Influence of Aluminium on melt flow behaviour of ZA alloys processed through Centrifugal Casting Process

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Abstract
ZA alloys are known as bearing materials due to its excellent tribological properties. Many researchers have worked on evaluating mechanical, wear, bearing, damping properties of ZA alloys processed through various casting techniques. From previous literature it is known that increase in the aluminium content increases mechanical properties of ZA alloys and also increases fluidity of the melt in continuous casting process. In the present work an attempt is made to study the effect on fluidity by increasing aluminum content in zinc alloys processed through centrifugal casting at rotational speed of 600rpm. ZA 8, ZA 12 and ZA 27 alloys were taken for the study to understand the effect of aluminum in ZA alloys during centrifugal casting process. Uniform cast tube was formed for ZA 8 alloy and non-uniform cast tubes were formed for other two alloys due to the increase in aluminum content which probably restricts fluid motion. The detailed discussion on fluid flow, microstructure and hardness of the cast tube were discussed finally.

Keywords: ZA alloys; melt flow; Horizontal centrifugal casting process.

1. Introduction

For better tribological properties, ZA alloys find their most common application in bearing materials and in self-lubricating parts [1]. ZA parts are used in various casting techniques like gravity casting process, permanent die casting process and also by centrifugal casting process. Centrifugal casting is a material processing technique in which the melt is poured into the rotating mould to form uniform cast tube. The quality of the cast depends on melt flow pattern in the rotating mould. Few works are reported in studying the melt flow behaviour in the centrifugal casting. It should be possible to produce uniform cylinder when the mould is rotating at lower speeds, but practically it has to be accelerated at higher speed to form a uniform cylinder. There is an optimum spinning speed at which the melt picks upward and form true cylinder cast tube. The above and below these rotational speeds, non-uniform tube is formed [2].

From the available literature survey, Jaluria [3] discussed the importance of fluid flow and explained its several aspects that changes cast properties in various processing techniques. Janco [4] indicates several important parameters like rotational speed of the mould, temperature of the melt and others in forming centrifugal cast tube, but not explained the importance of melt flow during this process. Ping [5] investigated microstructure of the cast tube, which reveals the mechanical properties of the material. Chang [6] studied the influence of process parameters on the micro structure formation in vertical centrifugal casting but not mentioned about the effect of liquid metal during the casting process. A brief survey of the earlier literature indicates that much work needs to carry out to study the mechanical properties of the alloys processed by gravity casting, die casting [7-9], vacuum casting process [10], continuous casting [11], rheo-casting [12] and squeeze casting. It is surprising to note that many investigations are directed towards enhancing the properties of the casting and

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not much attempt is focused in studying the melt behaviour and its effect on properties through centrifugal casting route. The author tried to explain the importance of fluid flow in centrifugal casting [13-16] but did not explain in detail the nature of flow during the process.

Coming to Continuous casting for ZA alloys, Balalan [17] observed that fluidity of the melt increases for higher aluminium content. Most of the researchers mentioned about the increase in the fluidity for high aluminium content in continuous casting and did not explain in understanding the fluidity of the zinc alloys with increased aluminium content during centrifugal casting process. This paper attempts to understand the fluidity of ZA alloy with increased aluminium content and discusses its microstructure and hardness during the process.

2. Experimental Details

Horizontal centrifugal casting machine driving 2 HP DC motor (variation of speed from 20 to 1200rpm Fig. 1) is employed to cast ZA alloys. The mould has dimension of φ81×120×6mm. Specimens are prepared by liquid Metallurgy route as per ASTM B669-82 standards and the chemical compositions of these alloys are given in the Table. 1. Electric resistance furnace is used for melting alloys and maintaining 200°C as super heat for processing of all cast tubes. Dilute nitric acid is used as etchant for microanalysis and micro structures along the radial direction are observed.

![Fig. 1 Horizontal type centrifugal casting machine](image1)

<table>
<thead>
<tr>
<th></th>
<th>ZA8</th>
<th>ZA12</th>
<th>ZA27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum %</td>
<td>8.8-8.0</td>
<td>11.5-10.5</td>
<td>28.0-25.0</td>
</tr>
<tr>
<td>Copper %</td>
<td>1.30-0.80</td>
<td>1.20-0.50</td>
<td>2.50-2.00</td>
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<tr>
<td>Magnesium %</td>
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<td>0.030-0.015</td>
<td>0.020-0.010</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>0.006</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>Cadmium(Cd)</td>
<td>0.006</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>Tin (Sn)</td>
<td>0.003</td>
<td>0.003</td>
<td>0.006</td>
</tr>
</tbody>
</table>

*Table 1 Chemical Composition of ZA 8, ZA 12 & ZA 27 alloys*

3. Results and Discussion

**Appearance of the cast tube**

A uniform tube was formed for ZA 8 alloy, processed at mould rotation of 600 rpm. This was mainly due to flow of melt along the axial direction and simultaneously moved in the circumferential direction of the mould. The centrifugal force developed derived the melt along the inner surface of the mould before it gets solidified. For ZA 12 alloy, a complete cylinder with uneven tube thickness at its inner surface of the cast tube was formed and for ZA 27 alloys the melt lift by the mould restricting its horizontal movement and formed non uniform cast tube. Increasing with the aluminium content may act as nucleating agent which in turn restricts melt flow and forming irregular cast tube in the process.

![Fig. 2 Complete cylinder for ZA 8 alloy and incomplete cylinder for ZA 12 and ZA27 alloys are formed.](image2)

**Microstructure of the Cast tube**

The microstructure of all the cast tubes at various sections were observed, in all these cast tubes for ZA 8 alloy, exhibited a fine grain structure due to the least influence of Aluminium, attained by uniform flow of the melt in the mould. The fluidity of
the melt helped in improving the solidification rate and is sufficiently enough to form a complete cylinder. The microstructures of ZA8 alloy at various sections are as shown in the fig.4 (a, b, c) the dendrite structure is transformed into fine structure across the cross section of the tube. The melt here moves along the axis and simultaneously rises along circumference forming uniform cast tube.

ZA 12 alloy displays a coarse grain structure which is the result of improper melt fluidity, due to this property setting time increases and solidification rate decreases. Small traces of α-Al were observed at the inner surface of the casting. The microstructures of ZA12 alloy at various sections are as shown in the fig.4 (d, e, f)

In ZA 27 alloy, aluminium content is more than that in ZA12, thus during pouring Aluminium gets solidified at a faster rate than that of Zinc, causing coarse grain structure throughout the casting. Due to density difference between zinc and aluminium, lumps of α-Al are seen at the inner surface of the cast tube obstructing the melt flow along the axis and thus complete cylinder formation is afflicted. The microstructures of ZA27 alloy at various sections are as shown in the fig.4 (g, h, i). Primary silicon are observed at the inner cast tube at the inner surface of the cast tube due to poor solidification rate

Section of tube manufactured from ZA 8 alloy
(a) Inner   (b) Middle   (c) Outer

Section of tube manufactured from ZA 12 alloy
(d) Inner   (e) Middle   (f) Outer

Section of tube manufactured from ZA 27 alloy
(g) Inner   (h) Middle   (i) Outer

*Fig. 4 Microstructure of ZA 8, ZA12 and ZA 27 alloys at different sections*

**Hardness of the Cast tube**

Vickers hardness tester of model MMT-X7A was used for measuring micro Hardness of the cast tube with an applied load of 1kg. Hardness is measured on 10mm square which is radially cut from the cast tube. Averages of three readings were taken on three layers i.e. outer, middle and inner layers of cast tube specimen. The tabulation of hardness value for ZA alloys are as shown in Fig.5. It is observed that as the aluminium content increases the hardness also increases. A uniform hardness value of the range 100-105 HV is observed for ZA 8 alloys across the section of the cast tube. For ZA 12 and ZA 27 alloys, owing to the increase in aluminium content it was found that hardness value was more at the inner surface than that at the outer and middle surface of the cast tube.

![Hardness Values](image)

*Fig. 5 Hardness values of cast tubes of ZA 8, ZA 12 and ZA27 at inner, middle and outer layer*

**Discussion**

Nature of molten metal flow during centrifugal casting is studied here. The flow of melt has a strong effect in the formation of full uniform cylinder. During the continuous casting process, the increase in the aluminium content will help in increasing its density and in turn its forward motion. Here the fluidity increases with the addition of aluminium, improving its solidification rate and forming fine microstructures. But it is reversed in the case of centrifugal casting. Several parameters are influencing the fluid flow and in turn the quality of the final cast product. In continuous casting, addition of aluminium will act as a nucleating agent making the liquid to move forward, becomes viscous which increase in its fluidity. But in case of centrifugal casting process, melt experiences various forces
During its motion, some of them redistrict the flow as follows:

1. Axial force, where it aids melts to move in axial direction in its low viscosity condition. When it becomes viscous and forms mushy, it finds difficult to move in the forward direction.

2. Centrifugal forces, which drives the melt in circumferential direction of the mould. Here the melt has to be rotated at higher rotational speed with low viscosity condition. At lower rotational speed of the mould, the melt forms Couette, Ekman and Taylor flow [2], which disturbs the fluid motion. When the melt gradually becomes viscous again there is slip due to its weight overcoming centrifugal force. The mould needs to be rotated at higher rotational speed to overcome slip and avoid melt weight.

3. Frictional forces, where the melt may slip along the mould wall resisting its forward motion at lower rotational speed. The melt needs higher drive to cover entire circumference of the mould.

The melt needs to be driven at higher rotational speed to avoid centrifugal force, frictional force and melt weight. The mould needs to be rotated at 600rpm to form uniform cylinder for a given dimension of the mould as per the author [18].

When the cast tube is processed at 600rpm for ZA 8 alloy, it moves uniformly along the axial direction in its low viscosity state and simultaneously covers the entire circumference of the mould before it becomes viscous nullifying melt weight. There is no stickiness on the flow and hence requires larger driving force between the melt and mould to form Couette flow inside the mould surface. The subsequent layer of the melt comes in contact with earlier melt coat helping it to move all along the circumference in its low viscosity state forming uniform and complete cast tube.

There is uniform spreading of molten metal during its motion along the axial direction as well as the circumference of the mould. The molten metal during cooling forms a liquid state and becomes viscous. The drive here is optimum such that it avoids gravity and melt weight. Uniform spreading of melt inside the mould surface helps in improving solidification rate and forming fine microstructure Fig 4(a, b, c). The grain size in the microstructure is determined to know its value across the section and found up to 90% of the grains are in the 3-5 µm range Fig 4(a) which is evident of having fine microstructure. The uniform hardness values are recorded across the section Fig 5 and it is the proof that there is uniform distribution of molten metal with increased solidification rate in the cast tube.

ZA 12 alloy in eutectic phase is poured into the mould through a sprue and rotating at 600 rpm. The melt moves along the axis at a faster rate due to increase in Al content. It bounces back after hitting the flange end and moves in the circumferential direction forming non uniform distribution of the melt. Also the melt, after pouring, immediately moves along the mould circumference forming non distribution of melt in mould surface. The aluminium may act as nucleating agent in making the melt viscous and placing in appropriate position of the mould after balancing centrifugal force with melt weight and gravity. Solidification rate becomes low as compared to the earlier alloy forming coarse microstructure in the section. About 60% of the grain size are formed in the range of 3-5µm and 40% are in the size range of 5-11µm defining coarse grains in the section Fig 6(b). This may be due to reduction in solidification rate due to increase in Al content. Even though higher hardness values are recorded with increase in Al content, but non uniform values are obtained across the section indicating the poor solidification rate Fig 5.

For ZA 27 alloy which is in hyper eutectic phase and has rich Al value, when poured into the mould through the sprue, finds difficult to move along axial direction due to dense viscosity. A small amount of molten metal succeeds in reaching the flange end and then simultaneously moves along the mould circumference forming a cylindrical shape Fig 3. Also the melt after reaching the flange end, starts sliding along the flange surface forming Ekman flow. The melt moves along the circumference of the mould in its viscous state during its journey, forming non uniform cast tube finally. Only half portion of cast tube becomes thick and the other forming thin is evident that the melt becomes viscous after pouring and tries to move along the surface avoiding its axial direction Fig 2. Coarse grain structures with primary aluminium is formed in the section and primary Al are seen in the middle and inner surface of the cast tube which is evident of high Al content helping in low solidification rate of the melt. The molten metal comes in contact with chill mould due to which its solidification rate increases forming fine microstructure at the outer surface Fig 4(i). Grains of 48% are in the size range of 3-5µm in the middle and inner surface of the cast tube Fig 6(c) which is mainly due to increase in Al content making molten metal viscous and forming non uniform cast tube. Hardness values are not uniform across the section due to poor solidification rate and these values are higher compared to other ZA 8 and ZA 12 alloys due to increase in Al content.
Fig. 6 Frequency of intercept lengths of (a) ZA 8 (b) ZA 12 (c) ZA 27 alloys with Rotational Speed of mould as 600rpm

Conclusions

The following points can be drawn from the above:

1. Axial force, centrifugal force and sliding force are the major causes of forces, which disturb the fluidity of the molten metal during centrifugal casting process. The melt in its low viscosity state needs to be rotated at higher values to avoid these forces. The melt becomes viscous with the addition of aluminium acting as nucleating agent which prevailed fluidity of the melt.

2. Uniform cast tube was formed for ZA 8 alloy due to the uniform distribution of melt in its low viscosity state. The above three forces are encouraging for its uniform distribution in the mould surface. The solidification rate is high here forming fine microstructure and uniform hardness value across the section.

3. Increase in aluminium content makes the liquid more viscous as it acts as nucleating agent in the process. The fluidity was disturbed as it becomes viscous for ZA 12 and ZA 27 forming non-uniform cast tubes. Poor solidification rate of melt formed a coarse grain structure and non-uniform hardness value in the section.

Reference

