of grains were of the size between 15 and 20 µm as portrayed in Figure 5(c). A further speed augmentation of about 200 rpm is achieved to reach the speed of 1200 rpm. In these conditions 80% of grains are found to be the of size between 60 and 80 µm and the grain count is portrayed in Figure 5(d).

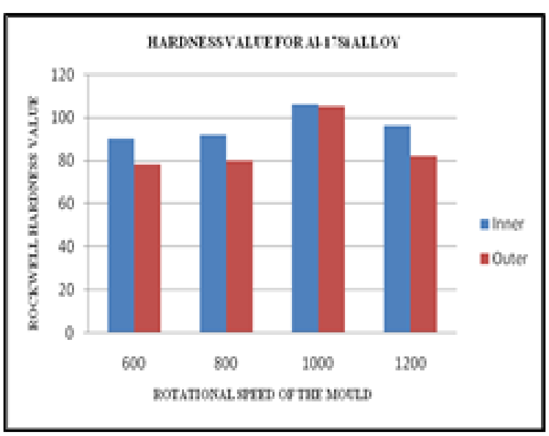
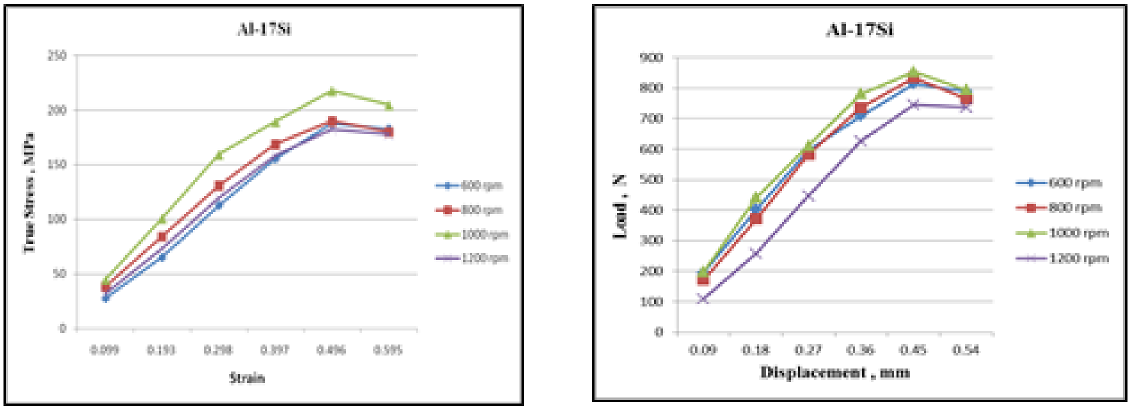


Figure 6. Hardness value v/s rotational speeds for 8 mm cast tubes of Al-17Si alloy.

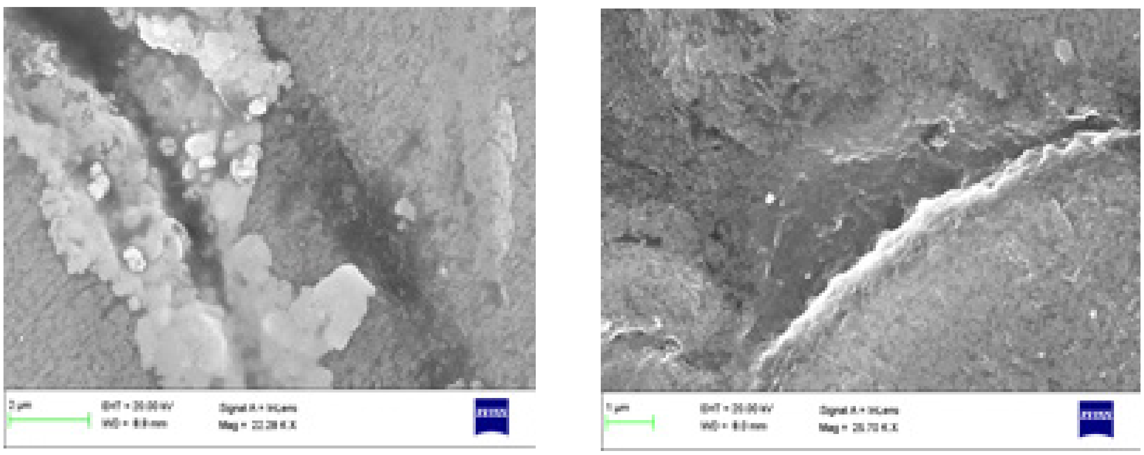
Figure 6 indicates uniform hardness and high hardness values recorded for Al-17Si alloys as the mould speed reached 1000 rpm. This is owing to even spreading of the alloy over the mould circumference and rapid solidification, the better hardness values are observed compared to the other cast tubes. The variation in hardness value is observed for the mould rotation with values larger than and lesser than 1000 rpm.

Tensometer was employed to conduct the tensile test. Figure 7 depicts the graphs of true stress versus strain and load versus displacement of Al-17Si alloys at rotational



(a) (b)

Figure 7. Tensile test of Al-17Si at speeds of 600, 800, 1000, and 1200 (speed units are in rpm). **(a)** True stress v/s Strain. **(b)** Load v/s Displacement



(a) (b)

Figure 8. **(a)** Fractography images of 8 mm thick castings at 800 rpm. **(b)** Fractography images of 8 mm thick castings at 1000 rpm.

speeds of mould from 600-1200 rpm in intervals of 200rpm. The results clearly show that the noticeably higher ultimate tensile strength and higher load-carrying capacity of casting samples were recorded at a mould rotational speed of 1000rpm, and this is due to the fine microstructure and small size primary α-Al grains in the casting as indicated in Figure 3(b) same can be noticed in SEM images too. The load-carrying capacity and ultimate tensile strength is low for mould speeds lower and higher than the critical rotational speed of 1000rpm.

SEM was employed to examine the fractured surfaces. The fracture propagation was less in the case of 1000 rpm; below and above this speed, the number of fracture origins was found to increase with the increase in the applied load. The images corresponding to 800 rpm and 1000 rpm as shown in Figures 8(a), (b).

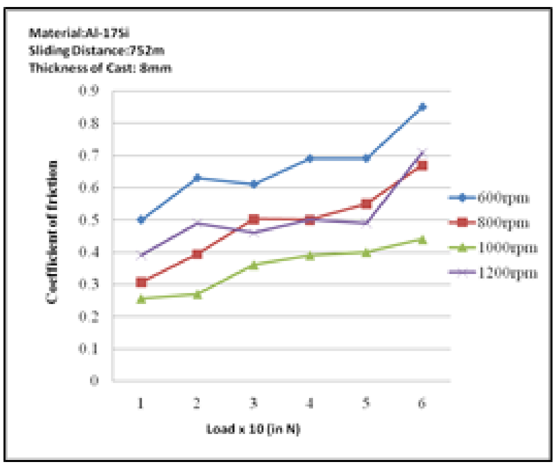
The studies on different Al-Si alloys using vertical centrifugal casting process in various applications, such as Al-7Si-0.3Mg is used for engine applications namely water-cooled cylinder head and transmission cases, etc. Al-18%Si is employed for crankshaft gears, cylinder liners, pistons, etc. Al-12Si-1.5Cu is employed for the manufacturing of pistons, replacing the conventional ferrous metals due to their higher strength-to-weight ratio[6,15]. Normally silicon is added as a secondary phase material to improve the wear resistance and seizure. The investigation of wear of Al-Si alloys has already been carried out principally on dry sliding conditions by some earlier authors[7,16,17].

2.4 Wear Characteristics

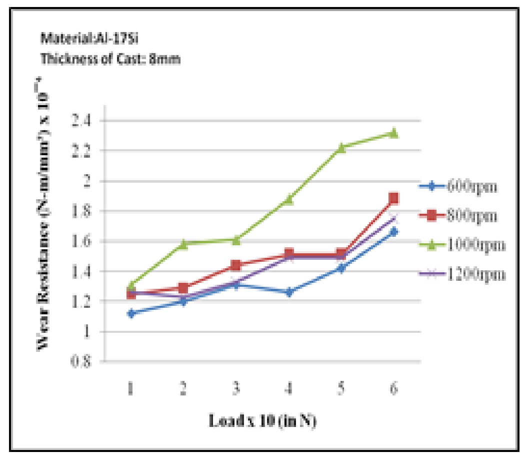
Figures 9(a), 9(b), and 9(c) various parameters used to estimate the wear characteristics of the material. Figure 9(a) depicts the effect of rotational speed on the dry sliding wear of Al-17%Si alloy as a function of normal load for a constant sliding distance of 752 m. Figure 9(a) clearly depicts that the "coefficient of friction" is lower for the sample of thickness 8mm made at a mould rotational speed of 1000 rpm and found to be higher for the cast tube made at lower and higher than this rotational speed. Figures 9(b) and (c) depict the wear characteristics of Al-17Si alloy produced at the different mould rotational speeds. The "volumetric wear rate" is low while the wear resistance is very high for the specimen processed at a rotational speed of 1000, which is in line with the observations of hypo-eutectic and eutectic Al-Si alloys.

2.5 Microscopic Aspects of the Cast Material

Figure 10 depicts a Scanning electron micrograph of the worn samples of Al-17Si alloy. Crack nucleation takes place for the samples processed at 600, 800, and 1200 rpm as portrayed in Figures 10(a), (b), (d). Due to inappropriate movement of the melt in the course of rotation, there are chances of asperity formation which develops high hydrostatic compressive pressure on the sample. In addition, the abrading particles are seen because of rubbing starts piercing the softer metal between the



(a)



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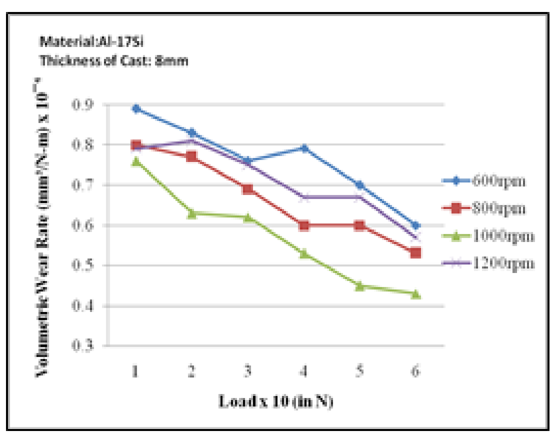

(c)

Figure 9. **(a)** Coefficient of friction v/s load. **(b)** Volumetric wear rate v/s load. **(c)** Wear resistance v/s load.

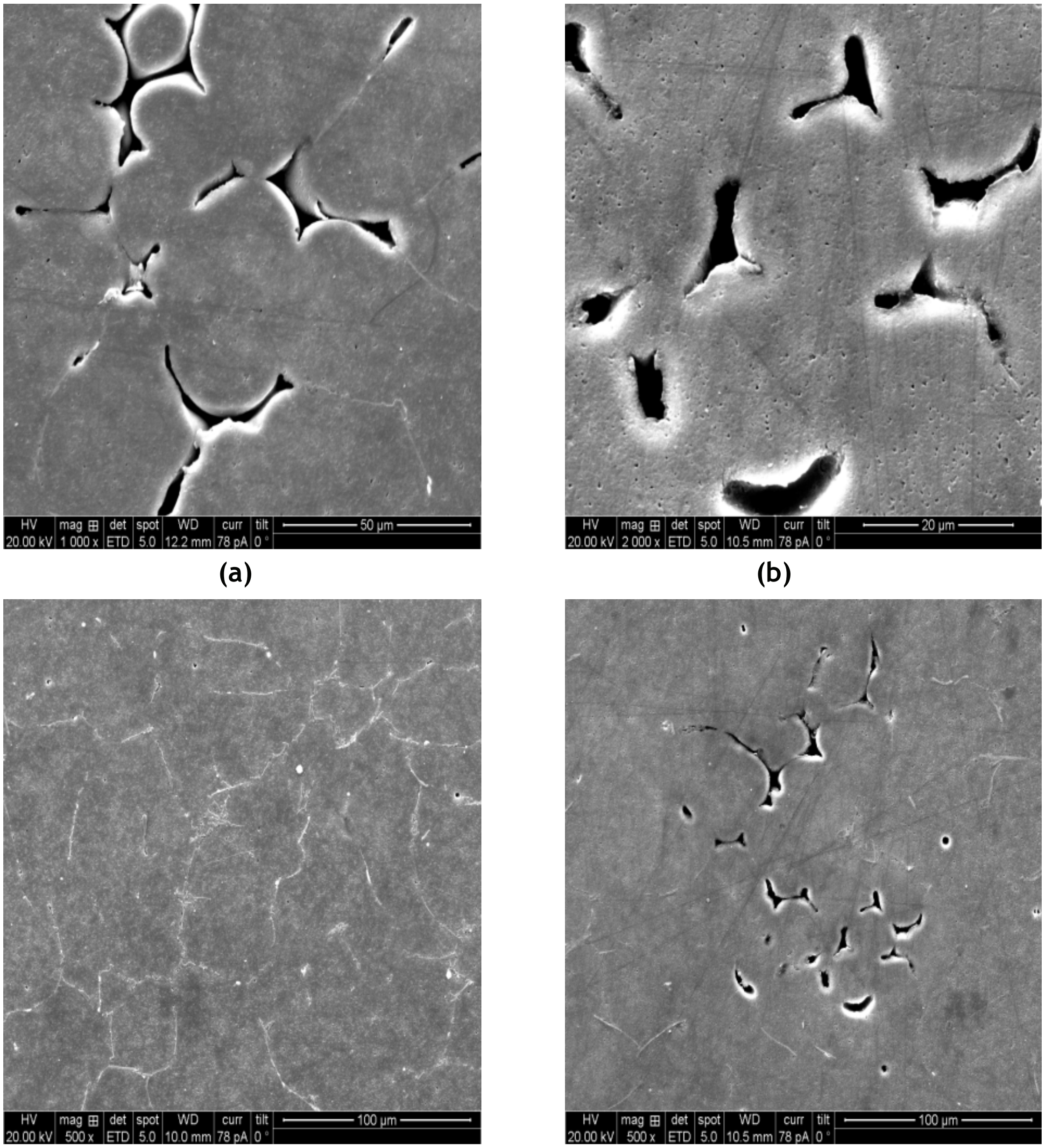

Figure 10. Crack growth near grain boundaries for **(a)** 600 rpm, **(b)** 800 rpm, **(c)** 1000 rpm and **(d)** 1200 rpm

two, these results in the initiation of cracks on the metal surface and might be propagated due to extensive plastic flow on the specimen during rotation and observed in the specimen. However, there is a reduction in the crack size with the rotational speed changing from 600 to 800 rpm because of better lift in the melt in the upward direction, giving rise to the reduction in asperity contact. The hard dispersions may mechanically get dislodged in the course of the wear process and behave as asperities which can support the load till it is levelled off. The magnitude of work hardening increases with the increase in the degree of grain refinement as can be observed in the samples at a mould rotational speed of 1000rpm as shown in Figure 10(c). The evenness of the melt in the course of rotational speed may assist in reducing asperity and consecutively crack propagation. At this point in time, there is no or very small crack initiated in the interior surface of the mould. At 1200rpm, due to the downward flow of melt, again asperities are formed where initiation of cracks are observed in the grain boundaries.

3.0 Conclusions

The Hardness, Tensile, and Wear properties of the cast tubes are strongly influenced by the flow of the molten metal. At mould rotations of 600 and 800 rpm, interruptions in the melt flow are present because of differences in the relative velocity that makes the movement in the upward direction complicated. At this point in time, poor mechanical and wear characteristics are observed. When the mould rotational speed reaches 1200 rpm the melt happens to slip once it arrives at the upper flange and yet again the formation of uneven cast tubes takes place. Poor cast tubes with porosity are initiated due to the formation of asperities. The coarse grains along with low-grade wear characteristics and poor mechanical properties are recorded. Enhanced mechanical and wear characteristics are recorded at this point of time, when the mould rotation is 1000rpm, the molten metal possesses low viscosity and is evenly spread with a notable increase in the rate of solidification. A fine grain without pores in the cast tube segment is detected owing to the even flow of the molten metal in the course of the mould rotation

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