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Influence of teeming temperature of molten tin in centrifugal casting

P. G. Mukunda[1], S. Rao Shrikantha[2], A. Rao Shailesh*[2] and S. Kiran Aithal[2]

During centrifugal casting, when a mould is rotated at very low and very high speeds, defects are found in the final castings. Obtaining the critical speed for sound castings should not be a matter of guess or based on experience. The defects in the casting are mainly due to the behaviour of the molten metal during teeming and solidification process. The studies of melt flow in partially filled rotating cylinders have indicated many features, which were not mentioned in the literatures of centrifugal casting. Motion of molten metal at various speeds and its effect during casting are addressed in this paper. Molten tin has been taken for the experiments, and its behaviour during various rotational speeds is explained.

Keywords: Fluid flow, Centrifugal casting, Teeming temperature

Introduction

One of the most crucial and active areas of research in fluids engineering today is that of material processing. Centrifugal casting is one of the material processing techniques in which the flow pattern of the molten metal during casting strongly affects the quality of the final product. Literature about fluid flow in centrifugal casting is very sparse. Depending upon the conditions of the molten metal, there must be an optimum speed at which the molten metal will be picked up to form a true cylinder.

Jaluria[1] discusses the importance of fluid flow in material processing. The author points out several aspects of fluid flow, which change the properties of molten metal, in various processing techniques. Most of the active researches have been carried out on continuous casting. Bergeles and Anagnostopoulos[2] put forward several important parameters involved in the centrifugal casting process.

Results and discussion

In this technical note, the behaviour of molten tin is explained to understand the role of an optimum speed during centrifugal casting process. For teeming temperature of 450°C, the authors start by describing a typical progression of phenomena encountered when the angular velocity of the cylinder is gradually increased. For 4 mm thick casting, prepared at low rotational speeds (Fig. 1*a* and *b*), a thin film of molten metal is pulled out of the pool and covers the entire cylinder inner surface. As the metal enters the bottom pool on the receding side, a straight front is created. An accompanying recirculation region is formed in the pool and simultaneously, the metal flows along the axis. The thin layer, circulated on the surface of the mould, gets solidified and forms Couette flow. Simultaneously, the melt gets a lift from the side wall and forms Ekmann flow. From the literature, it is learnt that these flows are formed in low viscous fluids.[3,4] With a gradual decrease in the viscosity, the molten metal pulled out from the pool also thickens. It eventually becomes unstable to a sloshing mode of motion on the rising side of the cylinder. The unstable liquid begins to slosh to and fro along the axis. During this stage, the metal gets solidified, and an irregular shaped casting is formed. At rotation speed of 600 rev $\min^{-1}$, the centrifugal force dominates, and the fluid coats the cylinder surface uniformly and rotates rigidly with the mould and thus forms a uniform hollow cylinder casting (Fig. 1*c*). With further increasing speed to 800 rev $\min^{-1}$, the molten metal moves along the inner surface of the mould due to large driving force. Only small portions of the metal succeed in moving along the axis and immediately get solidified during its motion. Finally, a thick casting is formed on one side and a comparatively thinner casting on the other. Moreover, the thickness of the resultant cylinder exhibits a non-uniform, step-like formation, as seen from Fig. 1*d*. The reduction in the teeming temperature also influences the appearance of the casting. In this case, the molten metal should be driven at higher rotational speed to form uniform cylinder for the following two reasons. The first is the high viscosity of the molten metal with decrease in teeming temperature and the second is the less value of the super heat temperature. For teeming temperature of 350°C, a larger driving force is required for the molten metal to spread along the axis and move along the side wall. At 600 rev $\min^{-1}$, the molten metal spreads out easily and tries to move along the side wall (Fig. 2*a*). The melt finally solidifies, having impression of Ekmann flow in the final casting. With further increase in speed to

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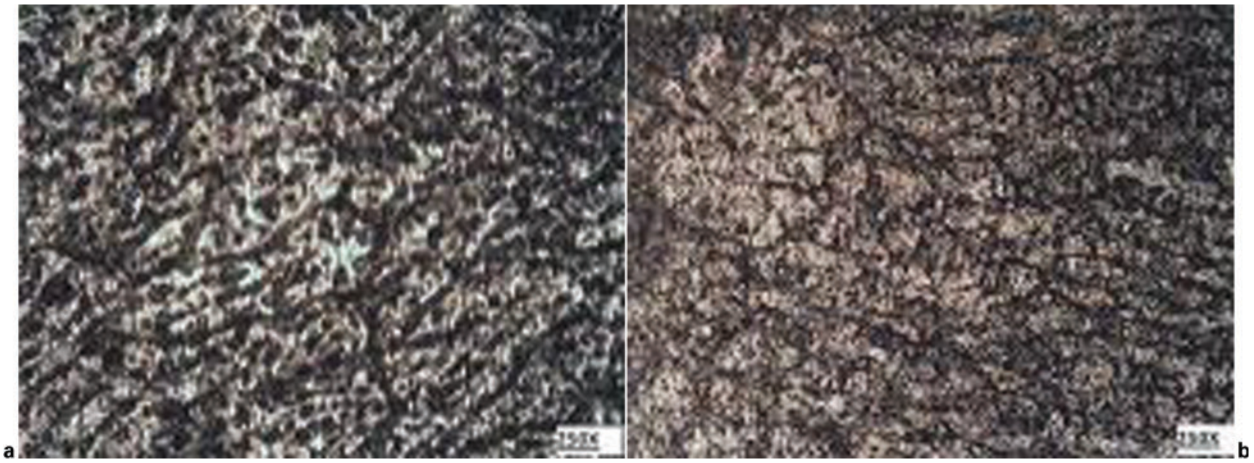
a 200 rev min^{-1}; *b* 400 rev min^{-1}; *c* 600 rev min^{-1}; *d* 800 rev min^{-1}

1 Casting for 4 mm thick tin during teeming temperature of 450°C

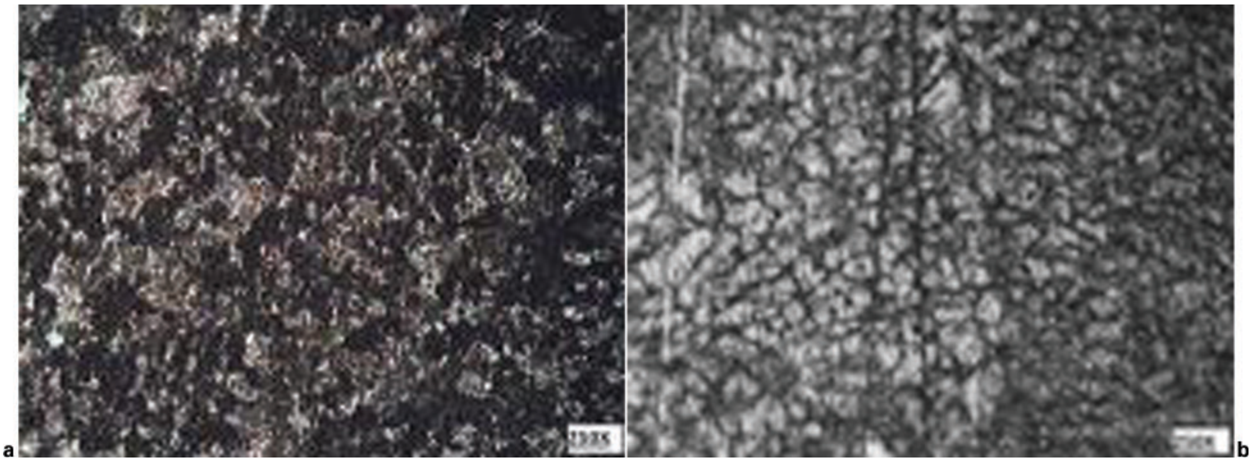
800 rev min^{-1}, a uniform hollow cylinder forms due to uniform spread of the melt along the axis (Fig. 2*b*).

The solidification structure of the castings is of great importance because of its role in determining the mechanical properties of the castings. A fine equiaxed

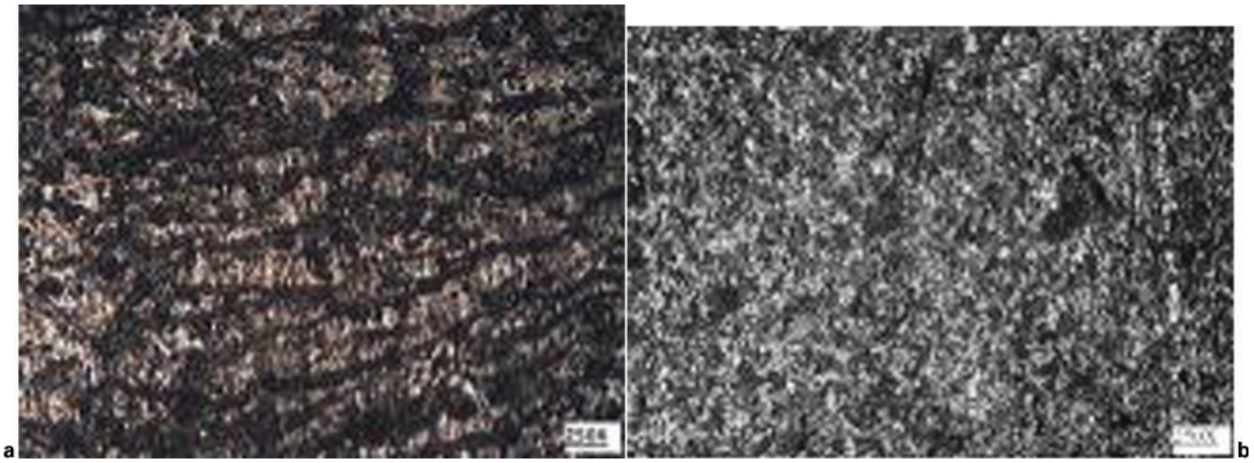
2 Casting of tin of 4 mm thick (teeming temperature: 350°C) at *a* 600 and *b* 800 rev min^{-1}



3 **Microstructure of tin of 4 mm thick (teeming temperature: 450°C) at *a* 200 and *b* 400 rev min^{-1} (inner surface)**



4 **Casting of tin of 4 mm thick (teeming temperature: 450°C) at *a* 600 and *b* 800 rev min^{-1} (inner surface)**



5 **Microstructure of tin of 4 mm thick (teeming temperature, 350°C) at *a* 600 and *b* 800 rev min^{-1} (inner surface)**

grain structure is required in order to obtain homogeneous and isotropic mechanical properties.

In the authors' experiments, the microstructure of the inner surface of the casting is studied. Upon pouring the molten metal into the rotating mould, having rotational speed of 200 rev min^{-1}, a lot of crystals nucleate on the cold wall mould as a result of supercooling, whereas the molten metal undercools at the middle and inner surface of the castings. During the solidification process, at rotational speed of 200 rev min^{-1}, the structures forms dendrite shapes, which grow freely in radial direction (Fig. 3*a*). The formation of dendrite begins to break down with increasing spinning speed to 400 rev min^{-1}. Here, centrifugal force dominates and lifts the molten metal outwards, leading to increase in cooling rates. At the inner surface, deflections of columnar grains are frequently observed in the centrifugal casting due to the Taylor flow, which is exhibited by the molten metal

(Fig. 3*b*). With increasing mould speed to 600 rev min^{-1}, the molten metal moves in streamline along the axis and simultaneously gets lifted, forming a uniform cylinder. The molten metal remains stable during solidification and hence, the solidification rate is more. Fine grains are observed at the inner surface of the cast (Fig. 4*a*). With increasing speed to 800 rev min^{-1}, the casting formed has thick section at one side and thin section at the other side. Taking the microstructure across thick section, fine structures are seen at the outer surface due to chilling effect of the molten metal. The solidification process at the middle and inner region takes place through conduction. Hence, dendrite structures are formed at the inner region of the casting (Fig. 4*b*). At teeming temperature of 350°C, a dendrite structure was seen on the inner surface of the cast rotated at 600 rev min^{-1} (Fig. 5*a*) due to the turbulent mode of the molten. At 800 rev min^{-1} (Fig. 5*b*), a fine structure was seen at inner surface of the cast due to the formation of uniform cylinder.

Conclusion

The authors observed that various flows (Coutte flow, Ekmann flow and Taylor flow) disturbed the molten metal, at low rotational speeds of the mould, and left their impressions in the final casting, too. Another highlight of the experimental results is that, as teeming temperature reduces, the rotational speeds required increases. In addition, at optimum speed, a uniform cylinder forms, having fine microstructure at the inner surface of the casting.

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