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EFFECT OF SOLIDIFICATION RATE ON WEAR BEHAVIOUR OF HYPO-EUTECTIC Al-Si (A380) ALLOY CASTING

[Muthukrishnan Mohandass, Jayaraman Venkatesan, Alankaram Venkatesan]

Abstract—**This research work reports the effect of solidification rate on structural morphology and wear behavior of unmodified Al-7Si-3.5Cu (A380) alloy casting. Solidification rate is an important processing parameter that affects microstructural features of cast alloy, which in turn significantly influences the mechanical properties and wear behavior. It is found that morphological features of eutectic silicon and copper aluminide ($CuAl_2$) have the substantial effect on wear characteristics of the alloy. The presence of refined eutectic silicon and $CuAl_2$ particles in water-cooled casting remarkably reduces the Coefficient of Friction (COF).**

Keywords— Al-Si alloy casting, eutectic silicon, $CuAl_2$, Coefficient of Friction (COF).

I. Introduction

Al-Si alloys have extensive applications in the automotive and aircraft industries. These alloys possess outstanding castability in conjunction with exceptional mechanical properties and good wear properties [1,2]. However, the demand by users and engineers for these alloys with superior properties is on the rise. The mechanical properties of Al-Si alloy castings depend on the microstructure [3]. Thus, it is very important to control microstructural evolution and casting defects in the finished Al–Si casting alloys. A number of investigations have been reported that grain refinement leads to fine equiaxed grains and reduced Secondary Dendrite Arm Spacing (SDAS), which in turn results in enhanced mechanical and wear properties [4-8]. Improvement in the mechanical properties of alloy castings with the control of microstructure by post processing like heat treatment has been extensively carried out.

Another way of improving the Structural-sensitive properties of Al-Si alloy castings can be obtained by increasing the rate of solidification, i.e. accomplishing a high rate of heat transfer while the liquid-to-solid transformation taking place [9]. Several researchers have studied the outcome of high cooling rates on the microstructure of the A1-Si alloy castings. Refined grains, extended solid solubility and precipitation of metastable phases obtained at high cooling rates will result in an enhancement of fatigue life, wear resistance and corrosion resistance of alloys [10].

Sri Venkateswara College of Engineering
India

It is not reported in the literature, to the best of knowledge of the authors, the effects of solidification rate on the wear behavior of A380 Al–Si alloy casting. Hence an attempt is made in this paper to study the effect of solidification rate on structural morphology of eutectic silicon and copper aluminide and their impact on wear resistance of unmodified A380 alloy casting.

II. Experimental Procedure

The procedure of casting processes and specimen preparation for microstructural evaluation and wear test are to be discussed in detailed manner in the following sections.

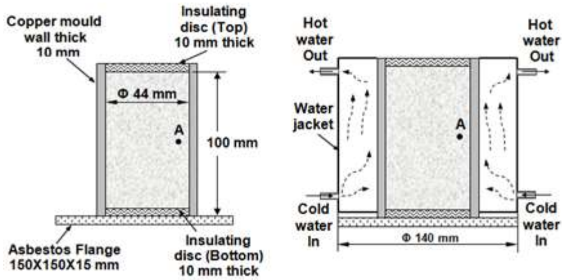
A. *Casting and Specimen preparation*

Commercially available unmodified hypo-eutectic A380 Al-Si alloy is used in this study. The chemical composition of alloy is given in Table I.

TABLE I. Composition of A380 Aluminium Alloy

Chemical Elements	Cu	Si	Mg	Fe	Mn
Wt. %	3.42	7.8	0.18	1.1	0.41
Chemical Elements	Ni	Zn	Pb	Ti	Al
Wt. %	0.3	2.64	0.25	0.18	Reminder

The ingot was placed in a silicon carbide crucible and re-melted using electric furnace in an inert gas (argon) atmosphere and melt was quickly transferred to a copper mould. In order to analyze the influences of solidification rate on microstructure and wear resistance of the alloy casting, the copper mould was cooled externally by two different methods: using ambient air and using flowing water (with a flow rate of 20 lit/min). The schematic diagrams of both air-cooled and water-cooled gravity die setups are shown in Fig. 1(a) & (b) respectively. During solidification the top and bottom of the die were insulated with asbestos discs to make sure that the heat transfer from the cast to the coolant takes place only through the mould walls. This may help in restricting the heat flow only along radial direction. The temperature of melt was measured using K-type thermocouple at the point A as shown in Fig. 1. The data from the thermocouple was continuously fed in a computer with the help of a USB based data acquisition card and LabVIEW software.



(a) (b)

Figure 1. (a) Air-cooled setup (b) Water-cooled setup

In case of water-cooled die casting setup the inner diameter of water jacket is 140 mm with 1mm wall thickness. Other geometric dimensions of the mould are identical for both the air and water-cooled setup. Water enters the jacket at the bottom and exits at the top.

At first, the casting process was done with thermocouples to record the temperature profile (Tc) of the casting at a point 'A' which is 5mm away from the mould wall at mid height of the cast. Thereafter, the alloy castings were produced for preparing the test specimens without thermocouples. The test specimens (Microscopy specimens and wear test-pins) were extracted from the region nearer to the cylindrical surface of the castings as shown in Fig. 2, where the temperature was already measured at the point A as shown in Fig. 1. Wear test pins were prepared as per ASTM-G99 standard with 8 mm diameter and 30 mm length.

B. *Wear testing*

Pin-on-disc apparatus was to be used for dry sliding wear test of both air-cooled and water-cooled casting pins. Quenched, tempered and surface finished EN31 steel discs of 50 mm diameter were used for testing. The rotating speed of the disc was adjusted to maintain a constant sliding velocity of 1 m/s and the test was conducted with two loading conditions viz. 10 N and 20 N respectively. The coefficient of friction was documented continuously using computerized data logger.

III. Results and Discussions

In the following sections, the temperature profile, microstructural feature and wear behaviour of both the air-cooled and water-cooled castings are described in detail.

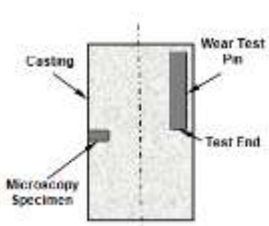


Figure 2. Schematic representation of extraction of microscopy specimen and wear test pin

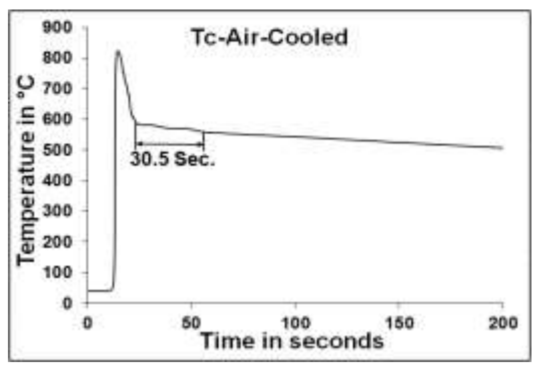
A. *Cooling curve Analysis*

Fig. 3(a) and (b) show the temperature profiles (Tc) of air-cooled and water-cooled castings respectively. From the cooling curves it is observed that the solidification takes place over a range of temperature rather than at a discrete melting point, since the metal is hypo-eutectic Al-Si alloy.

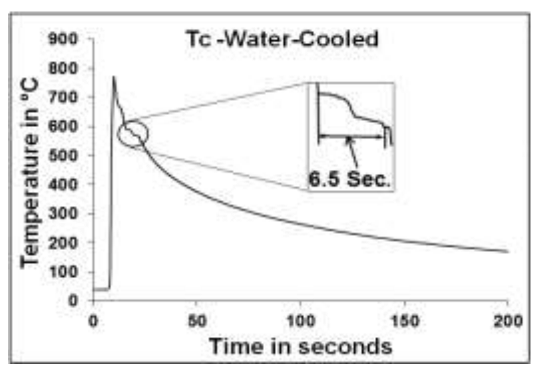
It is seen from the Fig. 3(b) that a short freezing (solidification) occurred in water-cooled casting as compared to air-cooled casting. The change of phase from liquid to solid completed within around 6.5 seconds in case of water-cooled casting. Where in the case of air-cooled casting the change of phase occurred over a long extended period of 30.5 seconds. The sudden phase change in water-cooled casting promotes the nucleation of primary α-Al, eutectic and CuAl2 grains concurrently at more points as compared to air-cooled casting system. The higher solidification rate during water cooled casting process is responsible for the well-refined grains, which in turn increases the material's strength, hardness and wear resistance.

B. *Microstructural features*

Fig. 4(a) and (b) show the microstructure of air-cooled and water-cooled Al-Si (A380) alloy castings respectively. This alloy has primary α-Al phase (matrix), secondary phase eutectic silicon and intermetallic compound CuAl2. It can be seen that in the case of air-cooled casting the coarse CuAl2 is highly segregated at a particular location.

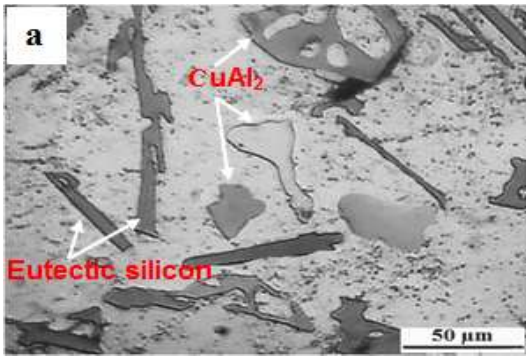


(a)

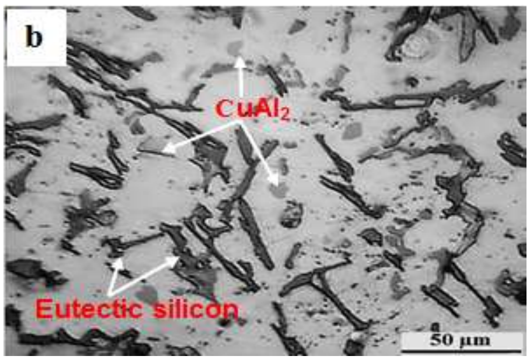


(b)

Figure 3. Temperature profiles (Tc) of (a) Air-cooled casting and (b) Water-cooled casting



(a)



(b)

Figure 4. Micrographs of (a) Air-cooled casting and (b) Water-cooled casting with 400X

It can also be seen that an air-cooled alloy casting consists of long and thick eutectic silicon platelets in the inter-dendritic regions of coarse α-Al matrix.

Significant changes can be noticed in the microstructure of alloy due to short freezing. Both the CuAl2 intermetallic compound and the eutectic silicon are refined in the water-cooled casting. It can also be noticed that fine particles of CuAl2 and eutectic silicon are evenly distributed throughout the micrograph of water-cooled casting.

The comparative study of microstructures discloses that, increase in the solidification rate has shown a remarkable improvement in the refinement of both the CuAl2 and the eutectic silicon of A380 alloy castings. Increased solidification rate promotes more number of nucleation sites and hence, high concentrations of eutectic silicon and CuAl2 particles were found in the α-Al matrix of water-cooled casting as compared to air-cooled casting.

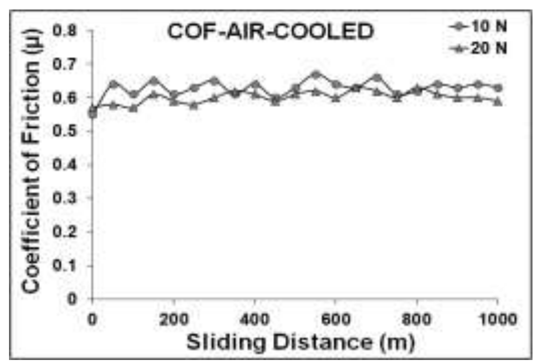
A. *Coefficient of Friction (COF) and Wear volume*

Fig. 5(a) shows the coefficient of friction of air-cooled A380 alloy casting as a function of sliding distance for 10 N and 20 N load conditions. It can be seen that the average value coefficient of friction for 10 N load is around 0.63, whereas for 20 N load, it is around 0.60. The Fig. 5(b) shows the plot of coefficient of friction versus sliding distance of water-cooled casting for 10 N and 20 N load conditions.

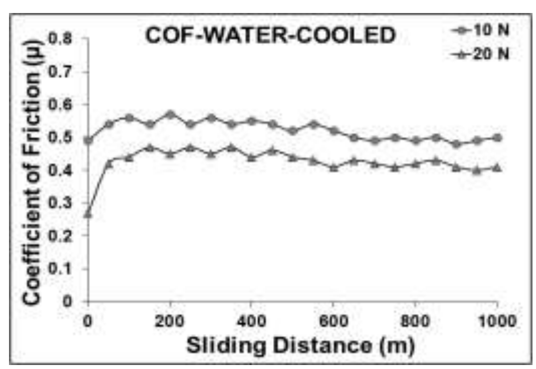
From the Fig. 5(b), it has been seen that the average value of coefficient of friction for 10 N load is around 0.52, whereas for 20 N load, it is around 0.42. In both air-cooled and water-cooled castings, the COF is less for 20 N load as compared to 10 N load condition. An increase in the load ruptures or breaks the peaks of sliding surfaces causing a decrement in the coefficient of friction [11].

The comparative study between air-cooled and water-cooled castings reveals that the average value of coefficient of friction decreases (about 20% for 10 N load & 30% for 20 N load) when the solidification rate increases. In the case of air-cooled casting, the presence of coarser eutectic silicon and CuAl2 particles become debris during wear test and worsen the surface condition whereas, in the case of water-cooled casting, the eutectic silicon and CuAl2 particles are highly refined. It can also be seen that the large amount of eutectic silicon particles exist in the water-cooled casting which may act as a solid lubricant causing a decrement in the coefficient of friction.

Fig. 6 represents the wear volume bar chart of both air-cooled and water-cooled cast pins for 10 N and 20 N loads. As discussed in the previous section, the presence of large number of refined eutectic silicon and CuAl2 in water-cooled casting considerably increased the wear resistance and hence, a less wear loss occurred (less by 48% & 29% for 10 N and 20 N loads respectively) as compared to air-cooled casting.



(a)



(b)

Figure 5. COF versus sliding distance (a) Air-cooled casting and (b) Water-cooled casting

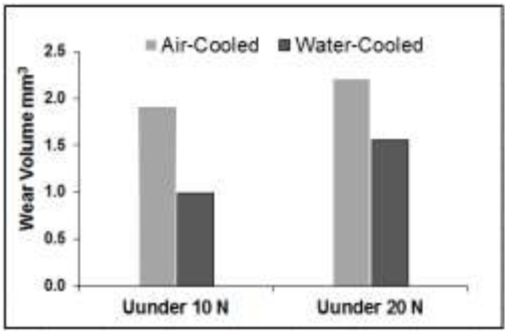


Figure 6. Wear volume-Bar chart

It has been seen that the high wear volume occurred with 20 N normal load. The increase in normal load generates heat between the sliding surfaces which increases the deformation of pin causing a further volume loss of alloy.

IV. Conclusion

In this work, a comparative study was carried out between water-cooled and air-cooled castings to understand the wear behavior of A 380. The outcome of this work can be summarized as follows. The water cooling technique greatly reduces the local solidification time of the casting. The increased solidification rate highly refines the eutectic silicon and CuAl2 particles of the alloy. The Coefficient of Friction is found to decrease with a reduction in size of the eutectic silicon and CuAl2 particles thereby decreasing the wear volume.

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