Effect of Cooling Rate and on the Addition of Magnesium on Microstructure, Hardness and Wear Rate of Al-Cu-Mg Alloys using Sand and Permanent Mould Castings

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Abstract

An investigation was carried out to understand the effect of Mg addition on the hardness, the wear rate and the cooling rate of cast Al-Cu-Mg alloy. The effect of Mg content was assessed by melting the Al-Cu-Mg alloy in a muffle furnace with the addition of varying wt% Mg (1-3% wt). The cooling curves were plotted for both sand and die castings. The chemical composition of the cast alloy was computed by using arc spectrometry. The microstructural evaluation was carried out using optical and electron microscope. It was observed that the secondary dendritic arm spacing reduced with Mg content concluding that Mg addition improves the formation of nucleation sites and thereby results in grain refinement. The Brinell hardness tester was used to measure the hardness of the alloy. It was found that the hardness increased with Mg content and comparatively, die cast samples showed improved hardness when compared with that of sand cast samples. The hardness of the developed alloy was compared with that of the base alloy and the effectiveness of the alloying element was evaluated. Wear test was carried out using the Pin-on-disc wear testing apparatus under dry sliding conditions in air. Reduction in mass loss was observed with Mg addition. The effect of Mg on UTS, Young's modulus and elongation were also evaluated. Salt water immersion test with 5% NaCl solution was carried out for 120 hrs and no weight loss was observed. The alloy was developed and the effect of cooling rate and on Mg addition on the mechanical and wear properties of cast Al-Cu-Mg alloy was assessed. The effect of heat treatment on the properties will be carried out as a future work.
Keywords: Al-Cu-Mg alloy, Dendrite arm spacing (DAS), Grain size, Hardness, Tensile strength

I. INTRODUCTION

Aluminium alloy materials or simply composites are combinations of materials. They are made up of combining two or more materials in such a way that the resulting materials have certain design properties on improved properties. The Aluminium alloy composite materials consist of high specific strength, high specific stiffness, more thermal stability, more corrosion and wear resistance and high fatigue life.

Conventional materials like Steel, Brass, and Aluminium etc. will fail without any indication if a stress is developed in it. Crack initiation and propagation will take place within a short span. Now-a-days to overcome this problem, conventional materials are replaced by Aluminium alloy materials. Aluminium alloy materials are found to be the best alternative with its unique capacity to design the materials to give required properties.

Cast Aluminium Copper alloys are widely used in the aerospace and automotive industries due to the high mechanical properties and excellent foundry characteristics. Optimal material is a necessity due to the new demands on effectiveness of energy while using products. High goals has been put up by the car manufacturers in reducing the emissions and fuel consumption in vehicles. During a short period of time from 2003 to 2012, the discharge of CO_2 shall reduce from 170 g/km to 120 g/km. High Reduction in discharge demands new technical solution and improvement of today's materials. Casting is an economical, environment friendly and effective method of production that allows shaping in one step. Casting in light alloys estimate to have a big unused potential in light weight constructions. Aluminium castings are used rarely in critical applications due to the concerns about the variability in properties. This variability is a consequence of structural defects in the casting, for example, pores and oxide films which degrade mechanical properties. The use of aluminum alloys increases every year. The focus of this work is to get an optimal amount of magnesium in the aluminum cast material. To realize this, it is important to have knowledge about alloying elements, casting processes and how the microstructure affects the cast material properties.

Cast Al-Cu Alloy is taken into consideration owing its application in vehicle structures as they offer attractive combinations of excellent cast ability and good weld ability, pressure tightness, and good resistance to corrosion. It can be used for aircraft pump parts, automotive transmission cases, aircraft fittings and control parts, water cooled cylinder blocks, aircraft structures and engine controls, nuclear energy installations, and other applications where high strength permanent mould or investment castings are required. However, in severe service circumstances like those in mining and rolling sectors, the low hardness and poor wear resistance limit its further industrial applications.

An investigation was carried out to assess the effect of magnesium addition on the properties of Al-Cu-Mg alloy and to optimize the melting parameters of the process. Further property evaluation including microstructure, secondary dendritic arm spacing, hardness test, density test, tensile test, wear test, corrosion test, spectroscopy, SEM and EDAX were carried out on cast Al-Cu alloy with varying Mg weight percentage.

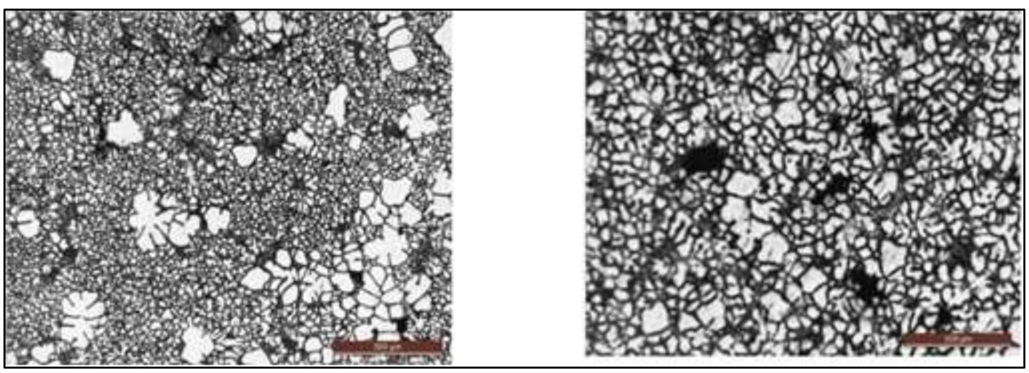
The addition of magnesium allows the castings to be heat treated whereby magnesium precipitates are formed which harden the alloy and impart specific combinations of strength and ductility. The composition and structure of these phases is affected by the solidification rate of the casting and the alloy chemistry. The coefficient of thermal expansion and its electrical resistivity increases a little. Al-Mg alloys have high strength, good ductility and excellent corrosion resistance. Al-Cu-Mg alloys respond well on heat treatment and a higher ultimate tensile strength and yield strength is achieved. The purpose of magnesium in Al-Cu alloy is to precipitate Mg particles but a disadvantage is that big intermetallic compounds can appear; those phases reduce the ductility. In alloys that have an amount of magnesium between 0.5% to 3% seems to decrease the amount of porosity.

II. METHODOLOGY

Al-Cu alloy is melted in a muffle furnace and Mg is added into it and again melted for proper mixing of the metals. It is then casted in a sand mould and permanent metal die to assess the cooling rate and the variation in the mechanical properties.

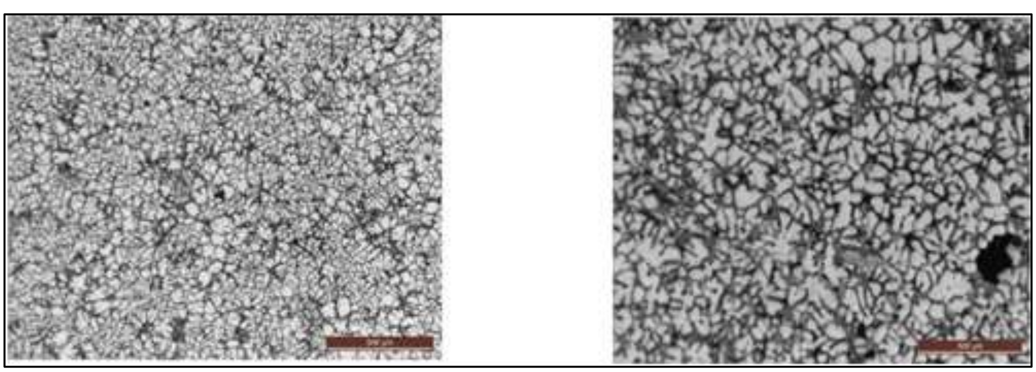
III. RESULTS AND DISCUSSION

A. *Microstructural Evaluation*



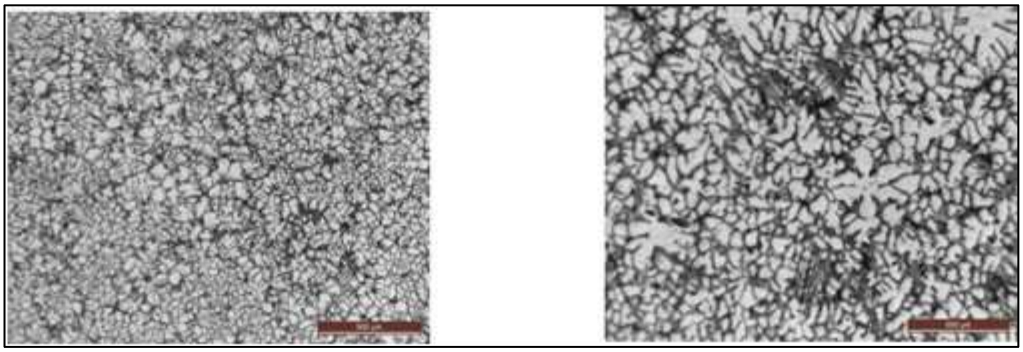
1 Wt% Metal Cast　　　　1 Wt% Sand Cast

Fig. 3.1: Microstructure of alloy with 1 weight percentage Mg



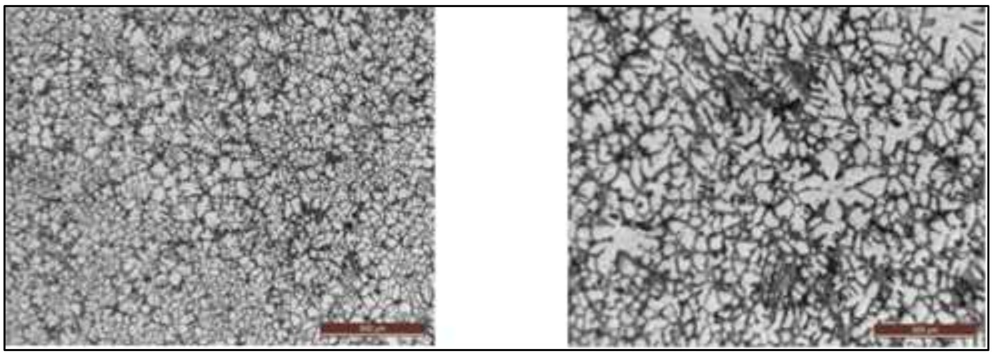
2 Wt% Metal Cast　　　　2 Wt% Sand Cast

Fig. 3.2: Microstructure of alloy with 2 weight percentage Mg



2.5 Wt% Metal Cast 2.5 Wt% Sand Cast

Fig. 3.3: Microstructure of alloy with 2.5 weight percentage Mg



3 Wt% Metal Cast 3 Wt% Metal Cast

Fig. 3.4: Microstructure of alloy with 3 weight percentage Mg

The microstructure of the developed alloy using 1, 2, 2.5&3.5 wt% Mg are shown in figure 3.1-3. 4.

It was observed that the refinement of grains occurs in the case of sample cast in metal die. This is attributed to the rapid solidification occurs in the metal cast sample. The same trend was observe in the case all wt% of Mg. Typical dendrite structure was observed in all the cases. The formation of intermediate phase was only be identified using SEM/EDAX.

B. Secondary Dendritic Arm Spacing

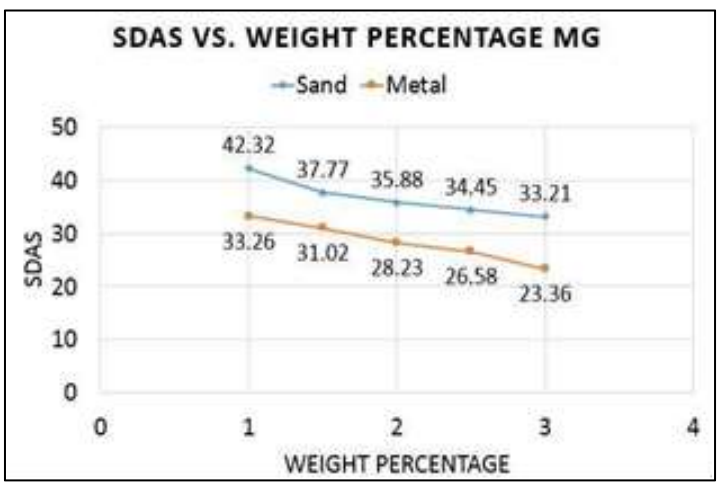


Fig. 3.5: SDAS vs. Weight Percentage

The variation in SDAS with wt % Mg is shown in figure 3.5. It is observed from the figure that the SDAS of metal casting is less than that of the sand casting. This is because of rapid solidification occurs in metal cast sample. Sand cast has coarse dendritic arm spacing and metal cast has fine dendritic arm spacing.

C. Hardness Test

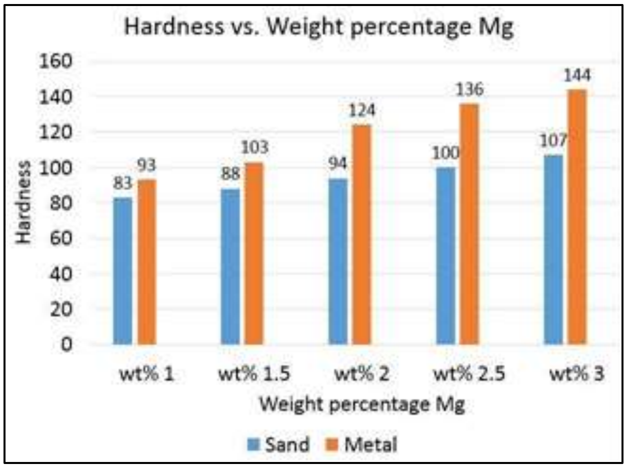


Fig. 3.6: Hardness vs. Weight Percentage

It is observed from the figure 3.6 that the metal casting depicts more hardness when compared with sand casting. It is also evident that as the percentage of Mg increases the hardness also increases. The hardness of the developed alloy is more than that of Al-Cu. The variation in hardness value for sand and metal die casting is due to the formation of nucleation sites and grain refinement

D. Density Test

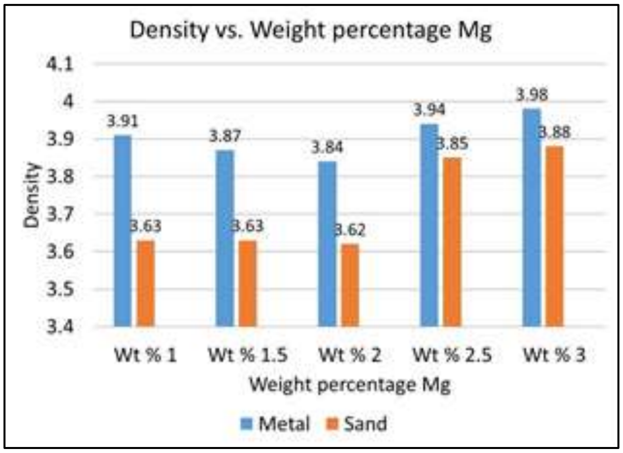


Fig. 3.7: Density vs. Weight Percentage

It is observe from the figure 3.7 that the density of metal cast is more than that of the sand cast samples. This is attributed to the variation in solidification rate for sand as well as metal cast samples.

E. Tensile Test

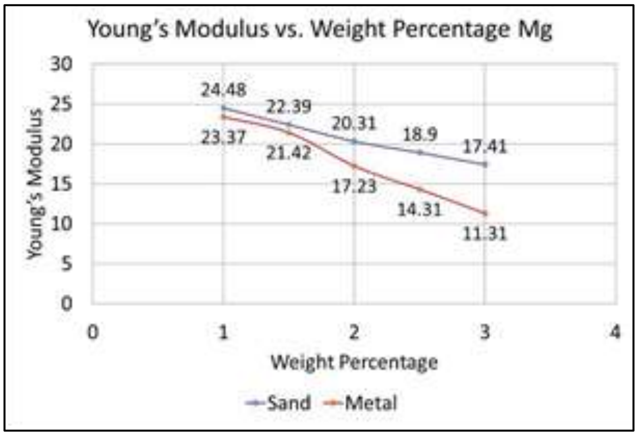


Fig. 3.8: Young's Modulus vs. Weight Percentage

The variation in Young's Modulus with varying wt % of Mg is shown in fig 3.8. It is observed that the young's modulus decreases as the Mg percentage increases. The ultimate tensile strength increases, therefore the elongation increases, thus ductility increases as Mg is added to the Al-Cu

F. Wear Test

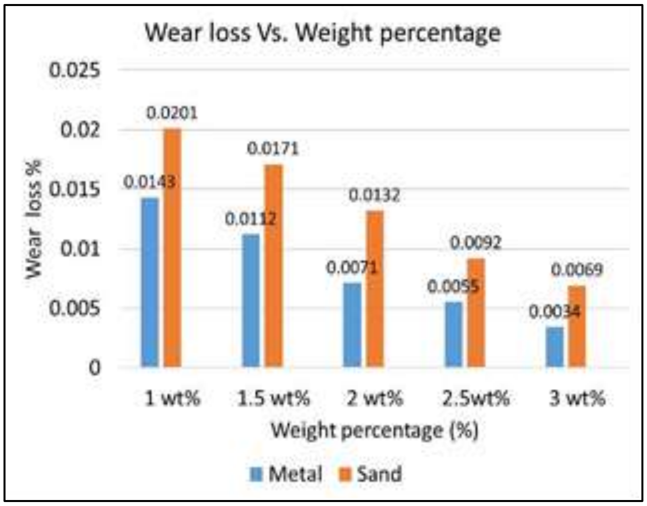


Fig. 3.9: Wear loss V.s Weight percentage

The wear loss for sand cast is more than that of metal cast. This is because the hardness of sand cast is less compared to metal cast is shown in the figure 3.9.

G. Corrosion Test

The alloys are kept immersed in 5% NaCl solution for 120 hours and there is no weight loss in the specimens tested.

H. Cooling Rate

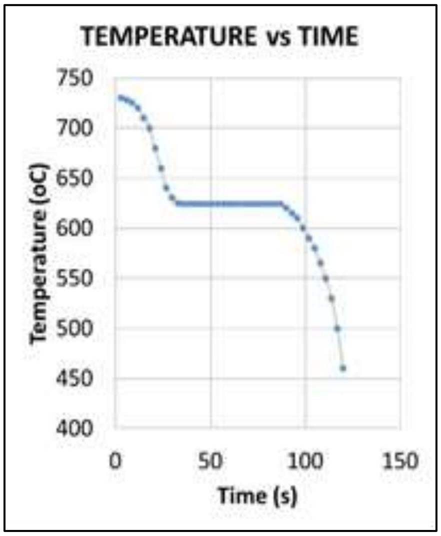


Fig. 3.10: Cooling Curve of Casting in Metal Die

The Figure 3.10 shows the cooling curve of the developed alloy casted in metal die. It is seen that there is a rapid cooling occurring from 725ºC to 625ºC in 30 seconds. Then the solidification takes place at 625ºC for 55 seconds. Again rapid quenching takes place and it is cooled to room temperature.

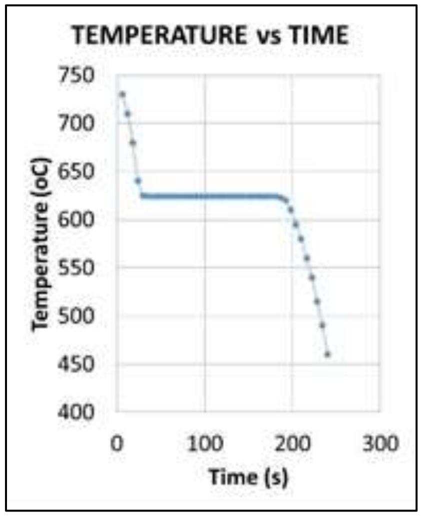


Fig. 3.11: Cooling Curve of Casting in Sand Die

The Figure 3.11 shows the cooling curve of the developed alloy casted in sand mould. It is seen that there is a rapid cooling occurring from 725ºC to 625ºC in 30 seconds. Then the solidification takes place at 625ºC for 155 seconds. Again rapid quenching takes place and it is cooled to room temperature.

I. SEM

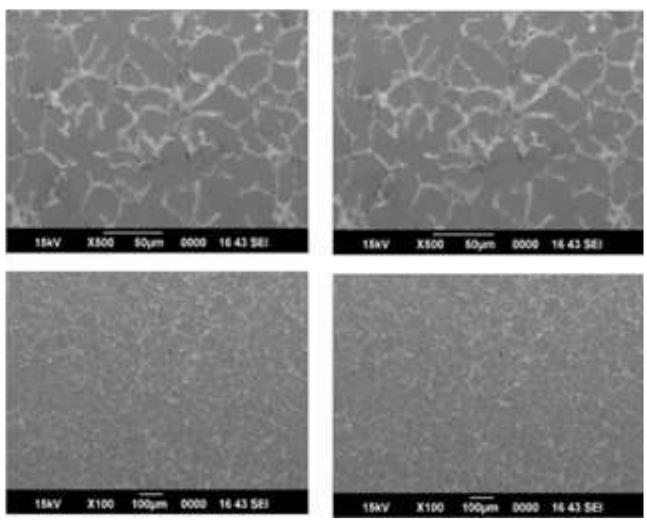


Fig. 3.12: SEM Image of 3 Wt % Metal Die Casting

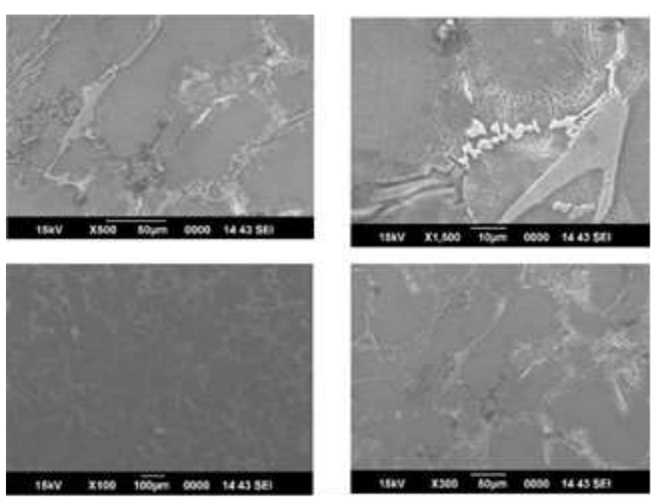


Fig. 3.13: SEM Image of 3 Wt % Sand Mould Casting

This method is to investigate the content alloying elements in the alloy. Investigation of the content of magnesium, copper and aluminium in the dendrite or in the structure is carried out. Figure 3.12 shows the SEM image of the developed alloy with 3 weight percentage Mg casted in metal die and Figure 3.13 shows the SEM image of the developed alloy with 3 weight percentage Mg casted in sand mould.

Comparing the SEM images of casting in metal die and sand mould we can infer that finer SDAS is obtained in metal die casting. This is due to the faster solidification rate of casting in metal die. Thus more intermetallic is formed in the case of metal die.

IV. Conclusion

Al-Cu alloy with varying Mg content was developed and property evaluation was carried out. Alloys cast in metal die showed refined grain structure when compared with sand cast alloy. Alloys cast in metal die were found to be denser than sand cast alloys. Alloys cast in metal die were found to exhibit more hardness and low wear rate than sand cast alloys. SDAS was found to reduce with the addition of Mg. Hardness was found to increase with Mg content. Mass loss was found to reduce with Mg content. Alloys were found to exhibit corrosion resistance for Salt water immersion test. UTS as well as elongation increased with Mg content.

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