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Determination of mechanical properties of Al-20%Si alloy developed by centrifugal casting method

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Abstract: Centrifugal casting process is most effective method in recent days to manufacture large quantities of circular components like pipes, tubes, etc. The mold rotates at a high velocity and the mold wall being opaque, it is difficult to know the flow patterns of molten metal inside the mold. The effects of rotational speed on the flow pattern, centrifugal force acting on the molten metal and motion of particle during centrifugal casting process plays a major role in the production of defect-free castings. To predict the quality of the castings the cast will be subjected to hardness test, tensile test and impact test and microstructure is developed in order to evaluate their mechanical characteristics.

Keywords* — *Aluminum, centrifugal casting, fluid flow, microstructure, particle distribution, rotational speed

I. Introduction

Centrifugal casting is a special type of casting process used for making hollow parts by rotating the mold at a predefined rpm and pouring the molten metal at a uniform rate from a ladle. The molten metal is solidified in the rotating mold. The size and shape of the job depends on the shape of the mold. In centrifugal casting, the mechanical properties of material are considered as more critical than the dimensional characteristics [1].

Factors that influence centrifugal casting are metal pour temperature, mold temperature prior to pour, mold speed, rate of solidification, pouring time, centrifugal force, fluid flow.

There are essentially two basic types of centrifugal casting machines: Horizontal centrifugal casting machine and vertical centrifugal casting machine.

Horizontal centrifugal casting machines are used for producing pipe and tubes of different metals, alloyed iron, steel, high-speed steel rolls for steel mills, iron and steel cylinder liners, gray iron piston rings, gray iron brake drums etc.

Vertical centrifugal casting machines are used for producing shorter parts, such as bushings, gear blanks, rings, short rolls, wheels, aluminum and copper electric motor rotors etc.

The features involved in centrifugal casting are fluid flow, thermal properties and solidification rate. By means of the centrifugal force and rapid solidification rate the finer equiaxed grain structures are formed to obtain homogeneous and isotropic mechanical properties. Fluid flow plays a major role in centrifugal casting and it affects the mechanical properties of the centrifugal cast [2]. So it is important to understand the fluid flow of centrifugal casting since it influence the microstructure, and it helps to design the optimum centrifugal casting process. Since the centrifugal casting process is most rapid process and mold being opaque, it is not possible to visualize the flow patterns. So simulation is one of the ways to analyze the fluid flow.

Jian Zhang et.al. [3] have developed hypereutectic aluminum alloy tubes with graded distribution of Mg2Si particles prepared by centrifugal casting. In their paper discussed about rotational speed and cooling rate that influences centrifugal casting process. Result shows that at lower rotational speed and higher cooling rate, better particle distribution and fine microstructure can be obtained.

G. Chirita et.al. [4] have studied sensitivity of different Al–Si alloys to centrifugal effect of the vertical centrifugal casting technique compared to the traditional gravity casting technique. It was observed that centrifugal effect is alloy dependent and well correlated with the eutectic volume fraction of the alloy. And also strain to failure and ultimate tensile strength can be satisfactorily correlated with the eutectic's volume fraction.

Keerthiprasad K.S. et.al. [5] have studied numerical simulations of flow field and carried out visualization experiments on cold models by horizontal centrifugal casting system and using transparent fluids of different viscosities to study the effect of different process variables on the flow pattern. Results reveals that Ekman flow disturbs the fluid flow at lower aspect ratio. And the numerical simulation results were compared with corresponding data obtained from cold modeling experiments.

B.Balout et.al. [6] have cast aluminum alloy A356 reinforced by 10%SiC particles. Mathematical modeling

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shows that volume fraction of the SiC particles varies with the viscosity of the liquid metal on the outer casting face. It was found that higher the initial pouring and mold temperatures, higher the effect of the viscosity variation on particle segregation.

From the literature reviews, it has been observed that there are various parameters that influence the properties of centrifugally cast Al-Si alloy, but still there is a grey area to improve mechanical properties of centrifugal cast.

The present article is an attempt to develop and characterize the mechanical properties of Al base alloy. Because of the extensive growth in application of Al base alloys in the last two decades, it is advisable to reduce the review to a feasible level by concentrating on the fluid flow and microstructure study of Al base alloy in centrifugal casting process. The work carried out here, is concerned with effects of fluid flow on development and microstructure study of Al base alloy. An attempt has been made here, to include all the important contributions in the current area of interest and they are outlined in the conclusions.

II. Centrifugal Casting Process

Centrifugal casting is a unique form of casting for metal. The casting process occurs inside of a tube-shaped machine that spins rapidly. Centrifugal castings are known for high densities in the outermost regions. Centrifugal casting machines may be either horizontal or vertical-axis. Horizontal axis machines are preferred for long, thin cylinders, vertical machines for rings.

Centrifugal casting uses a permanent mold that is rotated about its axis at a speed between 300 to 3000 rpm as the molten metal is poured. Centrifugal forces cause the metal to be pushed out towards the mold walls, where it solidifies after cooling. Parts cast in this method have a fine grain microstructure, which is resistant to atmospheric corrosion, hence this method has been used to manufacture pipes. Since metal is heavier than impurities, most of the impurities and inclusions are closer to the inner diameter and can be machined away.

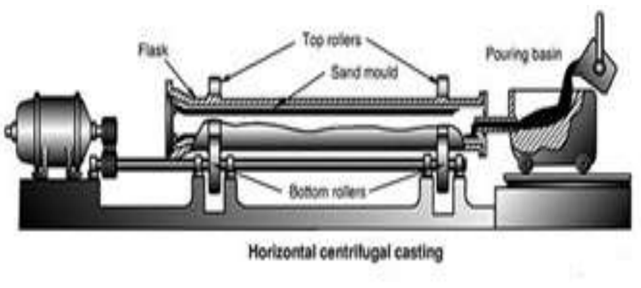

Fig.1. Schematic representation of centrifugal casting process

Industrially pure Al and Si were used as starting materials to prepare Al-20%Si alloy. The melt was centrifugal cast in a cold graphite mould at different rotation speeds of 400, 600, 800, 1000 and 1200rpm. Centrifugal tubes with 80mm in outer diameter, 6mm in thickness and 110 mm in length were obtained. Schematically illustrated diagrams of the centrifugal sets are shown in Fig. 1. All alloy specimens were cast at 8600C. For all casting processes, the rotating mould was adjusted to ±5 rpm of the set rotation speed before casting and continued to be rotated for at least 2 min after the liquid metal was poured into it to allow adequate solidification.

III. Experimental Details

The experimental setup of electrical heating furnace and centrifugal casting is shown in Fig. 2 and 3, which consists of a cylindrical die fixed to a driving flange. This driving flange is connected to the shaft of a DC motor, where the speed can be varied from 0 to 2000 RPM with high accurate speed controller. The flow of alloy into the mold is confined in the horizontally oriented, axially rotating cylindrical die. Molten Al-20%Si alloy is poured to pre-heated mold at 2000C, Microstructure, tensile strength, impact strength, and hardness will be analyzed.

Fig.2. Electrical furnace

The casting unit consists of a graphite crucible of about 3kg capacity, which is pre-heated to 2000C by electrical heating furnace. The temperature level of the furnace is controlled by thermocouple activated controlling unit. At the beginning, for the known cylindrical thickness (6mm) the mass required (Al-20%Si alloy) for the fabrication of cylindrical specimen is calculated by taking Al-20%Si density 2500 kg/m3 and weighed in the weighing machine. The Al-20%Si alloy to be melted is placed inside the graphite crucible which inturn is kept inside the electrical heating furnace. The temperature level of the furnace is set to 8500C in control unit and kept for 2 hrs.

Fig.3. Centrifugal Casting setup

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The molten Al-20%Si alloy is then poured into rotating mold in order to get the required cylindrical specimen of thickness 6mm for various rotational speeds. Five cylindrical specimens are fabricated for the rotational speeds of 400rpm, 600rpm, 800rpm, 1000 rpm, and 1200rpm. Further, the casts will be subjected to hardness test, tensile test and impact test in order to evaluate their mechanical characteristics.

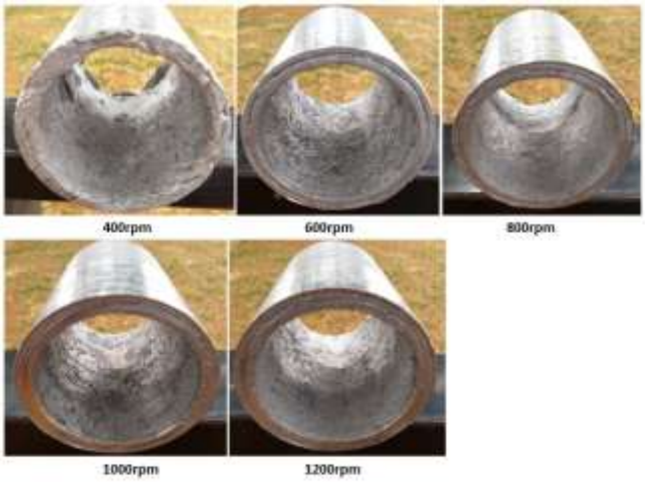

Fig.4. Pictorial view of specimens obtained at various rotational speeds

IV. RESULTS AND DISCUSSION

The following test have been carried out in order to evaluate mechanical properties

Tensile test has been carried out for all specimens of various rotational speeds

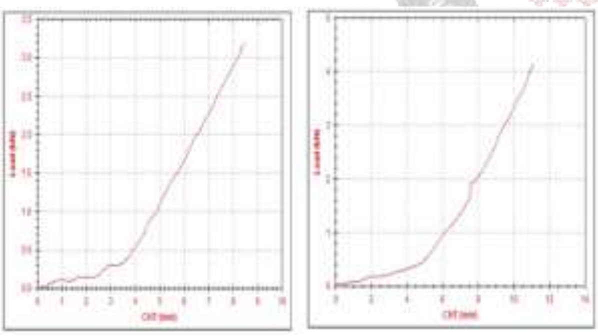

Fig.5 Rotational speed 400rpm and 600rpm

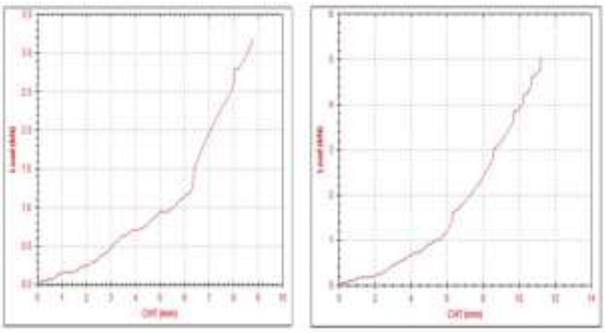

Fig.6 Rotational speed 800rpm and 1000rpm

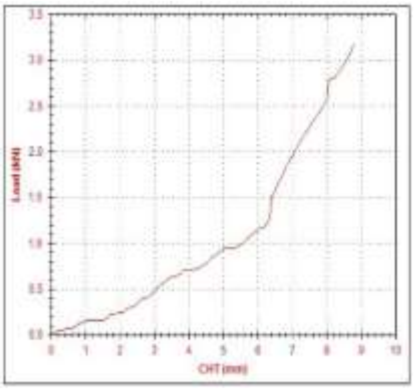

Fig.7 Rotational speed 1200rpm

Fig. 5 to fig. 7 illustrates elongation of specimens to a given load, it has been observed that maximum tensile strength of 120kN/mm2 was obtained for 1000rpm specimen and the elongation obtained was 2.8%. And specimen fails at approximately 5kN load.

The effects of silicon on the mechanical properties of Al-Si alloys are well studied. The mechanical properties of the Al-Si alloy are dependent on the size, shape and distribution of eutectic and primary silicon particles. Small, spherical, uniformly distributed silicon particles enhance the strength properties of Al-Si alloys.

Initially a thin metal is solidified and formed on the entire circumference as the molten metal during rotation first occupies the entire circumference of the rotational mould. This is because of the direct contact of the molten metal with the mould due to faster cooling [13].

The alternate layers of the molten metal then come in contact with the metal which was already solidified. As pouring of molten metal is continuous with respect to the rotating mould alternate layers of metal will be formed one on the other due to which the complete metal gets solidified.

OYMPUS Microscope BX51M with Clemex Image analyzer Equipment is used to study the microstructure of all specimens

Fig.8 shows the microstructure consists of primary silicon blocks, eutectic silicon crystals in a matrix of alpha-aluminum phase, a partial fibrous morphology of eutectic silicon is observed at the bottom surface and at the top surface.

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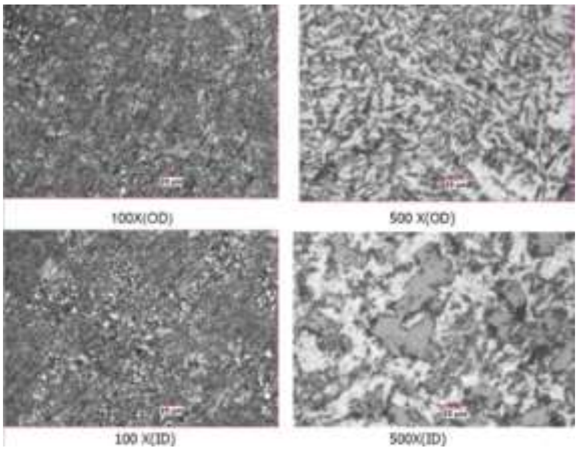

Fig.8 Microstructure of specimen obtained at rotational speed 400rpm

Fig.9 shows the microstructure consists of primary silicon blocks, eutectic silicon crystals in a matrix of alpha-aluminum phase. A partial fibrous morphology of eutectic silicon is observed at the bottom surface and at the top surface.

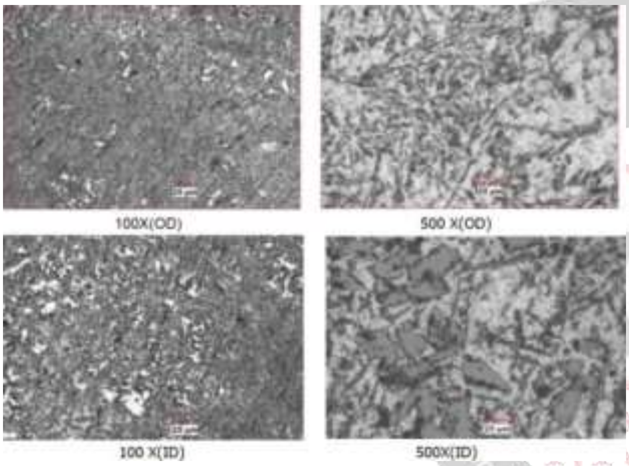

Fig.9 Microstructure of specimen obtained at rotational speed 600rpm

Fig.10 shows the microstructure consists of primary silicon blocks, eutectic silicon crystals in a matrix of alpha-aluminum phase. A partial fibrous morphology of eutectic silicon is observed at the bottom surface and a fibrous morphology is observed at the top surface.

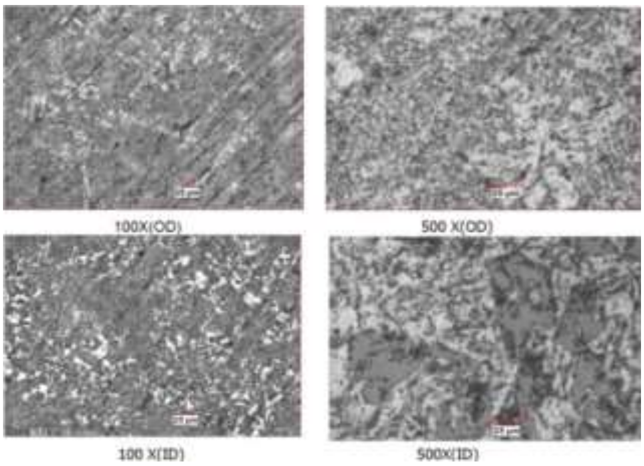

Fig.10 Microstructure of specimen obtained at rotational speed 800rpm

Fig.11 shows the microstructure consists of primary silicon blocks, eutectic silicon crystals in a matrix of alpha-aluminum phase. Acicular morphology of eutectic silicon is observed at the bottom half cross section and a fibrous morphology is observed at the top half cross section.

Al-Si alloys containing 20% Si exhibit a hypereutectic microstructure normally containing primary silicon phase in a eutectic matrix [14]. Cast eutectic alloys with coarse acicular silicon show low strength and ductility because of the coarse plate-like nature of the Si phase that leads to premature crack initiation and fracture in tension. Similarly, the primary silicon in normal hypereutectic alloys is usually very coarse and imparts poor properties to these alloys.

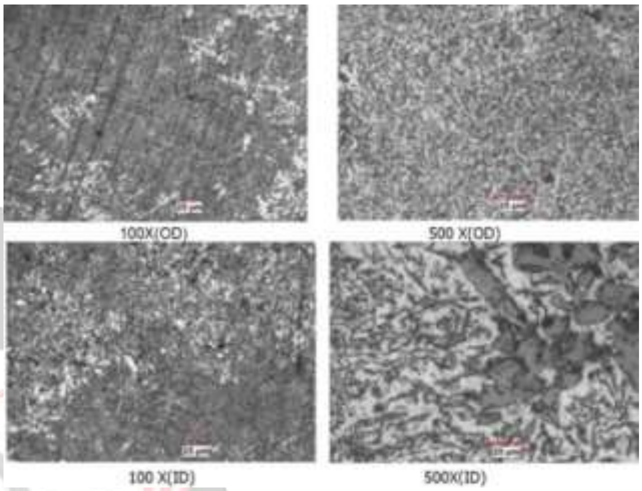

Fig.11 Microstructure of specimen obtained at rotational speed 1000rpm

Fig.12 shows the microstructure consists of primary silicon blocks, eutectic silicon crystals in a matrix of alpha-aluminum phase. Acicular morphology of eutectic silicon is observed at the bottom half and a fibrous morphology is observed at the top half.

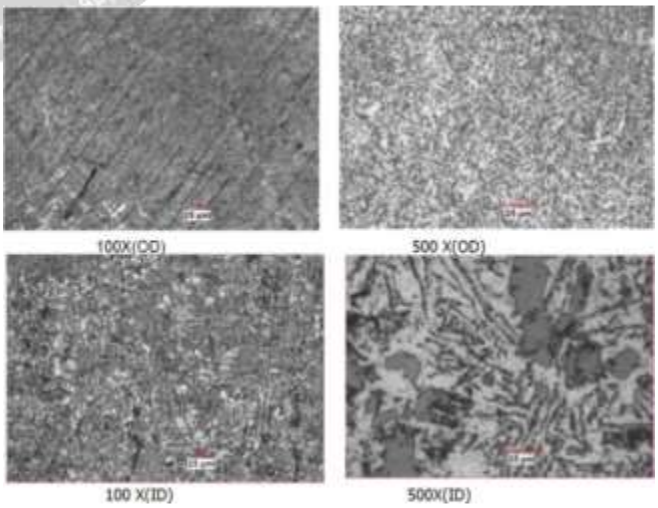

Fig.12 Microstructure of specimen obtained at rotational speed 1200rpm

From fig. 8 to fig. 12, it is observed that primary silicon blocks are less observed at the top surface (outer diameter) as compared to bottom surface (inner diameter).

A graded distribution of Si particles along the radial

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direction was observed in all specimens. Fig. 8 to fig. 12 illustrates the particle distribution profile in the centrifugal tubes obtained at different rotation speeds.

Centrifugally cast specimen has three parts according to their micro-structural features. In the outer periphery, the particle distribution at different rotation speeds is quite different from each other. While in the inner periphery, not very much difference can be observed. The change from the outer surface that contained particles to the middle particle free area was rather abrupt in all samples. However, the change from the middle region to the inner region varies.

In the specimen with a rotation speed of 400rpm, there was a gradual transformation from the particle free area to inner area in this sample when compared with other specimens. However, more casting defects were observed in this specimen due to an insufficient rotation speed. When the rotation speed increased, the thickness of the outer periphery containing particles increased. A similar trend in this area was observed in specimens obtained at 1200rpm.

V. Conclusion

It is suggested that a better gradient in the outer region was achieved in the specimens with a higher rotational speeds. This is because at the same rotation speed, the influence of the centrifugal field on the particle-moving pattern is similar.

It may be observed that as the amount of silicon in the alloy increases, the strength properties of Al-Si alloys also increase up to the eutectic composition, after which they show a decline with further increase in the silicon content.

The high viscosity reduced the movement of the Si particles and induced a better graded distribution along the radial direction rather than an abrupt change in the specimens produced at a lower rotational speed.

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