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Microstructural Study and Mechanical Properties of Al_2O_3 Reinforced Al 1100 (Mg) Cast Composites

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Abstract: *Aluminum MMCs are considered as conventional materials in the fields of aerospace, automotive and marine applications due to their improved properties like high strength to weight ratio, good wear resistance etc. Al_2O_3 can be considered as ideal reinforcements, because of their high strength, high aspect ratio and thermo-mechanical properties. The objective of this work is to reinforce Al_2O_3 particles with Al 1100 (Mg) alloy by melt stirring method. 0, 3, 6, 9 and 12 wt% of Al_2O_3 particles are added to Al 1100 (Mg) alloy to make aluminum based composites. Microstructural study using Scanning Electron Microscopy and Mechanical properties like tensile strength and hardness will be investigated for cast alloy composites. Variations in microstructures and mechanical properties in different wt% of Al_2O_3 particles have been compared with each other.*

Keywords: AMMCs, Al_2O_3 Particulates, SEM, Hardness, Tensile Properties

I. Introduction

The aluminum based composites are most commonly used in the transport, aerospace, marine, automobile and mineral processing industries, owing to their improved strength, stiffness and wear resistance properties. They have a large variety of mechanical properties depending on the chemical composition of the aluminium matrix. They are usually reinforced by aluminium oxide, silicon carbide, silicon dioxide, titanium dioxide, manganese dioxide, graphite, boron, tungsten carbide, aluminium nitride, titanium carbide etc.

Among the ceramic reinforced materials, silicon carbide (SiC) is most commonly used in MMCs. The second most used reinforcement is aluminium oxide (Al_2O_3). As compared with SiC, it is more stable and inert and has better corrosion and high temperature resistance. The impact of these reinforcements to aluminum alloys has been the subject of a significant amount of research work.

This study involves synthesis of composites by adding Al_2O_3 particles to molten alloy of aluminium and magnesium during stir casting. The objective of developing composites in this study by stir casting is to study their potential for application in structural components and the mechanical properties of these composites. It is an effort to understand the microstructure of the composites including particle distribution and defects like porosity, in order to correlate with the observed mechanical properties measured in terms of hardness and tensile properties.

II. Experimental Details

2.1 Chemical Composition of Matrix Materials

An alloy of Al 1100 and 3 wt% of magnesium was used as the matrix material. The molten Al 1100 was alloyed with magnesium as it promotes wetting between the molten alloy and the Al_2O_3 particles, in order to retain these particles inside the melt. The chemical compositions of Al 1100 and magnesium, in weight percent, are shown in the Table I.

Table 1: Chemical composition of the commercial Al 1100 and Magnesium used

Chemical composition (wt%)							
Material	**Fe**	**Mn**	**Cu**	**Zn**	**Si**	**Mg**	**Al**
Al 1100	0.132	0.052	0.041	0.022	0.074	0.005	Bal.
Mg	0.020	0.002	0.016	0.002	0.006	Bal.	0.023

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2.2 Mechanical Properties AL 1100 and Al_2O_3 Particles

The particles size of the Al_2O_3 used was in the range between 10 µm to 120 µm. The mechanical properties of Al 1100 and Al_2O_3 used are shown in the Table II.

Table 2: The properties of Al 1100 and Al_2O_3 used

Material/ Properties	Density gm/cc	Hardness (HB500)	Strength (Tensile/Compressive) (MPa)	Elastic modulus (GPa)
Al 1100	2.71	23-35	90 (T)	69
Al_2O_3	3.69	1175	2100 (C)	300

III. Processing of Composites

A stir-casting furnace cum bottom pouring set-up has been used for solidification processing of Al 1100 based composites. In this study, alloy of Al 1100 and 3 wt% of magnesium was used as the matrix material and Al_2O_3 particles is added as reinforcements in amounts of 3, 6, 9 and 12 wt%. About 600 gms of commercially pure Al 1100 was melted and superheated to a desired processing temperature in a clay-graphite crucible inside the furnace. A fixed amount of Al_2O_3 particles was added into molten Al 1100 at a processing temperature of 900°C and the rate of addition of Al_2O_3 particles. A magnesium lump of 3 wt% was wrapped by aluminium foil and added to the melt-particle slurry after the addition of Al_2O_3 particles to improve the wettability of the melt.

An alumina coated stirrer was used for proper mixing of the Al_2O_3 particles in the melt. The temperature of the melt was measured by using a chromel-alumel thermocouple. When the desired time of the stirring is completed, the stirrer speed is reduced. After completion of processing steps, the graphite stopper at the bottom of the crucible is removed by using the lever to pour the melt-particle slurry into split type graphite coated and preheated permanent steel mould. Mould is kept exactly below the graphite stopper, the mould containing that cast ingot is allowed to cool in air, in order to achieve better uniformity in distribution of the particles throughout the casting.

Different composites have been synthesized by adding powder as given in the Table III and these composites have been designated by using the letters A and M to indicate Al 1100 and Mg (3 wt%) alloy followed by a letter P indicates the percentage of Al_2O_3 powder of 3, 6, 9 and 12 wt% respectively. For example, the composite designated as AMP3 the first latter A and the following latter M indicate base metal Al 1100 and the alloying element of Mg (3 wt%) followed by latter P3 indicates addition of 3 wt% of Al_2O_3 particles.

Table 3: Nominal composition of the composite

Designation of alloy/composite	Magnesium weight (%)	Al_2O_3 weight (%)
AM	3	0
AMP3	3	3
AMP6	3	6
AMP9	3	9
AMP12	3	12

IV. Preparation of Specimens

4.1 Preparation of Specimen for Scanning Electron Microscopy

The scheme of sectioning the cast unreinforced alloy and cast composites were used to prepare the specimens for metallographic studies. Specimens for microstructural analysis were prepared as discussed below.

1. The cast unreinforced alloy and composites were initially cut into square/rectangular pieces of suitable dimension.
2. Then these samples were polished by using silicon carbide emery papers (water proof) of 400, 600, 800, 1000, 1200, 1500 and 2000 grit sizes.
3. The final polishing of the specimens was carried out in polishing machine on a fine velvet polishing cloth using polishing grade II alumina suspension.
4. After polishing in polishing machine, wash the specimen with water and etching has to be done by adding few drops of diluted hydrofluoric acid and wash the specimens with acetone.
5. The polished specimens were examined under scanning electron microscope.

The polished specimens of different cast alloy and cast composites were examined under scanning electron microscope to study the presence of particles in the matrix. The typical distribution of incorporated particles and various microstructural features of the matrix in cast alloy and cast composites were photographed and reported.

4.2 Preparation of Specimen for Hardness Test

The Brinell hardness test is a simple indentation test for determining the hardness of a wide variety of materials and it is particularly preferred for particle reinforced composites as it could provide a better average hardness over a larger area containing several fine particles in the matrix. The Brinell hardness of the cast unreinforced alloy and composites were studied on the samples prepared according to ASTM–E10 standards.

Specimens for hardness test were prepared as discussed below.

1. The cast unreinforced alloy and composites were initially cut into square/rectangular pieces of suitable dimension.
2. Then these samples were polished by using silicon carbide emery papers (water proof) of 400, 600, 800, 1000, 1200, 1500 and 2000 grit sizes.
3. The final polishing of the specimens was carried out in polishing machine on a fine velvet polishing cloth using polishing grade II alumina suspension.
4. The polished specimens were examined under Brinnel's hardness tester.

The testing was carried out at a load of 5000 N by using a steel ball of diameter 10 mm. The load was applied for 30 seconds on a sample and then the diameter of indentation was measured with the help of tool makers' microscope.

4.3 Preparation of Specimen for Tensile Test

The tensile tests were carried out at ambient temperature for cast unreinforced alloy and cast composites. The specimens were machined from all the cast ingots of alloy and composites. The tensile test specimens were prepared as per the ASTM-B557 standard as shown in the Fig. 1. At least three tensile specimens of 4.0 mm gauge diameter and 24.0 mm gauge length, machined out from segment of each cast ingots of alloy and composites.

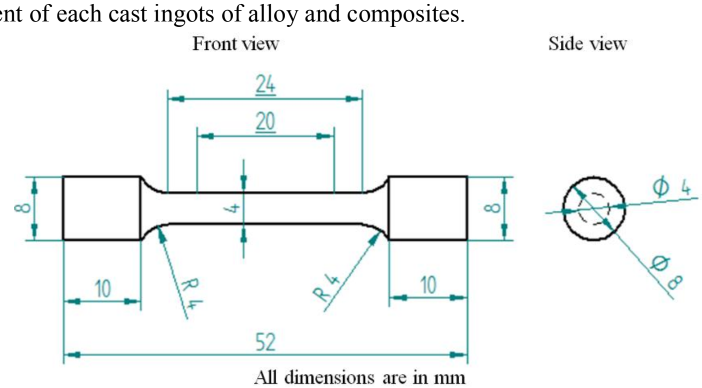

Figure 1: Size and shape of the tensile specimen

Tensile specimens were tested under uniaxial tension on Tensometer at an extension rate of 1 mm/min.

V. RESULTS AND ANALYSIS

5.1 Microstructure of Cast Alloy and Composites

Fig. 2 (a) shows the SEM micrographs of cast AM alloy. From Fig. 2 (a) it is expected the presence of needle shaped intermetallic compound Al_3Mg_2 and also some dark spots due to porosities. All other four SEM microstructures in Fig. 2 contain similar phases but their weight fraction varies depending upon the amount of Al_2O_3 additions. The composite, AMP12, has more distributed phases than that in composite AMP3. It is observed that the porosity (dark spots in micrographs) in the composite increases with increasing addition of Al_2O_3 particles. This is because of attachment of particle with bubble during processing and also due to solidification as the dissolved gases start nucleating on the heterogeneous surfaces of particles. The distribution of particles in the composites, developed by addition of Al_2O_3 powder, shows almost individual particles and no significant clustering in composites AMP3 and AMP6 as shown in Fig. 2 (b) and (c). As wt% of Al_2O_3 powder increases significant clustering of particles is observed as shown in Fig. 2 (d) and (e).

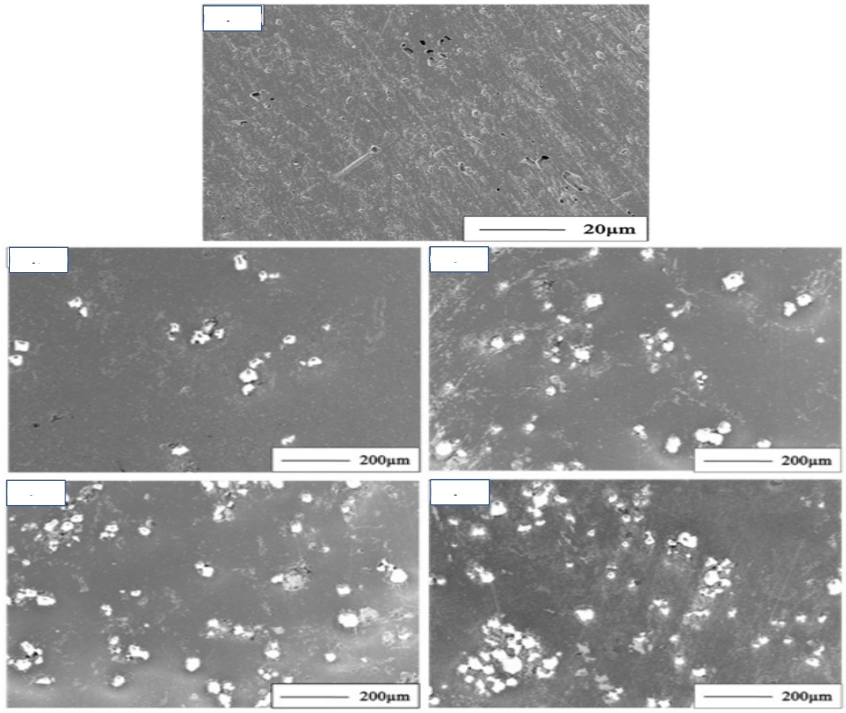

Figure 2: SEM micrographs of (a) cast alloy and different cast composites developed by increasing amounts of Al_2O_3 powder designated as (b) AMP3, (c) AMP6, (d) AMP9 and (e) AMP12 respectively.

5.2 Hardness of Cast Alloy and Composites

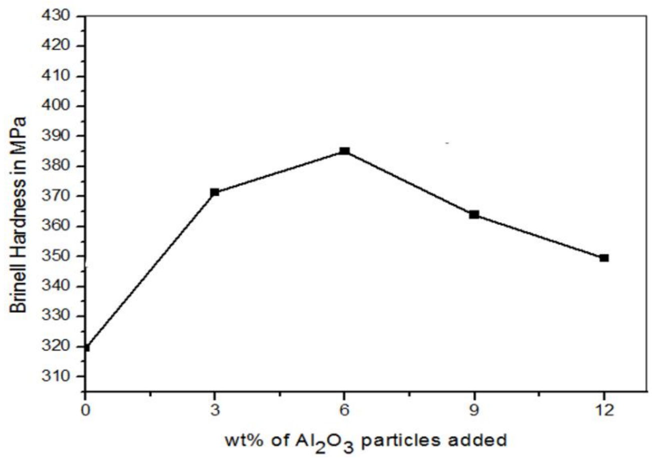

Figure 3: Variation of hardness in cast alloy and composites developed by increasing addition of Al_2O_3 powder.

Al 1100 - Mg alloy is a soft material and the reinforced Al_2O_3 particles being hard, helps positively to the hardness of the composites. The presence of harder Al_2O_3 reinforcement leads to increase in constraint to plastic deformation of the matrix during the hardness test. The hardness of the cast alloy and composites increases with increasing addition of Al_2O_3 particles to base alloy up to 6 wt% (385.2 MPa) as observed in Fig. 3. The hardness decreases for cast composites AMP9 (363.9 Mpa) and AMP12 (349.4 MPa) may be due to increased porosity and poor interface bonding between matrix and reinforcement particles. Tensile properties of Cast alloy and Composites

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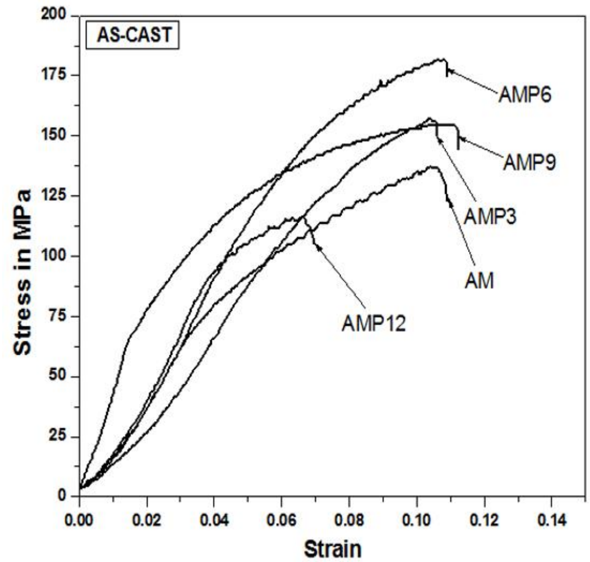

Figure 4: Tensile stress-strain behaviour of cast alloy and composites developed by addition of 0, 3, 6, 9 and 12 wt% of Al_2O_3 powder.

There is an observable improvement in the strength and ductility with powder addition for cast composites AMP3 and AMP6 compared to those observed in the base alloy. Cast composite AMP6 shows the highest tensile strength (161.50 MPa) but there is slight reduction in ductility (9.65%) as compared to AM (11.69%) and AMP3 (9.85%) composites but Composites AMP9 shows the moderate strength (153.7 MPa) and good ductility (10.79%) is as shown in Fig.4. Cast composite AMP3 shows higher strength (159.55 MPa) and moderate ductility (9.85%) as compared to the base alloy. The reduction in tensile strength of composites beyond 6 wt% Al_2O_3 is due to increased porosity, particle agglomeration and improper bonding between matrix and reinforcement materials.

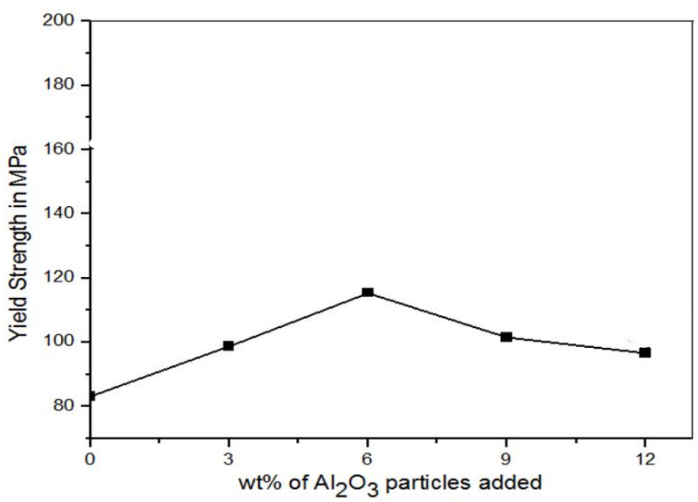

Figure 5: Comparison of yield strength in cast alloy and composites with increasing addition of Al_2O_3 powder.

The yield strength increases with increasing addition of Al_2O_3 powder up to 6 wt% in cast composites, yield strength decreases with further increase in wt% of Al_2O_3 powder. Yield strength improves most with 6 wt% addition of powder in cast composite (115.45 MPa) is as shown in Fig. 5. The composite with 12 wt% addition of Al_2O_3 powder particles exhibited low yield strength (96.70 MPa) this may be due to to increased porosity, particle agglomeration and improper bonding between matrix and reinforcement materials.

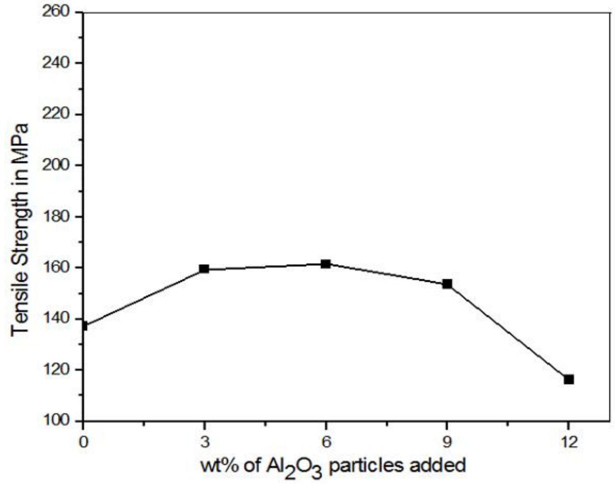

Figure 6: Comparison of tensile strength in cast alloy and composites with increasing addition of Al_2O_3 powder.

The tensile strength in cast composite improves most with 6 wt% (161.50 MPa) addition of powder, while in case of 0 wt% (137.30 MPa) to 3 wt% (159.55 MPa) much improvement is observed but marginal improvement from 3 to 6 wt% and beyond the addition tensile strength decreases is as shown in Fig. 6. The cast composites with 9 wt% (153.7 MPa) and 12 wt% (116.20 MPa) addition of Al_2O_3 powder particles exhibited low tensile strength due to to increased porosity, particle agglomeration and improper bonding between matrix and reinforcement materials.

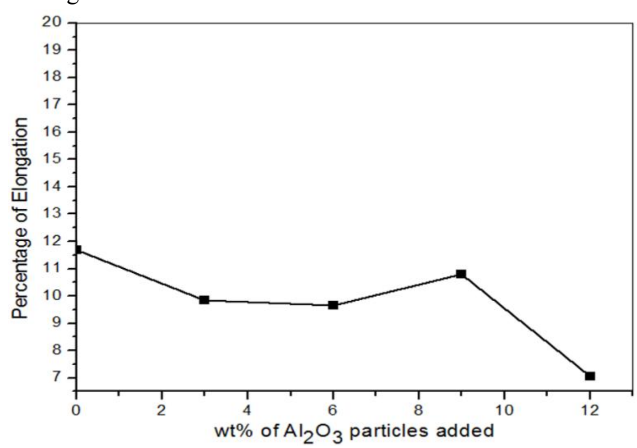

Figure 7: Comparison of percentage of elongation in cast alloy and composites with increasing addition of Al_2O_3 powder.

Fig. 7 reveals the variation of percentage elongation in cast alloy and cast composites with increasing addition of Al_2O_3 powder. In cast composites percentage elongation decreases with increase in wt% of Al_2O_3 powder addition except for composite with 9 wt% (10.79 %) of Al_2O_3 powder. The powder contains both coarser and finer particles (particle size from 10 µm to 120 µm) together appear beneficial for improvement in ductility in 9 wt% cast composites. For the finer particles to be able to counteract debonding of coarser particles there has to be sufficient concentration, which appears to happen in 9 wt% of Al_2O_3 addition composite.

VI. Conclusion

1. The stir casting technique was successfully adopted in the preparation of alloy and composites containing 0, 3, 6, 9 and 12 wt% of Al2O3 powder reinforcement.
2. SEM analysis shows porosity in cast composites increases with increasing addition of Al2O3 powder, comparatively more dark spots observed at AMP12 composites.
3. The hardness and tensile strength of the composites is found to decrease beyond 6 wt% of Al2O3 due increased porosity and improper bonding between matrix and reinforcement particles.

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