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Preparation of Leaded Aluminum-Silicon Alloys by Modified Vertical Centrifugal Casting Machine

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***Abstract:-* Centrifugal casting technique may be an applicable technique which may be adopted by industries for the bulk manufacturing. Present article discusses the possibility of using vertical centrifugal casting machine coupled with impeller mixing bottom discharge for the preparation of leaded hypoeutectic Aluminum-Silicon alloys. Optimized values of pouring temperature and speed of mould rotation have been established through a series of trial runs. Optical microscopic studies have been presented in order to show the distribution of lead in hypoeutectic Aluminum-Silicon alloys. Density and porosity values have been presented.**

***Keywords:* leaded aluminum-silicon alloys, pouring temperature, mould rotation.**

I. INTRODUCTION

Among the various materials, aluminum alloys, developed for bearing application has been increased considerably in recent years. Combination of low cost with good bearing qualities to a greater extent [1] than any other alloys, leaded aluminum and leaded aluminum-silicon alloys, represent an attractive alternative to the more commonly employed Al-Sn alloys due to the fact that tin(Sn) is costlier than lead. Moreover service properties of tin and lead are nearly identical [2]. However, there are some acute metallurgical problems associated with the production of leaded aluminum-silicon alloys [3]. The first problem is associated with the miscibility gap existing between the aluminum and lead & the second one is associated with the existing large difference in the densities of aluminum and lead which is nearly about 8.64gm/ml. The situation is further aggravated by the large solidification range of Al-Pb alloys. The kinetics of segregation of lead is very much accelerated due to the aforesaid reasons during the consequent solidification stages. The aforesaid facts can easily be understood with the help of the following Al-Pb phase diagram as shown in the figure 1. A large solidification range can be observed in the phase diagram and it is quite evident from the diagram that there is very little solid solubility between the phases involved in the phase diagram and thus, it is very difficult to disperse lead in an aluminum alloy up to a desired level so as to use this leaded aluminum-silicon alloys as a good cheap bearing material. Due to these factors the use of these alloys has been restricted to a very limited extent. Attempts have been made in the recent past to disperse lead in aluminum by the virtue of the processes such as induction and ultrasonic stirring during melting and casting, induction stirring and continuous strip casting atomizing, powder roll compacting and sintering.[4]-[6] These methods are very expensive and able to disperse lead in an aluminum alloy up to 10wt% only.

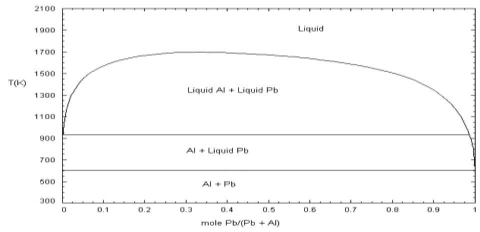

Fig 1: Aluminum- Lead phase diagram

If leaded aluminum alloys are to be used under thin oil film conditions, the minimum amount of lead must be more than 10wt%.Attepts have been exercised in the present article by the authors to disperse lead up to 20, 25&30 wt% in Al-6.5wt%Si base alloy with the help of vertical centrifugal casting machine coupled with impeller mixer bottom discharge assembly. Till now no attempts have been made in this direction.

II. EXPERIMENTAL DETAILS

A. Materials Required

Followings were the materials required for the preparation of the alloys

- -commercial aluminum (98.68wt%pure)
- -commercial lead (98.00wt%pure)
- -Al-20wt%Si Master alloy

Fireclay powder (-150 mesh size) was used for mould coating

B. Equipment

Vertical centrifugal casting machine coupled with impeller mixing bottom discharge technique was used for the preparation of the alloys. The castings produced were in the shape of hollow cylinders. Photographic view of the machine assembly is shown in the figure 2. Propeller type of impeller mixer, in which there were three stainless steel blades mounted at equal spacing on a central shaft, was used. The mixer rotated centrally in a baffled crucible with small clearance between the impellers and the crucible wall. At high rotation speeds, very high rates of shear had been provided by this design [7-8]. Moreover only axial and radial flow currents were utilized for mixing purpose without any appreciable vortex formation. Mixing condition of such a type is desirable for mixing of low viscosity immiscible liquids with a wide density difference (8.64 gm/ml in this case). The machine also consisted of cylindrical cast iron mould

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having inner dia. $10x10^{-2}$metre, length $15x10^{-2}$metre, mounted vertically on a shaft with cover plate which retains the liquid metal in the mould and also controls the height of the casting.

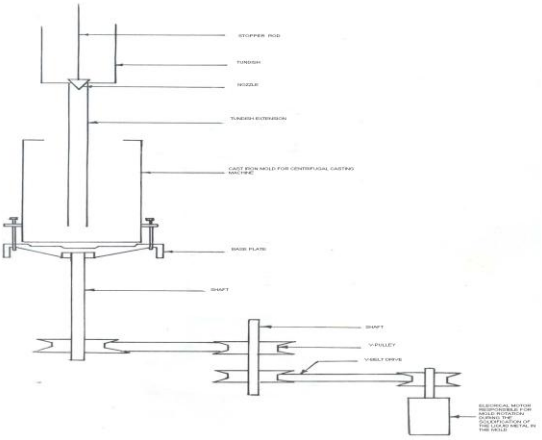

Fig 2: Vertical Centrifugal Casting Machine

The shaft was connected with an electric motor by a belt & driven by this arrangement through a speed varying pulley, which could be adjusted with the help of a lever attached with it, for a speed range of 500-2000 rpm in steps of 100 rpm. In order to protect the operator, from splashing of liquid metal, if any, during the casting operation, steel shield was used. Before use, a coating of fireclay powder was employed in the mould. The coating material was sprayed by a spray gun, traversing the mould length in the longitudinal direction, during the rotation of the mould. Instantaneously, a gas torch was used to dry the coating so that particles struck where they landed on the inner surface of the mould wall. The pouring arrangement consisted of a cylindrical basin with an extension tube at the bottom. A thick coating of the fireclay powder was employed on the inner wall of the basin. After that the coating was dried and fired in order to remove the moisture. A stopper rod was used to control the flow of liquid metal. The extension tube was projected inside the mould to guide the pouring of molten metal into the mould. Prevention of excessive splashing of liquid metal during pouring was another function of the extension tube.

C. Procedure

The required quantities of commercial aluminum, lead& Al-20wt%Si master alloy of stoichiometric composition were weighed. Except lead, the whole charging mixture was charged into a plumbago crucible placed inside an oil fired furnace, for melting. A superheat of about 473K was provided after the end of melting. Liquid metal thus obtained was poured into a mixing vessel of the impeller mixing unit, already preheated up to a temperature of 973K. The temperature of preheating was monitored by a digital temperature controller & an indicator. After pouring the liquid metal into the mixing vessel hanged in the electrical resistance type holding furnace, mixer stirrer was inserted into the melt and stirred for 180 seconds. During the stirring process lead chips of uniform size were charged into the mixer. Lead has a low melting point of nearly 600K and hence got melted. While continuing the mixing, liquid mixture containing lead was released from the impeller mixer by removing the stopper rod and let to fall into the rotating mould of the vertical centrifugal casting machine adjusted at an optimized speed of 1600rpm (optimized after a series of trial runs). In each preparation of the production of alloys, mould spinning at a speed of 1600rpm was kept nearly for 300seconds for completion of the solidification. After the solidification the casting was taken out of the mould for further investigation such as density & porosity measurement and the optical microscopic characterization.

III. RESULTS

A. Centrifugal casting of Al-6.5wt%Si-20wt%Pb alloy

Al-6.5wt%Si-20wt%Pb alloy was chosen as a reference alloy. The pouring temperature and the speed of mould rotation, the two important parameters of the machine assembly had been optimized for this alloy. Castings of alloys having the compositions Al-6.5wt%Si-25wt%Pb & Al-6.5wt%Si-30wt%Pb had been prepared using these parameters.

Table 1: Wall Thickness Achieved At Different Mould Speed with Fixed Pouring Temperature

Mould Speed (rpm)	Bottom wall thickness(m)	Middle wall thickness(m)	Top wall thickness(m)
1200	$1.58x10^{-2}$	$1.29x10^{-2}$	$0.91x10^{-2}$
1300	$1.51x10^{-2}$	$1.19x10^{-2}$	$0.98x10^{-2}$
1400	$1.42x10^{-2}$	$1.09x10^{-2}$	$1.08x10^{-2}$
1500	$1.35x10^{-2}$	$1.17x10^{-2}$	$1.13x10^{-2}$
1600	$1.04x10^{-2}$	$1.00x10^{-2}$	$1.00x10^{-2}$
1700	$1.12x10^{-2}$	$1.21x10^{-2}$	$1.24x10^{-2}$

It can be very easily observed from the above table that at a mould speed of 1600 rpm, the three values of wall thickness at various positions are equal and hence this value was supposed to be an optimized value. Another set of castings of Al-6.5wt%Si-20wt%Pb alloy were prepared at different pouring temperature with constant mould speed of 1600 rpm. The wall thicknesses at various locations were measured again & the results were tabulated as given in table number 2.

Table 2: Wall Thickness Achieved At Different Pouring Temperature with Fixed Mould Speed

Pouring temperature(K)	Bottom wall thickness(m)	Middle wall thickness(m)	Top wall thickness(m)
973	$1.48x10^{-2}$	$1.19x10^{-2}$	$0.83x10^{-2}$

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1073	$1.40x10^{-2}$	$1.18x10^{-2}$	$0.96x10^{-2}$
1173	$1.02x10^{-2}$	$1.00x10^{-2}$	$1.00x10^{-2}$
1273	$1.09x10^{-2}$	$1.10x10^{-2}$	$1.08x10^{-2}$

It is evident from the above table that a pouring temperature of 1173 K, the wall thicknesses at various locations in the hollow cylindrical casting are equal and hence this value was taken as the optimized value for the pouring temperature.

Two types of forces are responsible for affecting the liquid metal inside the rotating mould of the vertical centrifugal casting machine. These forces are (i) gravitational downward pull and (ii) centrifugal force developed due to mould rotation. The centrifugal force is responsible for throwing the liquid metal away from the central axis of the casting. The metal impinges against the rotating mould wall and tries to rise up. At the same time the gravitational downward pull tries to pull the metal downwards. At lower mould speed (rpm), gravitational downward pull dominates over the centrifugal force, whereas at higher speeds, the centrifugal pull dominates over the gravitational pull. At mould speed higher than 1600 rpm, centrifugal force dominates over the gravitational pull and due to this there is a decrease in the bottom wall thickness, while the top wall thickness increases[9]. At 1600 rpm speed, centrifugal force and gravitational downward pull forces were balancing each other and henceforth there were a nearly uniform wall thickness of the casting at top, middle and bottom portions.

At around 1173 K pouring temperature, the top, middle and bottom wall thicknesses were roughly equal. The fluidity of the molten metal at this temperature was such that the centrifugal and gravitational forces were balancing each other. Density values have been determined and compared with the theoretical values. The results are tabulated as given in table number 3

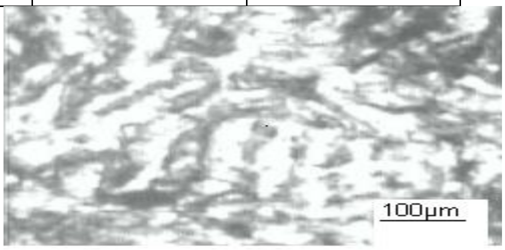
Table 3: Experimental and Theoretical Densities of the Alloys Prepared

Alloy composition	Experimental density(kgm/m^3)	Theoretical density(kgm/m^3)
Al-6.5wt%Si	$2.646x10^3$	$2.686x10^3$
Al-6.5wt%Si-20wt%Pb	$3.085x10^3$	$3.166x10^3$
Al-6.5wt%Si-25wt%Pb	$3.236x10^3$	$3.314x10^3$
Al-6.5wt%Si-30wt%Pb	$3.365x10^3$	$3.477x10^3$

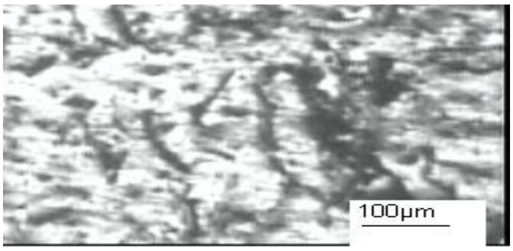
It can be observed easily that as wt%Pb increases the experimental and theoretical densities increase

B. Optical microscopic studies for alloys prepared.

Optical microstructures have been shown in fig 3(a-f), corresponding to Al-6.5wt%Si-(20,25,30)wt%Pb alloys taken at one third and two third heights from the top of the hollow cylinder casting resulted from vertical centrifugal casting coupled with impeller mixer bottom discharge assembly. The microstructures show the dispersion of lead in a hypoeutectic aluminum- silicon alloy. The white regions correspond to the α- aluminum ie solid solution of silicon in aluminum, whereas the darker regions correspond to the silicon and lead phases. It can be emphasized from the Al-Si phase diagram, as shown in fig 4, that silicon has very little solid solubility in aluminum(1.65 wt%) at 577^0C and hence it creates a driving force for silicon to remain in an uncombined or undissolved form. This undissolved silicon, often referred to as β- silicon or aluminum dissolved in silicon. β-Silicon may also be regarded as pure silicon as aluminum as well has very little solid solubility in silicon. Both these phases, viz β- silicon and lead find their places in the interdendritic region as shown in the figures below. Samples have been examined through optical microscopy at one third and two third heights in order to establish the effect of centrifugal force created during a vertical centrifugal casting process on the dispersion of the lead in the aforesaid alloy systems. In all of the aforesaid microstructures, it can be easily visualized that in the case of 20 wt%Pb alloy there is hardly any variation in the lead content at two heights.



(a)



(b)

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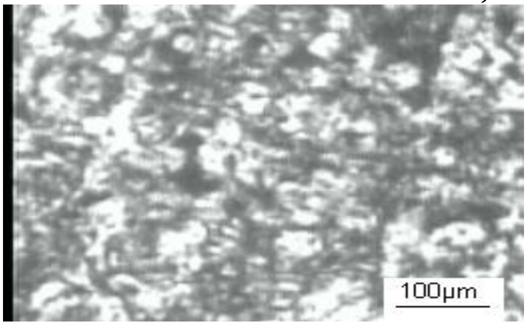

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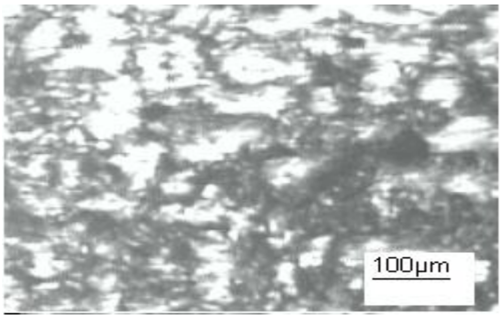

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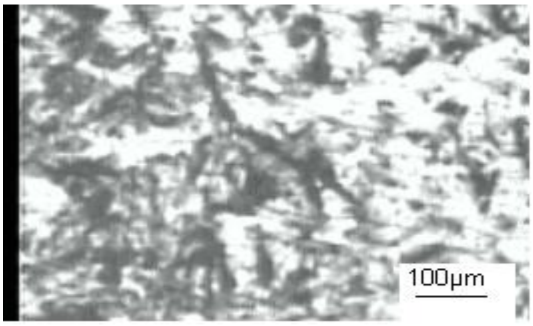
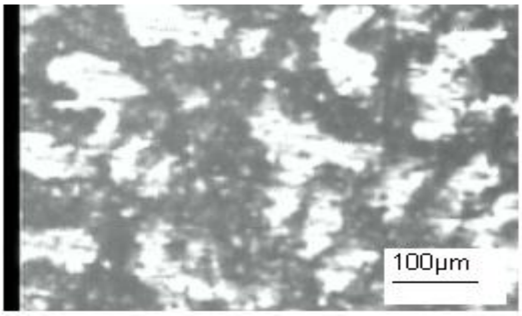


(e)



(f)

Fig 3(A) & (B): Microstructure of Al-6.5wt%Si-20wt%Pb Alloy at One Ant Two Third Heights Respectively. (C) & (D): Microstructure of Al-6.5wt%Si-25wt%Pb Alloy at One Ant Two Third Heights Respectively. (E) & (F): Microstructure of Al-6.5wt%Si-30wt%Pb Alloy at One Ant Two Third Heights Respectively.

So far as the other two compositions are concerned, eg corresponding to 25 and 30 wt%Pb, it can be seen that percentage dark area is increasing. Referring to the microstructure as shown in figs 3(c) and (d), concentrated dark regions are there which may be due to the fact as lead is heavier and the solidification range is wider in nature, hence the centrifugal force also became ineffective to some extent for the present alloy. Also the larger density value of lead had caused some segregation in the bottom part of the casting. The chances of constitutional super cooling resulted from the movement of liquid melt right from the stirring, when it was in the impeller mixer assembly to latter stages of solidification in the mold of the vertical centrifugal casting machine where the mold had been rotated at a speed of an optimized value of 1600 rpm. That increased undercooling coupled with density difference might lead to some segregation of lead in the bottom part of the casting which was nothing but the two third height of the casting from the top most portions. It also can be observed that due to the large density difference and large solidification range of leaded aluminum alloys, the larger lead chunks are there in the microstructures eg Fig 3 (b) to 3(f).

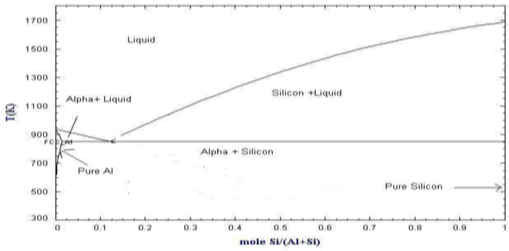


Fig 4: Al-Si Phase Diagram

VI. CONCLUSION

(a) Hollow cylindrical castings (length=$15.0x10^{-2}$ m ,inner diameter=$6.5x10^{-2}$ m and outer diameter=$8.5x10^{-2}$ m) of an uniform thickness of $1.0x10^{-2}$ m of alloys having compositions Al-6.5wt%Si and Al-6.5wt%Si-(20,25,30)wt%Pb can be prepared using the vertical centrifugal casting machine coupled with impeller mixer bottom discharge unit.

(b) Optimum values of speed of rotation of mould and temperature of pouring were found to be 1600 rpm and 1173 K respectively, under the present experimental conditions.

(c) For uniform mixing of aluminum and lead, propeller type of impeller mixer should be used.

(d) As mould speed increases, top wall thickness of casting increases whereas bottom wall thickness decreases.
(e) The formation of lead chunks increase in the microstructure as the amount of lead increases in the Al-Si-Pb alloys.

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