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Effect of mould rotation Speed on hardness and Sliding wear resistance of Hypereutectic Al-Si alloy

KEYWORDS: Centrifugal casting, Hypereutectic Al-Si alloy, Hardness.

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ABSTRACT The properties of aluminium silicon alloy, high strength to weight ratio, good formability, good corrosion resistance and recycling potential make it the ideal candidate to replace heavier materials (steel or copper) in automobile to respond to the weight reduction demand within the automotive industry. The aim of the present study is to investigate the influence of the Horizontal centrifugal casting technique on hardness and tribological studies of hypereutectic Al–17Si alloy at different rotational speed. With increase of mould rotation speed, the primary silicon particles are refined from coarse form to finer form. Result of Vickers hardness shows that hardness value is decreasing from inner periphery to outer periphery. For present investigation, optimum mould rotation speed was found as 700 rpm. Specific wear rate of inner and outer periphery of cast sample was found minimum at optimum speed. Hardness results were rationalized in terms of the lower density of Si compared to Al alloy which provided the movement of Si particles under the action of centrifugal forces during rotation.

Introduction

Centrifugal casting is material processing technique in which flow pattern of molten metal during casting strongly affects the quality of casting. The centrifugal casting process is generally preferred for producing a superior-quality tubular or cylindrical casting, because the process is economical with regard to casting yield, cleaning room cost, and mould cost. In centrifugal casting of hollow sections, nonmetallic inclusions and evolved gases tend toward the inner surface of the hollow casting. Centrifugal casting process provides higher rate of heat flow and a more rapid solidification rate, resulting in increased mechanical properties [1]. The vertical mould orientation is usually used when diameter of casting is greater than its length or L/D ≤ 1.5. Horizontal

centrifugal casting is mainly used to cast pieces with a high length-to-diameter ratio or with a uniform internal diameter. It is mainly used for casting a part which is sufficiently long i.e. L/D >1.5 [2, 3]. V. O. Abramov, O. V. Abramov, B. B. Straumala and U.W. Gust have studied the effect of ultrasonic treatment on the microstructure of hypereutectic Al-Si based alloys. The ultrasonic treatment results in an increase of the plasticity and strength of the alloys [4]. B.C. Ray, U.K. Mohanty and B.B Verma had studied the effect of rotation speed of mould on hardness, cast structure and impact properties of Al¬-Si alloy containing 13% Si. There exists an optimum speed of rotation of mould under given experimental condition which results in optimization of some characteristics mechanical properties of the casting [5]. G. Chirita, D. Soares, F.S. Silva had discussed the mechanical properties advantages of using the vertical centrifugal casting technique for the production of structural components when compared to traditional gravity casting [6]. G. Chirita, I. Stefanescu, J. Barbosa, H. Puga, D. Soares and F.S. Silva had studied investigation of influence of vertical centrifugal casting technique over mechanical and metallurgical properties of a hypereutectic Al–18Si alloy. The fluid dynamics effect of the centrifugal casting is the main factor promoting higher mechanical properties by dispersing the mould temperature transfer through the whole mould thus increasing the solidification rate. [7]. In the present investigation, effect of mould rotation speed was studied on hardness and tribological behaviour of hypereutectic aluminium silicon alloy by horizontal centrifugal casting method.

Experimental Procedure

Horizontal Centrifugal Casting Process

Al–Si alloys with 17 % Si contents were selected and will be referred in this study. Materials were melt in an induction vacuum furnace at temperatures above their liquidus temperature and then poured into a cast iron mould. The permanent mould was preheated to 250° C for all castings. Zircon-water based coating is used for mould coating as proved effective and is known to give excellent surface finish. Then melt was degassed with 1% hexachloroethane tablet. After fluxing and proper degassing, 1% Al-3Ti-1B wrapped in aluminium foil, was added to the molten alloy with stirring of the melt at pouring temperature. This was followed (after 10 minute of addition of grain refiner) by addition of 1% of strontium in the form of Al-10%Sr master alloy to the melt. After the holding for 10 minute, dross was removed and temperature is measured using "MICRO TEMP DETECTOR" subsequently molten alloy was poured in rotating mould of Horizontal centrifugal casting machine. During Horizontal centrifugal casting, the mould was rotating around the central axis of the casting machine at different rpm (500 (K1), 600 (K2), 700 (K3), 750 (K4) and 800 (K5) rpm) and the molten aluminium was poured into the mould cavity by centrifugal force.

Size of Casting sample: ID=70mm, OD=100 mm and Length=150 mm)

Element	Composition(%)	Element	Composition(%)
Si	17.16	Cr	0.0282
Fe	1.63	Pb	0.0322
Cu	1.29	Sn	0.000514
Mn	0.854	Ti	0.0285
Mg	0.589	B	0.00736
Zn	1.08	Al	77.1
Ni	0.949		

Table 1 Chemical Composition

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Figure 1. Horizontal Centrifugal Casting Machine Setup

Figure 2. Casting sample.

Vickers Hardness measurement

The ASTM E 384 standard test method is used to determine the hardness of materials. The specimen is placed on an anvil that has a screw threaded base of Vickers hardness test machine. The anvil is turned raising it by the screw threads until it is close to the point of the indenter. With start lever activated, the load is slowly applied to the indenter. The load is released and the anvil with the specimen is lowered. The operation of applying and removing the load is controlled automatically. The applied load during the testing was 5 kgf, with a dwell time of 15 second. It has a square-base diamond pyramid indenter. Hardness tests were taken at three points on the sample of the casting. At least three measurements of Arithmetic mean diagonal were taken for each sample and the average values. Vickers Hardness Number (VHN) can be calculated by equation

$$HV = \frac{1.854 \times F}{D^2}$$

Pin on disk wear test

To determine wear rate, Pin on Disk test apparatus was used. Wear test specimens are rounded at one end of 6 mm diameter and flat surface at other end having dimensions of 25 mm length and 12.5 mm X 12.5 mm in cross section. The tip of pin was positioned perpendicular to a flat circular disk made of EN 31 steel (Diameter 145 mm and Thickness 16 mm). The round portion of pin was kept in contact with a rotating disc during wear test. The pin (specimen) was fixed and the disc (EN31) was rotating at a speed of 202 rpm. The pin is pressed against the rotating disc at a specified load using lathe tool dynamometer. EN31 steel disc was directly attached on spindle of lathe machine with the help 3-jaw chuck as shown in Figure 3.

Figure 3. Pin on Disc Test Apparatus

Throughout this experiment, constant track diameter 50 mm is used. Unlubricated pin-on-disk configuration wear tests were conducted on the external and internal zones of the centrifugally cast samples. The tests were conducted for different loads ranging from 10–30N at a sliding velocity of 0.523 m/s, a track diameter of 50 mm and a sliding distance of 317.8 m. During wear test, sliding velocity and sliding distance were kept constant.

Determination of Amount of Wear

The weight loss(Δw) of pins was measured using electronic microbalance having accuracy of 0.001mg. The wear rate was calculated from the weight loss technique. Wear rate W (t) in terms of volume loss was calculated by dividing the weight loss to density (ρ) and the time (t).

$$W(t) = \frac{\Delta w}{\rho t}$$

The Specific wear rate, Ws was calculated by using the following formula:

$$Ws = \frac{W(t)}{V_s \times F_n}$$

Where Vs is sliding velocity in m/s and Fn the input weight or normal load in N or kg m/s2 with an assumption that the temperature is constant.

Results and discussion

Vickers hardness value of both inner and outer section of different samples obtained at different rotational speed is tabulated in Table 2.

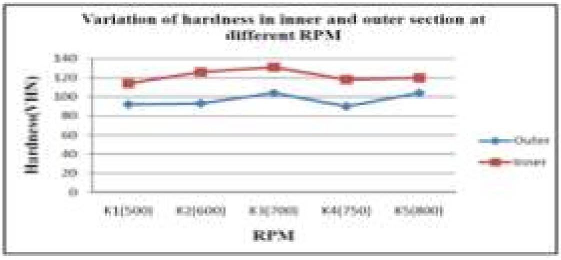
Effect of Rotational Speed of Mould on Hardness of Sample

There is increase in hardness as the rotational speed of mould is increased from 500 rpm to 700 rpm. Beyond 700 rpm hardness profile does not follow the linear relationship with rotational speed of mould. At lower rotational speed, solidification rate is slower compared to higher rotational speed of mould during centrifugal casting. So there is formation of coarse primary silicon particle during solidification due to slow cooling rate. The coarse silicon particle and low volume fraction of particle might be responsible for lower hardness at lower rotation speed. At higher mould rotational speed of mould, fragmentation of primary silicon takes place due to centrifugal force acting on the liquid metal during solidification. The fine silicon particle and high volume fraction of particle might be responsible for higher hardness at higher rotation speed. The higher hardness in inner periphery confirms that there is more concentration of primary silicon particle in inner periphery compared to outer periphery for a casting sample. These primary Si particles were pushed towards the rotation axis under the centrifugal force due to their lower density as compared with the remaining liquid.

Sample	Outer	Inner
K1	92 HV5	114 HV5
K2	93 HV5	126 HV5
K3	104 HV5	131 HV5
K4	90 HV5	118 HV5
K5	1045 HVS	120 HV5

Table 2 Vickers hardness values of samples.

From Figure 4 it can be seen that hardness is decreasing from inner to outer region for all samples. At 700 rpm, maximum hardness was reported in inner and outer region among the all samples.Thus, In present investigation 700 rpm might be optimum rotation speed.



Effect of Rotational Speed of Mould on Specific wear rate of Sample

The wear tests on the samples are carried out (considering the operating parameters of wear) i.e. by constant sliding velocities and sliding distances, varying applied load (10N, 20N and 30N) and specific wear rate values are reported in Table 3.1, 3.2 and 3.2 respectively.

Sample	Specific wear rate ($mm^3 * 10^{-4}$ / N.m)	
	Outer	Inner
K1(500)	2.23	1.41
K2(600)	1.76	1.05
K3(700)	1.41	0.82
K4(750)	12.00	5.29
K5(800)	3.17	2.23

Table 3.1 Specific Wear Rate of Samples (Normal Load: 10N)

Sample	Specific wear rate ($mm^3 * 10^{-4}$ / N.m)	
	Outer	Inner
K1(500)	2.23	1.58
K2(600)	2.00	1.29
K3(700)	1.64	1.00
K4(750)	6.76	3.35
K5(800)	2.82	2.64

Table 3.2 Specific Wear Rate of Samples (Normal Load: 20N)

Sample	Specific wear rate ($mm^3 * 10^{-4}$ / N.m)	
	Outer	Inner
K1(500)	2.98	2.31
K2(600)	2.74	1.80
K3(700)	2.58	1.76
K4(750)	4.82	2.90
K5(800)	3.25	2.39

Table 3.3 Specific Wear Rate of Samples (Normal Load: 30N)

For 10N normal load, when mould rotation speed is varied from 500 rpm to 700 rpm, specific wear rate is continuously decreasing in inner and outer region of samples as shown in Figure 5 and Figure 6. Further increase in rotational speed (750 rpm) of mould shows different wear behaviour i.e. abrupt increase in wear rate in both inner and outer region of samples. The steep rise in specific wear rate of sample obtained at 750 rpm can be correlated with the reduction in hardness in the same sample.

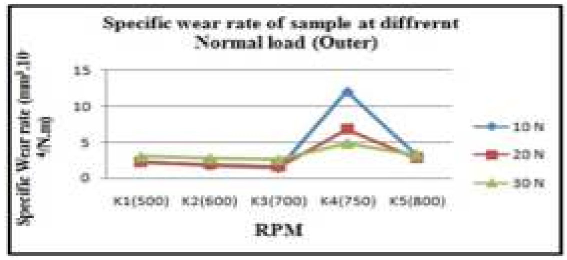


Figure 5. Specific Wear Rate of Samples (Outer section).

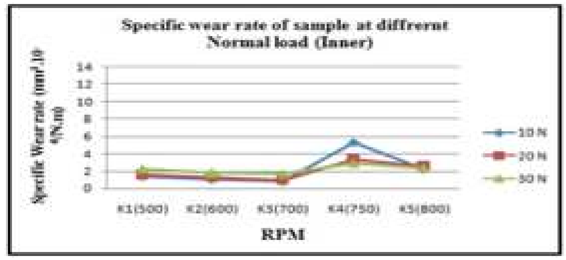


Figure 6. Specific Wear Rate of Samples (Inner section).

Again increase in rotational speed from 750 rpm to 800 rpm, specific wear rate is reduced from 12 to 3.17 (mm3.10-4 / N.m) and from 5.29 to 2.23 (mm3.10-4 / N.m) for outer and inner region of samples. From wear test data it can be emphasized that minimum wear rate is observed at 700 rpm for both inner and outer part of sample.

At optimum rotational speed fine primary silicon particles are formed which leads to better wear resistance. In some literature, it has been reported that uniform distribution of finer silicon particles endowed better resistance to wear.

From Figure 5 and Figure 6, it is concluded that profile of specific wear rate against mould rotation speed for 20N and 30N remains same as obtained for 10N applied load. But specific wear rate for 20N and 30N applied load is higher than former one. It can be seen that inner section offers more wear resistance than the outer section for samples. This is due to presence of primary silicon particle in inner periphery. In inner and outer periphery, specific wear rate shows slight variation against rotational speed of mould for different applied load. But at 750 rpm, there is noticeable variation in wear rate at different normal load

Conclusion

- Mould rotation speed of centrifugal casting has strong impact on hardness and wear behaviour of Hypereutectic Al-Si alloy
- The influence of rotational speed on the hardness and wear behaviour of the hypereutectic aluminium silicon (Al-17Si) alloy was investigated and the both were mainly dependent on the size and volume fraction of primary silicon particles in the matrix.
- There is decreasing trend in hardness from inner to outer periphery of cast sample due to primary silicon particle are pushed toward inner region during horizontal centrifugal casting.
- There exists optimum speed of rotation mould under given experimental condition. In our experiment it was found to be 700 rpm. At optimized speed, there is optimization of refinement of primary silicon particle and uniform distribution of constituent phase, resulting in optimization of hardness and wear rate.
- At optimum mould rotation speed, specific wear rate was found minimum in inner and outer periphery of cast sample and hardness was found maximum in inner and

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outer periphery of cast sample.

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