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EFFECT OF MELT AND HEAT-TREATMENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AL-SI-MG CAST ALLOYSGRAPHITE MOULD VIBRATING

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ABSTRACT

This paper presents the results of investigations carried out on the effects of heat treatment in cast alloys, on major mechanical properties such as tensile strength, ductility and hardness. Al-Si-Mg alloys with 7, 12, 16 %Wt. silicon and cast with modification, combined modification & vibration and heat treatment were tested adopting standard testing procedure have been compared. Samples cast with modification, vibration during solidification and heat-treated exhibit relatively better mechanical properties. Optical microscopy study of these samples show enhanced spheroidisation and uniform distribution of eutectic silicon crystals particularly at higher solutionising temperature. Scanning Electron microscopy slides clearly indicate while modified alloys show predominantly cleavage fractured surface and modified and vibrated alloys a mixture of cleavage and dimple fractured surfaces, samples with modification, vibration and heat treatment exhibit predominantly dimple fractured surface.

Keywords: *Cast Al-Si-Mg alloys; Modification; Mould vibration; Heat treatment; Mechanical properties; Microstructure*.

I. INTRODUCTION

Aluminium with silicon as a major alloying element has been widely accepted material for most shaped castings manufactured, especially in aerospace and automotive industries due to its high strength to weight ratio, good machinability, thermal conductivity and excellent castability which renders them potential candidate particularly for a number of tribological applications [1]. Properties of cast Al-Si alloys are predominantly governed by the microstructure characteristics, such as silicon morphology and intermetallic compounds depending upon the presence of alloying elements, solidification rate and dendrite arm spacing (DAS). Many researchers and material scientists have been endeavouring over the past four decades, for effective process variations towards achieving improved mechanical properties of these alloys by controlling their microstructure [2].

Modification is a chemical treatment adopted to refine the grain structure of Al-Si alloys for improving their mechanical properties. Modifying actions transform the flake eutectic silicon into a fibrous form, producing composite like structure with increased tensile strength (UTS), ductility, hardness and machinability. Application of vibration during the solidification has also been proved successful in refining the microstructure (refinement of microstructure due to improved nucleation leading to grain refinement and multiplication of eutectic cells). The metallurgy of aluminium and its alloys fortunately offers a wide range of opportunities for employing thermal treatment practices to obtain desirable combination of mechanical and physical properties. This investigation attempts to exploit the major advantages in employing modification, vibration and Short solution heat treatment, towards strengthening of particularly Al-Si-Mg with 7% Silicon (hypoeutectic), 12%Silicon (Eutectic) and 16% Silicon (hyper eutectic) alloy castings.

II. EXPERIMENTATION

Alloy samples for experimentation were prepared by standard foundry practice. After degassing with 1% solid hexachloroethane (C_2Cl_6), hypoeutectic and eutectic alloys were modified by adding 0.02wt. % Strontium and hypereutectic alloy was modified using 0.015wt. % Phosphorous [3]. All the three melts were stirred for 30 seconds with zirconia coated iron rod after the addition of modifier. Melts were held for 5 min and poured into a cylindrical Dextrin-chromium trioxide sand mould (50 mm diameter and 150 mm height). Modified vibrated test specimens were fabricated by pouring the modified melt into the mould, rigidly mounted on a vibrating table (fig.1). The table was set to vibrate at 15Hz with 1mm Amplitude [4]. After solidification, castings were subjected to T6 heat treatment involving solutionising, quenching and aging. In order to investigate the effect of solutionizing temperature on properties such as ultimate tensile strength, percentage elongation and hardness, the cast alloys were heated to different initial temperatures ranging from 450^0C to 540^0C for a duration of 2 hours and water quenched(30^0C) along with artificial aging at 180^0C for 5 hours.

Samples obtained from the longitudinal section of the billets and polished according to standard metallographic procedure and etched with Keller's reagent, were used for microstructure studies for examination through optical microscope. Tensile and hardness test were carried out on specimens prepared according to ASTM standards. Scanning electron microscope (SEM) was employed for the examination of fractured surface of the selected samples under different conditions.

III. RESULTS AND DISCUSSION

Microstructure

The micrographs obtained with Al-(7-12-16) %Si-0.35%Mg cast alloys under modified, modified-vibrated and modified-vibrated & heat-treated conditions are presented in Figs 2, 3 and 4. The micrographs of modified Al-7%Si-0.35%Mg and Al-12%Si-0.35%Mg cast alloys exhibit the primary α-aluminium dendrites embedded in the matrix of the eutectic structure (Fig.2a, 2b), which is a mixture of α-Al and eutectic silicon phase. However, it is observed that increase in silicon content cause increased fraction of the eutectic phase in the interdendritic region. The optical micrograph of the modified cast Al-16%Si-0.35%Mg alloy shows coarse.

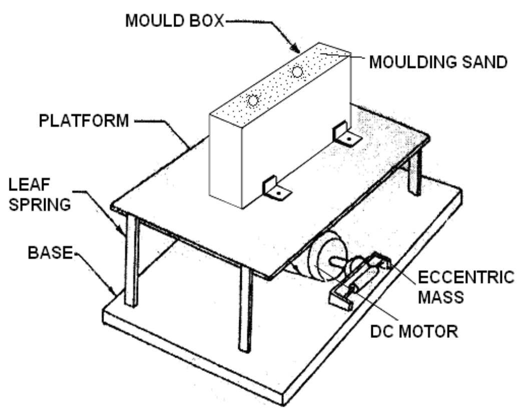

Fig.1.Schematic diagram of vibrating table

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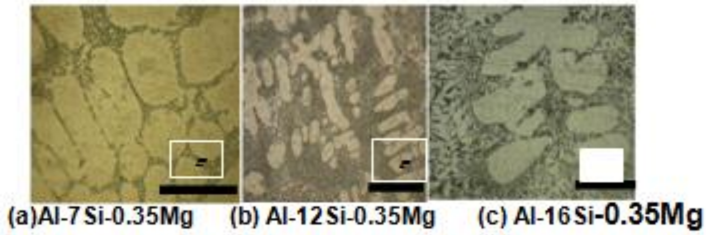

Fig. 2. Optical microphotographs of modified cast alloys (at 500X).

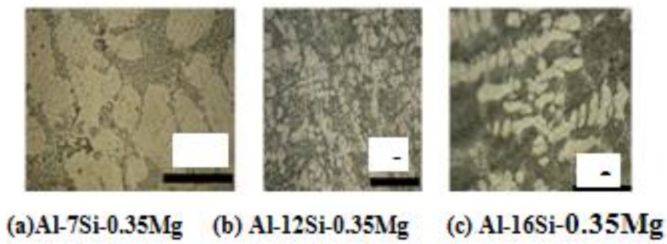

Fig.3.Optical microphotographs of modified-ed cast alloys (at 500X).

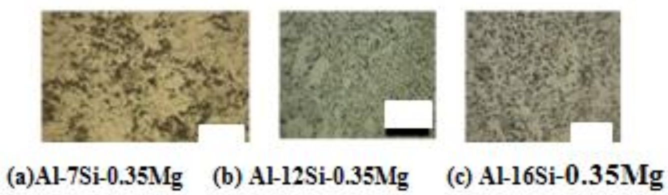

Fig.4.Optical microphotographs of modified-vibrated and heat treated Al-(7-12-16) %Si-0.35%Mg alloys

polyhedral shaped primary silicon crystals (~50µm) predominantly present in the eutectic matrix (Fig.2c). The optical micrographs of Al-(7-12-16) %-0.35%Mg cast alloys in modified-vibrated condition are presented in fig.3. Vibration during solidification of Al-7%Si-0.35%Mg (fig.3a) and Al-12%Si-0.35%Mg (fig.3b) exhibits refinement of primary α-Al, modification in eutectic silicon and partial fragmentation of α-Al dendrites with eutectic structure undergoing a flake-fiber transition. In modified Al-16%Si-0.35%Mg alloy (fig.3c), vibration results in reduction of gas content in addition to the refinement and structure modification. In general, it is observed that mould vibration causes change in morphology of silicon from flake to fiber with an increased uniformity in microstructure as compared to that of modified alloys (Fig.3). Optical micrographs of Al-(7-12-16) %Si-0.35%Mg cast alloys in modified-vibrated & heat-treated conditions are presented in Fig.4. It can be observed that, the dendritic structure has gradually been broken down with an increase in solution temperature (from 450^{0}C to 540^{0}C), along with coarsening of aluminium grains. Spheroidisation of eutectic silicon is also observed in the heat-treated alloys. Increase in solutionising temperature enhances the distribution and refinement of eutectic silicon particles. While in general, the coarsening of α-Al grains and spheroidisation of eutectic silicon particles takes place in all the three alloys, the fraction of spheroidised eutectic silicon particles is more in case of Al-12%Si-0.35%Mg as compared to Al-7%Si-0.35%Mg. However, micrographs of heat treated modified-vibrated Al-16%Si-0.35%Mg alloy shows that while eutectic silicon particles are spherodised completely primary silicon particle are able to retain the morphology of polyhedral shape only partially. Furthermore, from silicon point of view, it is observed that an increase in the silicon content lowers the proportion of α-Al and increases the fraction of the eutectic silicon.

Mechanical properties

Fig.5, 6 and 7 presents the variation of UTS, % elongation and hardness values obtained from samples cast with different silicon concentrations and employing the four process methodologies. The unmodified alloys consist of large

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primary α-Al grains and interdendritic networks of eutectic silicon (acicular/plate-like). Acicular silicon structure acts as internal stress risers and provides easy path for fracture, which is the primary reason for the poor mechanical properties of these alloys. The modifier (strontium/phosphorus) converts large α-Al grains into fine equated α-Al grains and eutectic silicon (plate like) into fine particles in the interdendritic region resulting in the improved mechanical properties. The increase in mechanical properties by vibration during solidification can be thought of as arising out of the wavy motion experienced by the molten metal. The increase in the amount of eutectic composition apart from grain refinement observed in the case of modified-vibrated alloys may also have contributed to the enhancement of mechanical properties. The improved strength probably results from the combined effects of better alloying distribution on a micro scale and a finer grain size due to vibration during solidification.

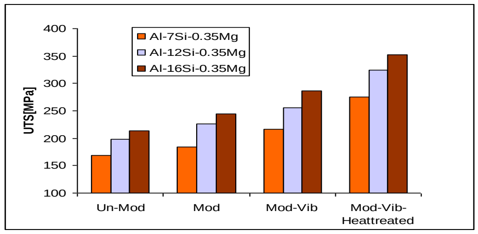


Fig. 5

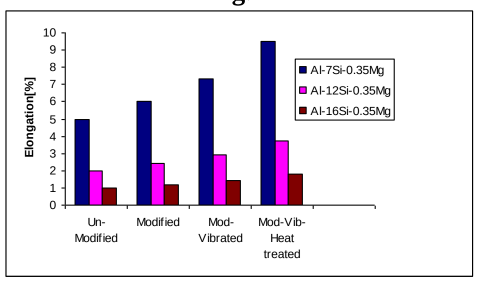


Fig.6

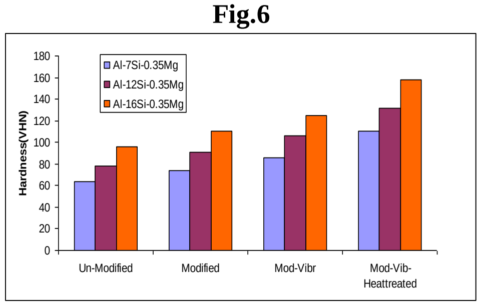


Fig .7

Ultimate tensile strength [UTS], %Elongation and Hardness obtained using different process methodologies(figs. 5,6,7)

Fig.8, 9 and 10 depicts the variation in the mechanical properties obtained for the different silicon concentration by varying the solutionising temperature employed during heat treatment process from 450^{0}C to 540^{0}C. The results demonstrate a proportional increase in UTS, %elongation and hardness values with increase in solutionising temperature reaching to a maximum value at 540^{0}C.

Theoretically, solution treatment on castings may affect in three ways: it (1) dissolves the Mg_2Si particles, (2) homogenizes the structure, and (3) changes the morphology of the eutectic silicon. The solution treatment increases the ultimate tensile strength, % elongation and hardness. The increase in UTS is through solute solution strengthening mechanism (Mg and Si atoms go into the solution during solution heat treatment and are retained in the Al matrix during quenching, on subsequent aging, combine with the matrix to form Mg_2Si precipitates in various stages). The increase in % elongation is due to the spheroidisation of silicon particles [5-6]. Analysis of the microstructure (Fig.4) of the heat-treated alloys reveal more number of uniformly distributed spherical Mg_2Si particles in the Al matrix of modified-vibrated alloys as compared to unmodified alloys. The uniform distribution and large number of Mg_2Si

particles in the Al matrix of modified-vibrated alloys are responsible for the high strength and % elongation of the alloys (Fig.8&9). In general, the α-Al phase is soft and ductile and its proportion decreases with any increase in silicon content. Further, due to the presence of hard primary silicon particles in the matrix of α-Al phase (especially in hyper eutectic alloy) results in the reduction of % elongation of hypereutectic alloy in relation to hypoeutectic and eutectic alloy cast under identical conditions (Fig.9). Increase in the hardness of heat-treated alloys may be attributed to two independent mechanisms. First is precipitation hardening, owing to the formation of Mg_2Si particles and its uniform distribution in the alloy. Second is due to the increased cohesion between free silicon crystals and the soft aluminium matrix resisting the flow of the soft aluminium matrix under external load (Fig.10). The variation in UTS, % elongation and hardness are comparable with the results reported by Zhang, Taylor and Kashyap [7, 8 and 9].

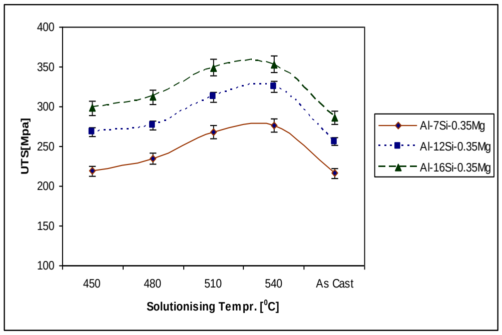


Fig. 8

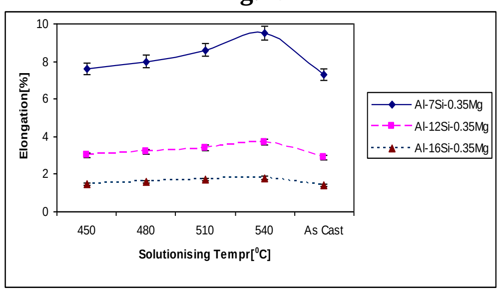


Fig. 9

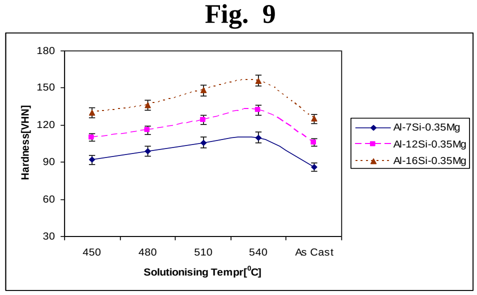


Fig.10

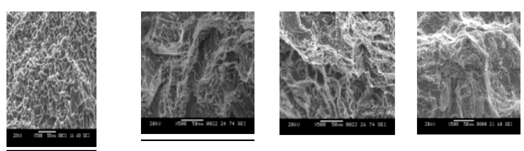
Ultimate tensile strength [UTS], %Elongation and Hardness as function of solutionising temperature for varying silicon content (Aged at 180 ^{0}C).

SEM study of tensile fractured surfaces

The SEM image of the tensile fractured surface of the hypoeutectic alloy (Fig.11a) in modified condition shows predominantly well faceted brittle appearance of silicon particles and black rounded areas demonstrating cleavage formation. This can be attributed to the presence of hard silicon particles, and the hard and brittle Mg_2Si phase. However, a relatively low percentage of fine dimples, intergranular and decohesion features can also be observed on the surface. Finer dimples indicate occurrence of plastic deformation before the fracture. On the other hand the fractured surface of modified-vibrated alloys (Figs.11b) show a fine and homogeneous fracture surface with increased amount of fine dimples along with intergranular and decohesion feature surfaces, indicating relatively larger occurrence of plastic deformation before the fracture as compared to modified alloys.

In case of heat treated alloy (Figs 11c & 11d) the occurrence of dimples is further enhanced explaining the increase in properties such as UTS and % elongation. Heat treatment of the alloys refines and distributes the eutectic silicon particles in the Al-Si-Mg alloy apart from spheroidisation. With homogeneously distributed spheroidised particles, the resistance to nucleation and growth of cracks increases. This will encourage the ductile fracture. It has been observed that higher solution and aging temperatures result in more dimples on the fracture surface than cleavage facets. It may be attributed to the finer distribution and spheroidisation of eutectic silicon particles at higher temperatures. Also, the stress required for nucleation of void or crack at the particle/matrix interface increase with the spherical morphology [10]. This increases resistance to the external load. It is observed that at low solution temperature (450^0C) and aging temperature (180^0C) the cleavage fracture dominates over the dimple fracture, while at high solution temperature (540^0C) and aging temperature (180^0C) dimple fracture dominates over cleavage fracture. This is also obvious from the SEM images of tensile fractured surface of the alloys solutionized at 450^0C (Fig.11c) and 540^0C (Fig.11d).

In the cases of eutectic and hyper eutectic alloys the increased presence of silicon contributes to increased cleavage formations as compared to dimple formations rendering relatively insignificant improvements due to change in process methodologies from modified to modified and vibrated and heat treated alloys. The SEM photographs under these conditions not only reveal this phenomenon but also validate the results obtained for the different mechanical properties.



(a) As cast Modified | (b)Modifie d anc vibrated | (c)Modifiec -vibrated and hea treated (450^0C) | (d)Modified -vibrated and hea treated (540^0C)

Fig.11. SEM images of tensile fractured surfaces of Al-7%Si-0.35%Mg alloy in different conditions

IV. CONCLUSIONS

The investigations carried out provides with large amount of insight in to the influence of silicon morphology and the process methodologies upon the structural formation of the alloy and thereby on the mechanical properties.

Apart from the silicon content of the alloy, the process methodology employed in casting has significant influence on mechanical properties. While there is a gradual enhancements of all the mechanical properties investigated as the process methodology is included with modification, modification and vibration during solidification and subsequent heat treatment, The improvements obtained with heat treatment of the alloy subsequent to casting significantly helps in achieving considerable improvement in the properties. It is also observed that vibration during solidification contributes to a uniform distribution and refinement of silicon particles and hence the time required during the heat treatment process can be considerably reduced. It is also observed that while the UTS and Hardness increases with increase in silicon content from hypo eutectic alloy to eutectic and hyper eutectic alloy, % elongation decreases proportionately. The mould vibration during solidification of modified alloys leads to better distribution of magnesium and silicon in aluminium matrix on a micro scale apart from the finer grain size, and there by results in improved mechanical properties. Better results were observed in case of hypoeutectic alloy compared to eutectic and hypereutectic alloys.

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