International Journal of Mechanical and Materials Engineering (IJMME), Vol. 5 (2010), No. 1, 101-105.

EXPERIMENTAL STUDY ON RATE OF SOLIDIFICATION OF CENTRIFUGAL CASTING

Madhusudhan[1], S. Narendranath[2], G.C.M. Kumar[2] and P.G. Mukunda[1]
[1] Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology, Yelahanka, Bangalore, India
[2] Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal, India
Email: madhusudan_75@rediffmail.com

ABSTRACT

Centrifugal casting is a process of producing casting by causing molten metal to solidify in rotating moulds. The quality of the final casting is mainly depending upon the flow pattern of the molten metal and rate of solidification, which in term depends upon the rotational speeds of the mould. Experiments have been conducted by rotating a partially filled horizontal axis cylinder at different rotational speeds and also at different fluid temperatures. Cooling rates of the liquids were observed at different rotational speeds, which depend upon the relative movement between the inner surface of the rotating mould and the fluid. This study gives us some insight into the effect of rotational speed on solidification rate of centrifugal casting. Micro structures of centrifugally cast Al-12 Si castings are also exhibit the same behavior for different rotational speeds.

***Keywords*:** Partially filled rotating cylinder; Cooling rate; Relative movement; Optimum speed of mould.

1. INTRODUCTION

Centrifugal casting is a process of producing castings by causing molten to solidify in rotating moulds. The quality of the final centrifugal casting is mainly depending upon many parameters such as: pouring temperature, initial temperature of the mould, rotating speed and size of the mould, time of pouring the mould, composition of the composite, type, diameter and shape of particles and others (R. Zagorski, 2007). The mathematical description of centrifugal casting is very difficult due to of a lot of parameters mentioned above are involved in the processes, e.g. thermal, hydrodynamic, solidification, segregation of particles (R. Zagorski, 2007, A Halvaee 2001). The features involved in centrifugal casting are fluid flow, thermal properties and solidification (Evans P L, 2004). On pouring the melt into a rotating mould it starts to cool with its viscosity increasing gradually. The molten metal is very viscous just before and during freezing. Here the process is rapid and the behavior of melt cannot be understood properly. Since the mould in centrifugal casting is opaque it is not possible to visualize the flow patterns in a rotating mould (K. Suzuki, 2004). There is a rich assortment of stationary and temporally varying spatial patterns inside a horizontally rotating cylinder for one single particle size and one particular size of the cylinder (Amy Q Shen, 2002). Rotational speed of the mold is one of the important process variables which affect the cooling rate of the molten metal. As the rotational speed is increased the centrifugal force is increased by a square proportion, which may create a strong convection in the liquid pool and then produce a homogenization of temperature in the bulk liquid (Wu Shi Ping, 2006). As a result, the growth of equiaxed grains is favored (Wu Shi Ping, 2006). So it is required to review and focus on the fluid flow phenomena in the centrifugal casting. The present state of art in analytical, experimental and numerical techniques can be employed to study the fluid flow and effect of fluid flow on the process of the product. The fluid exhibits different flow patterns when it is rotated at different speeds, like Ekmann flow, Coutte flow and Taylor flow which are disturbed flows (A Shailesh Rao, 2007).

A brief survey of the earlier literatures indicates that many investigations have been directed to study the behavior of the fluids and its effect in the casting process, but the factors involved in fluid instabilities that influences casting and rate of cooling need to be investigated. Moreover, the physics of fluid behavior has hardly been understood. Some analysis software can be used to predict the effect of process variable in casting process in order to reduce casting defects (N. H. Mohamad Nora, 2009). From this brief survey of the literature, it is surprising to note that many investigations have been directed at the solution of a particular case and no attempts have been made for generalization. It is necessary to make preliminary examinations of the nature on the flow of fluids in a partially filled rotating cylinder at various speeds to study the various fluid patterns and also the rate of cooling at different rotational speeds.

The cold modeling approach aids in finding the flow of the fluid but fails to simulate the complete process where other complexities like phase change, variation of viscosity and heat transfer are quite important. Results obtained in this cold modeling experiment are matching with the actual casting process and hence cold model experiments are more effective to correlate the actual casting process. Effect of other process variables can also be studied by this type of experiments.

2. EXPERIMENTAL PROCEDURE

The water modeling experimental setup consists of an aluminum cylindrical mould fixed to a driving flange as shown in the Figure 1. This driving flange is connected to a shaft of a DC motor, where the speed can be varied from 20rpm to 2000rpm with high accurate speed controller. The flow of water into the mould is confined in the horizontally oriented, axially rotating cylindrical mould. The rotational speed of the mould is increased from zero to optimum speed of rotation where the fluid forms a uniform thick layer inside the rotating mould. The experiment is conducted in three different cases. In the first case cylinder was kept stationary with water at about 80^{o}C is poured and decrease in temperature is recorded at various intervals of time. In the second case the cylinder is made to rotate slightly at higher speeds like 200rpm, 300rpm, and 450rpm. As the rotational speed of the mould is gradually increased the thick film is pulled out from the pool and the lump of water oscillates. Here the water tries to lift in a mass and falls back to the pool and the water exhibits different flow patterns like Ekmann flow, Taylor's flow etc (A Shailesh Rao, 2007). And in the third case the cylinder is rotated at above optimum speed (about 600 rpm) and in this case the liquid forms a uniform thick layer with speed same as the speed of the rotating cylinder. In this mode centrifugal forces dominate and the fluid coats the cylinder surface uniformly and rotates rigidly with it. In all the three cases the decrease in temperatures with respect to the time intervals has been recorded. Same experiments for the three cases have been conducted for actual centrifugal casting of Al-12Si alloy by replacing Aluminum mould by Mild Steel. Due to the high density the optimum speed required for the molten metal is high.

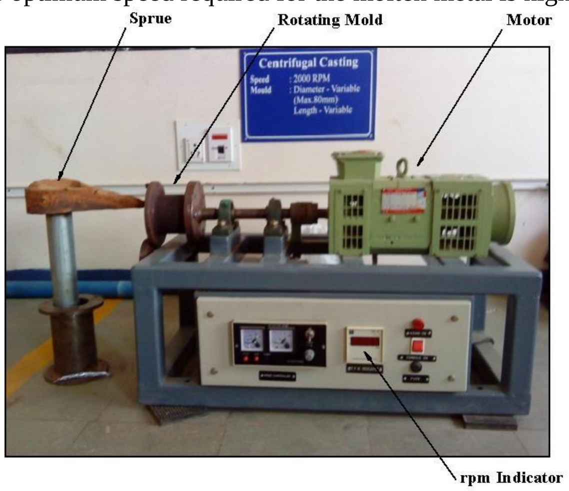

Figure 1 Experimental Set up

2. RESULTS AND DISCUSSIONS

a. Water modeling:

Effect of rotational speed of the mould on the rate of solidification has been analyzed experimentally and curves of variation of water temperature with respect to the time have been plotted as shown in the Figure 2. There is a rapid cooling is observed in the beginning due to the chilling effect of liquid with the cold mould and later stages the mould wall temperature increases and rate of cooling(slope of the tangents drawn at different intervals) decreases. At the intermediate rotational speeds due to the turbulence flow the cooling rate is faster, hence all the curves corresponding to the intermediate speeds are found to have fallen below the previous curves. Figure 3 shows the cooling rate of water at different rotational speeds of the cylinder.

As the rotational speed increases the centrifugal force also increases which creates a strong convection in the liquid pool and this leads to the rapid cooling of the liquid. From the graph, it is clear that cooling rate is maximum at around 400 rpm which is less than the optimum speed of the rotating cylinder, minimum rate of cooling is observed for the stationary mould, this is due to the reason that in case of stationary cylinder, the relative movement between the cylinder and the hot liquid is approximately zero; hence the liquid cools down slowly. Also in case of rotational speed above optimum speed the relative movement is minimum hence again the cooling rate decreases. Rotational speeds below the optimum speed the liquid shows different flow patterns and the flow becomes turbulent, hence the cooling rate is high.

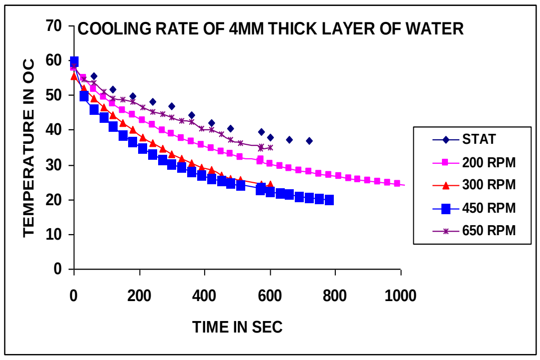

Figure 2 Temperature variation of the water at different intervals of time

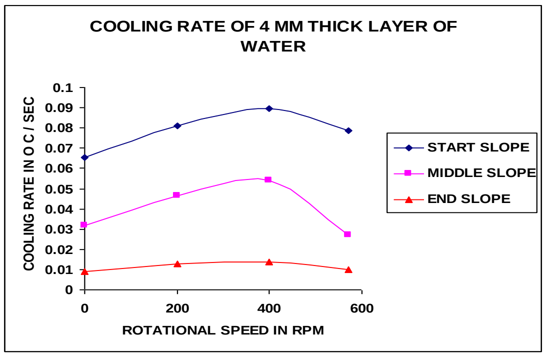

Figure 3 Cooling rate at different rotational speeds

b. Microstructure Analysis:

Figure 4-7 shows the microstructures of Al-12Si alloy castings which are produced by rotating the mould at different rotational speeds of the mould. Formation of primary silicon is seen at the inner and middle surface of the castings which are produced by rotating the mould at 200 rpm; this is due to the slow solidification rate.

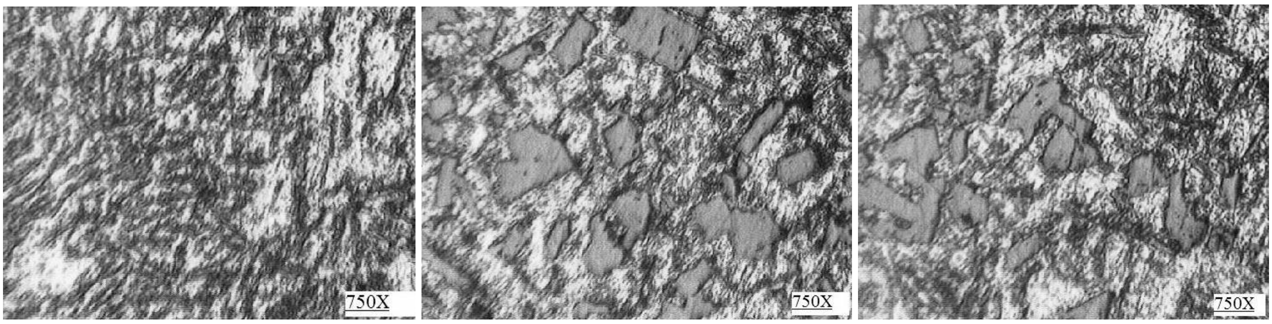

Figure 4 Microstructures at outer, middle and inner surfaces for rotational speed 200 rpm

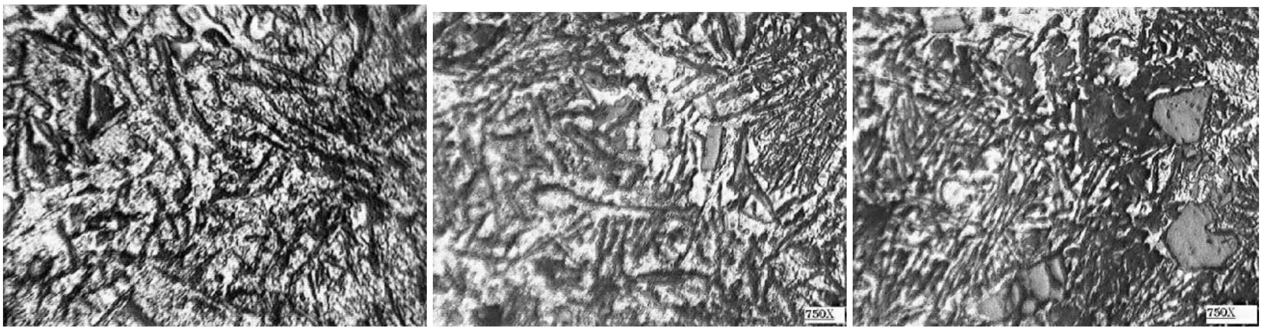

Figure 5 Microstructures at outer, middle and inner surfaces for rotational speed 400 rpm

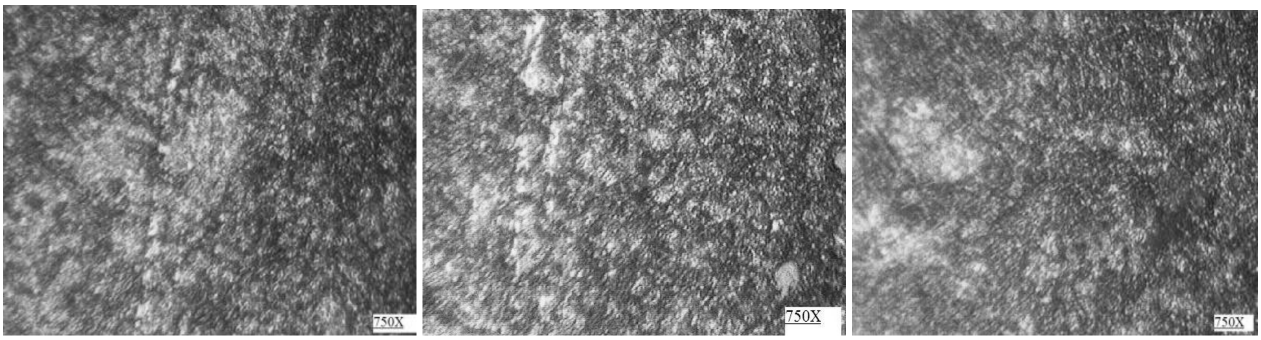

Figure 6 Microstructures at outer, middle and inner surfaces for rotational speed 600 rpm

Figure 7 Microstructures at outer, middle and inner surfaces for rotational speed 800rpm

With the increased rotational speed to 400 rpm the solidification rate increases due to the turbulence and broken primary silicon structures are formed at inner and middle regions, needle shaped structure of Silicon is exhibited at the outer surface. Castings produced at 600rpm forms uniformly thick cylindrical casting byrapidly crossing the turbulent stage. Fine silicon particles exhibiting good mechanical properties were observed in all the three surfaces of the casting as shown Figure 6**.** With the increase in rotational speed to 800, the molten metal gets lifted immediately, hence dendrite structures are seen at the middle and inner surfaces and fine structures are seen at the outer surface due to chilling effect of the molten metal when it comes in contact with the cold mould and needle shaped and also primary silicon are seen at the middle and inner surfaces due to slow solidification. Slow solidification due to the absence of relative movement between the mould and the molten metal.

c. Actual Casting

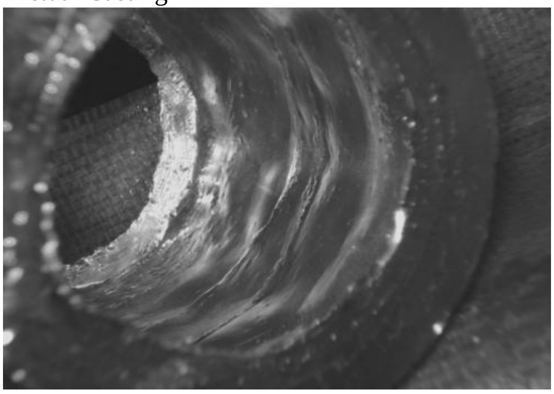

Figure 8 a Centrifugal Castings (size Ø 80, 120mm long) produced at a) 400 rpm

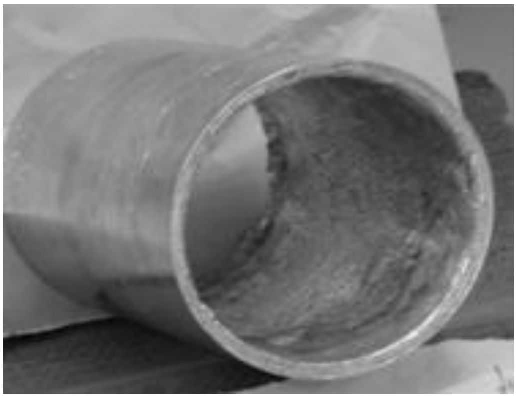

Figure 8 b Centrifugal Castings (size Ø 80, 120mm long) produced at 600 rpm

The actual castings produced at 400 rpm and 600 rpm are shown in the Figure 8 a and Figure 8 b. At 400 rpm due to turbulence irregular profile is observed at inner surface and uniformly thick casting is produced at 600 rpm. This 600 rpm speed is known as optimum speed.

3. CONCLUSIONS

Rotational speed of the mould has been found to play an important role in the rate of cooling (solidification) of the casting. At moderate speeds (below the optimum speed), the flow of the metal will be turbulent hence cooling rate becomes faster. This is due to the fact that as the rotational speed is increased the centrifugal force is also increased, which create a strong convection in the liquid pool, at rotational speeds above the optimum Speed, the cooling rate is slower due to the negligible relative movement between the rotating cylinder and the hot liquid. Because at this stage, the fluid forms a uniform layer concentric to the mould profile. These results are helpful to correlate the centrifugal casting process. Presence of primary silicon in the casting produced at slow speed and speed above optimum speeds shows the slower cooling rate due to absence of relative movement of molten metal and the rotating mould. At medium rotational speed due to the turbulence cooling rate is faster and hence broken primary silicon structures are formed at inner and middle regions, needle shaped structure of Silicon is exhibited at the outer surface. At optimum speed of 600rpm, the metal forms full cylinder, heat transfer takes place by conduction through the metal and the solidification time is comparatively less so fine structures are formed.

ACKNOWLEDGEMENT

The author acknowledges Dr N R Shetty, Director and Dr H C Nagaraj, Principal, Nitte Meenakshi Institute of Technology, Yelahanka, Bangalore for their kind support for this project.

REFERENCES

Amy Q Shen “Granular fingering patterns in horizontal rotating cylinders”, Physics of Fluids, Vol 14, No 2, Feb 2002, 462-470.

A Halvaee, et al, ‘Effect of process variables on Microstructure and segregation in Centrifugal casting of C92200 alloy’, Journal of Materials Processing Technology, 118 (2001) 123-127.

Evans P L, et.al “Steady and unsteady solutions for coating flow on a rotating horizontal cylinder: Two-dimensional theoretical and numerical modeling”, Physics of Fluids, Vol 16, No8, 2742-2756, 2004.

J. Sleziona, R. Zagorski “Pouring mould during centrifugal casting process”, Archives of Materials Science and Engineering, International Scientific Journal, Vol 28, Issue 7, July 2007.

K. Suzuki, M. Yao, “Simulation of Mold Filling and Solidification during Centrifugal Precision Casting of Ti-6Al-4V Alloy”, METALS AND MATERIALS International, Vol. 10.1(2004), pp. 33~38.

N. H. Mohamad Nora, N. Muhamadb, M. H. Ismaila, “Flow behavior to determine the defects of green part in metal Injection molding”, IJMME, Vol. 4

(2009), No. 1, 70 -75.
P G Mukunda, A Shailesh Rao, “An understanding of fluid behavior in Centrifugal casting”, AFT / TFI -2007, Commemoration of the 100th Anniversary of Tohoku University, December 14-15, 2007, Sendai, Miyagi, Japan.
Wu Shi Ping, Liu Dong Rong, Guo Jing Jie, et al “ Numerical simulation of microstructure evolution of Ti – 6Al -4V alloy in vertical centrifugal casting”, , School of Materials Science and Engineering, China, 2006.