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INFLUENCE OF CRUCIBLE ROTATION SPEED ON HARDNESS, CAST STRUCTURE AND IMPACT PROPERTIES

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ABSTRACT

An Al-Si alloy containing 13% Si is cast in a cylindrical, split metallic mould rotating at different speeds about it's vertical axis. Microphotographs of the castings are taken along the radii. Microhardness profile are determined across the cross-section and Impact-tests are conducted on samples obtained from the castings produced at different speeds of rotation of the mould. The speed of rotation is seen to have a positive effect on grain refinement and distribution of the constituent phases, the effect being optimum at an optimum speed. This optimum speed of rotation of the mould is found to have resulted in an optimization of the Hardness and Impact properties of the casting.

1. INTRODUCTION

Al-Si alloys, through some attractive characteristic properties such as high wear resistance, high strength to weight ratio, high thermal stability, i.e., low coefficient of thermal expansion, etc., find use in Automobile Industries in the form of piston-block, piston-ring, gears, crank shafts, etc..

Silicon as an alloying element in Aluminium decreases the contraction associated with solidification and having a lower density than Aluminium reduces the over-all weight of the cast component. Also silicon has a very low solubility in Aluminium. Therefore , during solidification it virtually precipitates as pure silicon which is hard and hence improves the abrasion resistance of the cast alloy.

No significant benefits are obtained by attempts at solution heat-treating and ageing of Al-Si alloys [1]. Therefore, these alloys are used in as cast condition and any desired improvement/optimization of properties through structural refinements, avoidance of micro/macro segregations, uniform distribution of the constituent phases, etc., are achieved during the casting process it self.

The present invistigation aims at evaluating an Al-Si alloy cast in the centrifugal casting route. Centrifugal casting method is expected to bring in structural refinements and affect distribution of the constituent phases [2,3] by imparting a motion to the inter-dendritic liquid during solidification, in the radial direction. The effect of centrifugal forces on grain refinement is more pronounced at low alloy contents because it involves less mass transfer then. Keeping this in mind an alloy of Al-13% Si is chosen which is hyper eutectic but very close to the eutectic composition of 11.67% Si, having the minimum melting temperature in the system.

The main parameters controlling casting quality in centrifugal casting methods include speed of rotation of the crucible, pouring speed , pouring temperature and mould temperature [4,5]. In the present experiment the effect of speed of rotation of the crucible on the cast structure and hence the related properties have been vividly studied and recorded.

2. EXPERIMENTAL

The alloy is melted in an Induction Furnace at 750^{0}C and poured into a split, vertical, metallic mould,

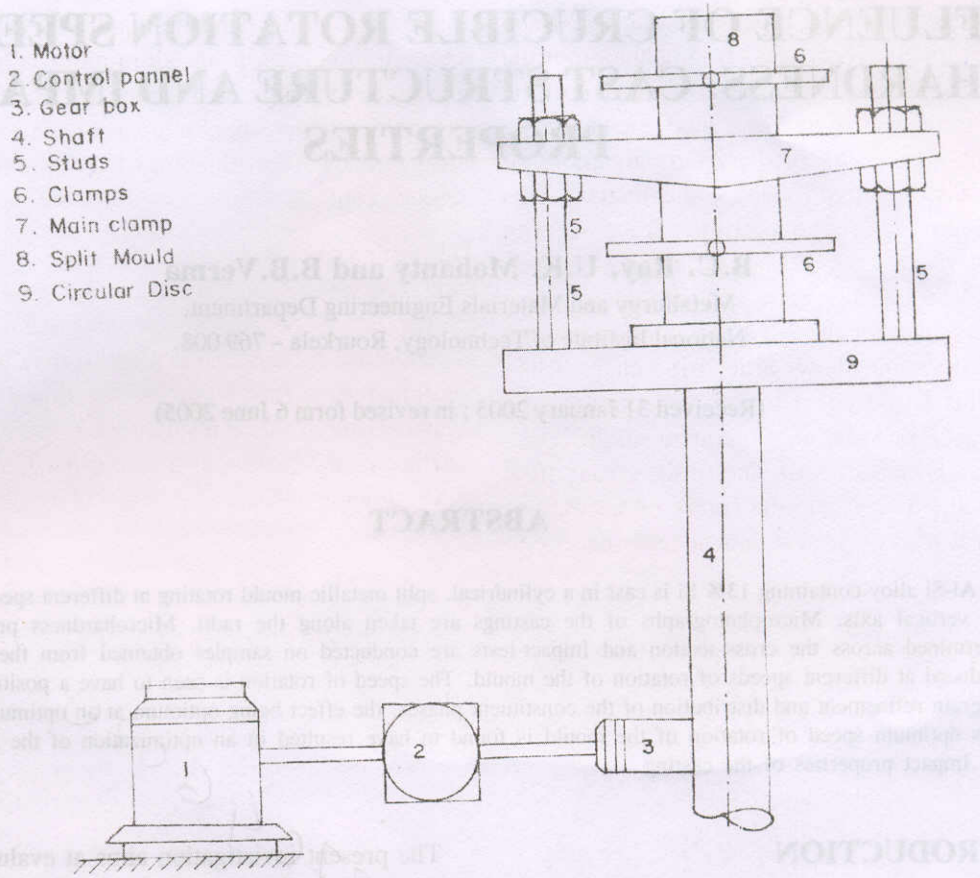

Fig. 1: Schematic view of Experimental set-up.

mounted on an electrically powered rotating device. Through voltage variations the mould could be rotated at different speeds. Five numbers of castings were produced this way at 0, 30, 60, 90 and 120 rpm speeds respectively. A line diagram of the experimental arrangement is presented in Fig. 1.

In order to make the findings more representative, the top portions of the castings containing the central pipe formed due to rotation of the crucible is not considered for experimentation. So also about 5.0 cms from the bottom of the casting is separated from the main body of the casting and is not taken in to account for further characterization.

A slice of about 12.5 mm thick from the central portion of the remaining part of the casting along the length is selected for measuring the hardness profile and for micro-structural studies. The hardness profile across the radius of the slice is measured. Microstructure of the slice, one at the center and the other near the edge is recorded by SEM.

Now two portions of the castings are left behind, one above the middle slice of 12.5mms and the other below it. Charpy impact test specimen are prepared, one from each of the top and bottom portions from the opposite quadrants and impact test is conducted. Readings varying by more than 5% are not considered and the test is repeated. The average of the two readings is reported.

3. RESULTS AND DICUSSION

3.1 Microstructural Studies

The microphotographs are presented in Fig.2-11. The microphotographs pertaining to the casting cast in the static mould show distinct Si cuboids randomly disbursed in a matrix of the eutectic mixture of α + Si, the edge samples revealing a more or less chilled structure. The microphotographs pertaining to the castings obtained from the mould rotating at 30 and 60 rpm respectively, show clear fragmentation of the Si cuboids. This fragmentation may be a result of the centrifugal force acting on the liquid metal during solidification. The fragmented cuboids are more or less evenly distributed throughout the matrix. This may be a result of sowering effect during solidification. There are no major differences between the microstructure at the centre and the edge of these castings excepting that the edge specimen pertaining to the 60 rpm sample shows a dendritic channel like structure. This is attributed to the re-melting of the surface of the casting and its subsequent solidification at comparatively slower rates due to the strong flow of the hot liquid away from the centre on account of the centrifugal force [6]. It is acknowledged that the Si segregation at the dendrite-liquid interface may affect eutectic nucleation in aluminium alloys. Recent research [7] has suggested that primary aluminium grain structure develops due to a wave of nucleation events triggered by the formation of constitutionally under cooled zones.

The microphotographs of casting pertaining to 90 and 120 rpm speed reveal a coagulation of the free Si cuboids . The presence of inter dendritic channels of solidified melt is also evident. It may be reasonably assumed that this flow of the liquid along such channels might have resulted in the remelting of the surface of the casting as a result of which Si cuboids start flowing through the channel resulting in their coalescence [8].

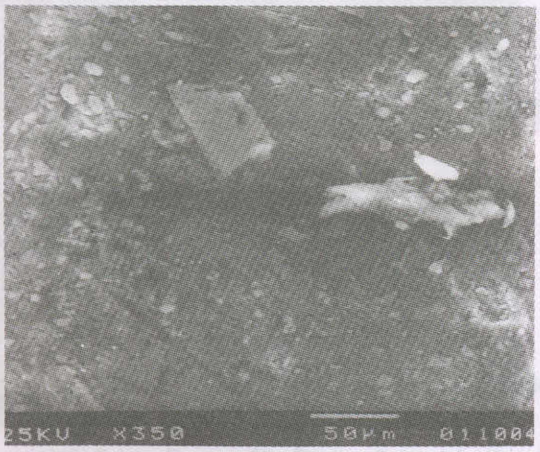

Fig. 2: Static Mould Edge Sample.

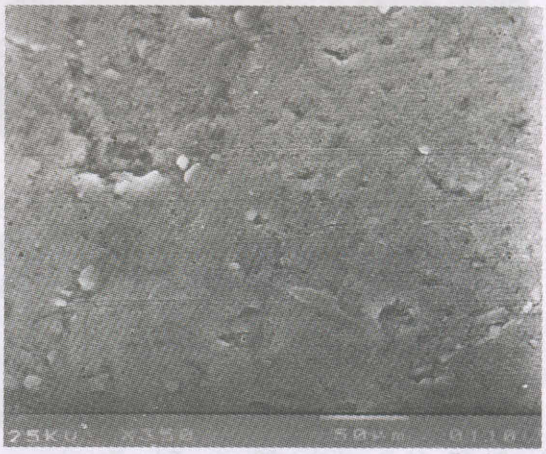

Fig. 3: Static Mould Centre Sample.

Fig. 4: Mould Revolution 30 rpm. Edge Sample.

Fig. 5: Mould Revolution 30 rpm. Centre Sample.

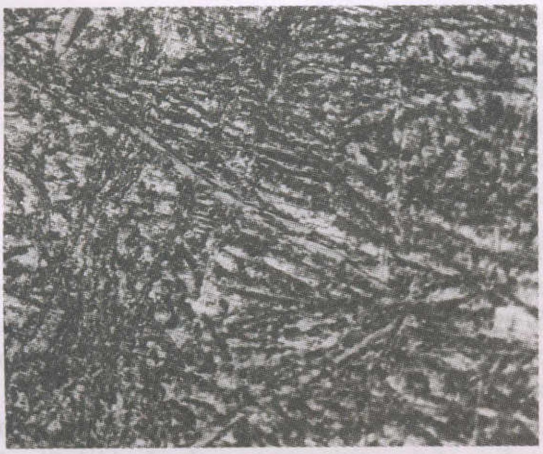

Fig. 6: Mould Revolution 60 rpm. Edge Sample.

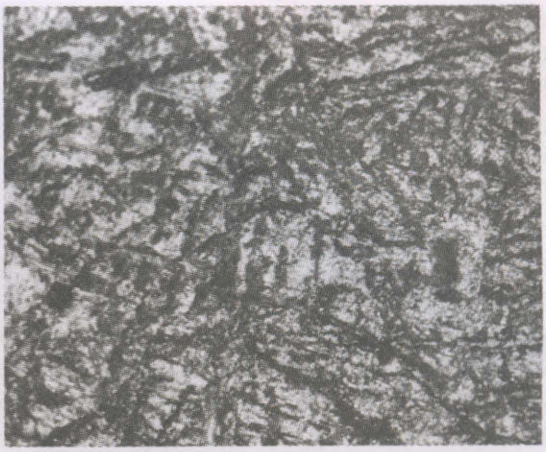

Fig. 7: Mould Revolution 60 rpm. Centre Sample.

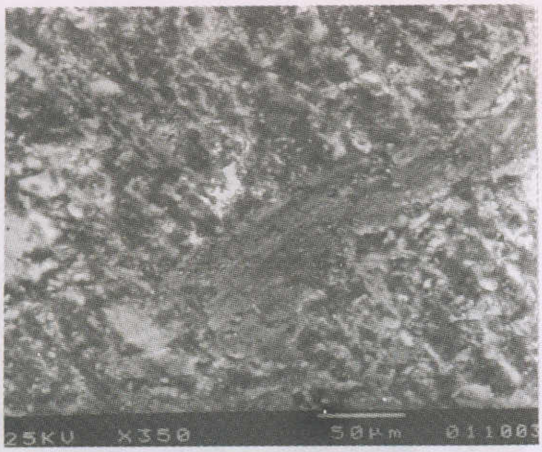

Fig. 8: Mould Revolution 90 rpm. Edge Sample.

Fig. 9: Mould Revolution 90 rpm. Centre Sample.

Fig. 10: Mould Revolution 120 rpm. Edge Sample.

Fig. 11: Mould Revolution 120 rpm. Centre Sample.

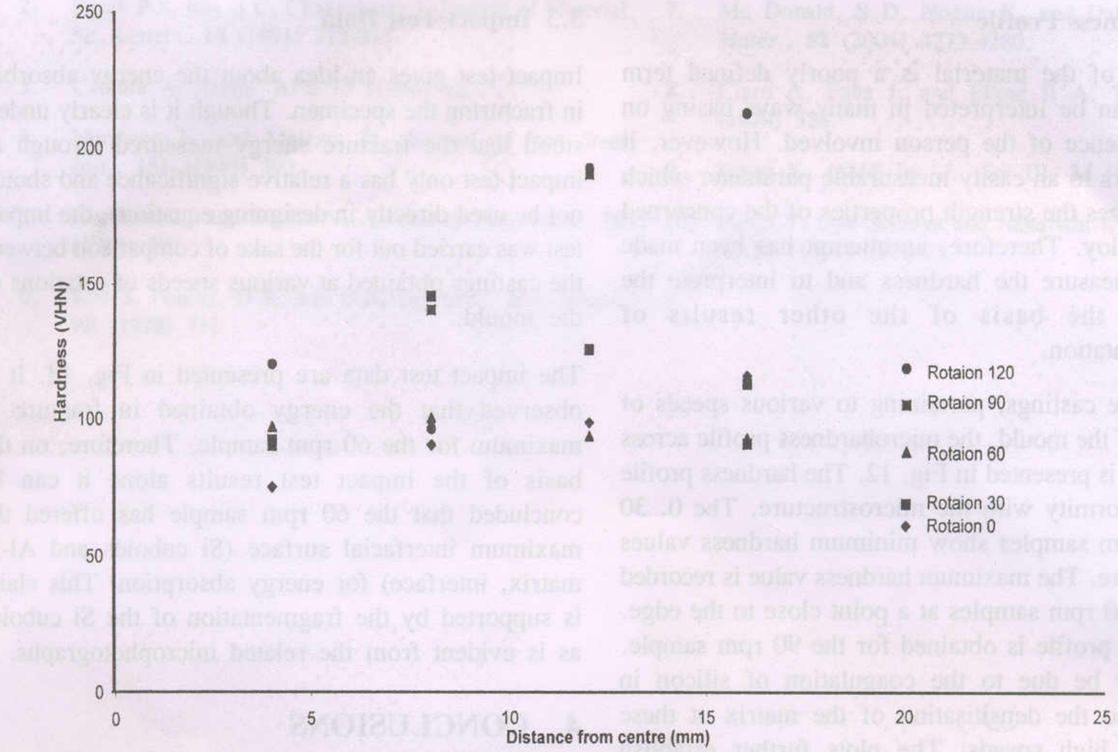

Fig. 12 : Hardness Profile

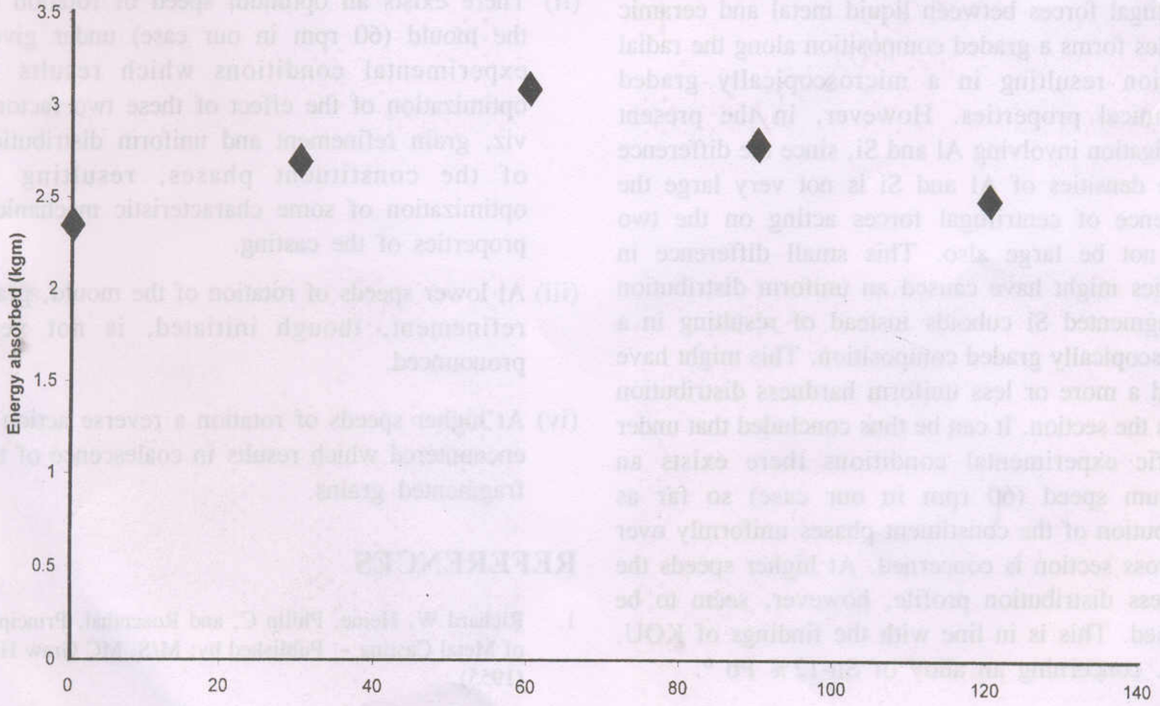

Fig. 13 : Impact Test Results

3.2 Hardness Profile

Hardness of the material is a poorly defined term since it can be interpreted in many ways basing on the experience of the person involved. However, it often refers to an easily measurable parameter which characterizes the strength properties of the concerned metal / alloy. Therefore, an attempt has been made here to measure the hardness and to interprete the data on the basis of the other results of experimentation.

For all the castings, pertaining to various speeds of rotation of the mould, the microhardness profile across the radius is presented in Fig. 12. The hardness profile is in conformity with the microstructure. The 0, 30 and 60 rpm samples show minimum hardness values at the centre. The maximum hardness value is recorded for the 120 rpm samples at a point close to the edge. A similar profile is obtained for the 90 rpm sample. This may be due to the coagulation of silicon in addition to the densitisation of the matrix at these relatively high speeds. The plots further establish that the 60 rpm sample exhibits a more or less uniform hardness distribution across the cross-section.

Fukui et. al. [9,10], while working with a melt containing Al and SiC, claimed that the difference in centrifugal forces between liquid metal and ceramic particles forms a graded composition along the radial direction resulting in a microscopically graded mechanical properties. However, in the present investigation involving Al and Si, since the difference of the densities of Al and Si is not very large the difference of centrifugal forces acting on the two must not be large also. This small difference in densities might have caused an uniform distribution of fragmented Si cuboids instead of resulting in a microscopically graded composition. This might have caused a more or less uniform hardness distribution across the section. It can be thus concluded that under specific experimental conditions there exists an optimum speed (60 rpm in our case) so far as distribution of the constituent phases uniformly over the cross section is concerned. At higher speeds the hardness distribution profile, however, seem to be reversed. This is in line with the findings of KOU. et. al. concerning an alloy of Sn-12% Pb [6].

3.3 Impact Test Data

Impact test gives an idea about the energy absorbed in fracturing the specimen. Though it is clearly understood that the fracture energy measured through an impact test only has a relative significance and should not be used directly in designing equations, the impact test was carried out for the sake of comparison between the castings obtained at various speeds of rotations of the mould.

The impact test data are presented in Fig. 13. It is observed that the energy obtained in fracture is maximum for the 60 rpm sample. Therefore, on the basis of the impact test results alone it can be concluded that the 60 rpm sample has offered the maximum interfacial surface (Si cuboids and Al-Si matrix, interface) for energy absorption. This claim is supported by the fragmentation of the Si cuboids as is evident from the related microphotographs.

4. CONCLUSIONS

(i) Grain refinement and uniform distribution of the constituent phases could be obtained by casting the hyper eutectic Al-Si alloy (Al-13% Si) in the centrifugal casting route.

(ii) There exists an optimum speed of rotation of the mould (60 rpm in our case) under given experimental conditions which results in optimization of the effect of these two factors, viz, grain refinement and uniform distribution of the constituent phases, resulting in optimization of some characteristic mechanical properties of the casting.

(iii) At lower speeds of rotation of the mould, grain refinement, though initiated, is not very pronounced.

(iv) At higher speeds of rotation a reverse action is encountered which results in coalescence of the fragmented grains.

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