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

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Abstract - Aluminium Metal Matrix Composites 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. Hot Extrusion of the reinforced AMMCs can lead to break up of particle agglomerates, reduction of porosity, and improved bonding, all of which contribute to improve the mechanical properties of these materials. Aluminum oxide 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 0, 3, 6, 9 and 12 wt% of Al_2O_3 particles with Aluminium-Magnesium alloy by melt stirring method to make aluminum-based composites and hot extrusion is carried out for the same composites. Microstructural studies like Scanning Electron Microscopy (SEM) and Mechanical properties like tensile strength and hardness will be investigated for extruded alloy and composites. Variations in microstructures and mechanical properties have been compared.

Key words - AMMCs, Al_2O_3 particulates, hot extrusion, SEM, hardness, tensile properties

I. INTRODUCTION

Metal Matrix Composites are being increasingly used in aerospace and automobile industries due to their enhanced properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures, wear resistance, weight savings over unreinforced alloys. In general, metal matrix composites utilize at the same time, the properties of the matrix (light weight, good thermal conductivity, ductility etc.) and of the reinforcement, usually ceramic (high stiffness, high wear resistance, low coefficient of thermal expansion etc.). The commonly used metallic matrices include aluminium, titanium, magnesium, copper and their alloys. These alloys are most commonly used matrix materials for the production of metal matrix composites (MMCs).

The development of aluminium matrix composites (AMCs) is receiving considerable emphasis in meeting the requirements of various industries. Due to the desired properties of aluminum matrix composites, such as low weight, high specific strength, good corrosion resistance and excellent wear resistance, they have received a great interest in the recent years. Compared to the ferrous alloys, aluminum alloys have lower density and higher strength to weight ratio, higher thermal and electrical conductivity. And also, they are cheaper than other lighter metals, such as magnesium and titanium.

Silicon carbide (SiC) is most commonly used in metal matrix composites. 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 effect of these reinforcements to aluminum alloys has been the subject of a significant amount of research work.

The current study involves synthesis of Al 1000 – Mg alloy and composites by adding alumina particles to molten alloy during stir casting and hot extrusion of the composites. The objective of developing hot extruded composites is an effort to understand the microstructure of the extruded composites including particle distribution and defects like porosity and correlate with the observed mechanical properties measured in terms of hardness and tensile properties between the extruded composites of different wt % of reinforced particles.

II. EXPERIMENTAL METHODOLOGY

A. Chemical composition of commercial Al 1100 and Mg Used

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

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1100 and magnesium, in weight percent, are shown in the Table 1.

Table 1: Chemical Composition of Commercial Al 1100 and Mg Used

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

B. Mechanical Properties of Al 1100 and Al_2O_3 used

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 2.

Table 2: 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

C. Stir Costing

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. 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.

A stirrer coated with Al_2O_3 particles 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 3 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

D. Extrusion

The sample of 35 mm diameter and length of 35 mm were prepared from cast ingots by turning operation for hot extrusion. Before extrusion all the composites and alloy were heated in furnace up to a temperature of 450°C for 90 minutes to homogenize the sample temperature throughout the volume. The graphite powder is mixed with grease with a proportion of 1:3 by making a mixture of solid and semi solid lubricant. The mixture is applied to the inner surface of the die and container in order to reduce the friction during extrusion process. The mixture is used due to its capacity of withstanding high temperature of the billet, which is to be extruded. There after they were extruded and then cooled in air before sampling for various testing samples. In the present work the cast alloy and composites were hot extruded from 35 mm diameter to 10 mm diameter with an extrusion ratio 12.25.

III. Result and Analysis

A. Microstructure of Cast Alloy and Composites

All the extruded composites of varied compositions and alloy were extruded. Extrusion causes significant reduction in porosity over that in corresponding cast composite particularly at higher particle content. The temperature used for hot extrusion is more than the recrystallization temperature of Al-composite, and then comparatively more phases are expected. SEM microstructures of all the composition is as shown in Fig. 1 (a) AM, (b) AMP3, (c) AMP6, (d) AMP9 and (e) AMP12 respectively contain similar phases but their weight fraction varies depending upon the amount of Al_2O_3 additions. The SEM clearly reveals reduced porosity because the extrusion has led to significant break up of particle agglomerates, reduction of porosity and improved bonding between matrix and reinforcement materials, particularly at higher particle content.

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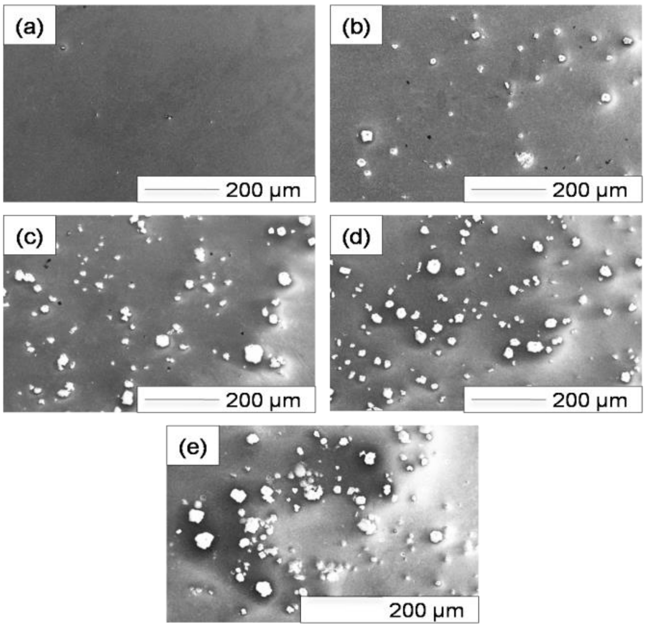

Fig.1: SEM micrographs of different extruded composites developed by increasing amounts of Al_2O_3 powder designated as (a) AM (b) AMP3, (c) AMP6, (d) AMP9 and (e) AMP12 respectively.

The extruded composite AMP12 has more distributed phases than that in the composite AMP3. It is observed that the porosity (dark spots in SEM micrographs) in the composite increases with increasing addition of Al_2O_3 particles. This is often attributed to attachment of particle with bubble during processing. This attachment takes place during particle transfer by stirring. It may also happen during solidification as the dissolved gases start nucleating on the heterogeneous surfaces of particles. Often these bubbles are not able to float out rapidly due to increased density because of attached particles and get entrapped during solidification, enhancing the porosity in composite. Thus, porosity increases with increasing addition of Al_2O_3 powder in composites.

The particle distribution 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. 1 (b) and (c). As wt% of Al_2O_3 powder increases to 9 wt% there are some clustering of two or three particle is observed as shown in Fig. 1 (d) and further increases to 12 wt% addition significant clustering is observed as shown in Fig. (e).

B. Hardness of Extruded alloy and Composites

Extruded alloys and composites developed by addition of 0, 3, 6, 9 and 12 wt% of Al_2O_3 powder, designated respectively as AM, AMP3, AMP6, AMP9 and AMP12 respectively. The comparison of average hardness in extruded composites with extruded alloy is given in Table IV. The hardness of the extruded composites increases with increasing addition of Al_2O_3 particles to base alloy up to 6 wt% of Al_2O_3 particles as observed in Table 4. The hardness decreases for composites AMP9 and AMP12 may be due to increased porosity and poor interface bonding between matrix and reinforcement particles.

Table 4: Average hardness for different extruded composites.

Designation of alloy / composite	BHN (MPa)
AM	347.6
AMP3	395.6
AMP6	412.9
AMP9	381.2
AMP12	371.4

In extruded alloy and composites increase in hardness is observed as shown in Fig. 2., which may be due to break up of particle agglomerates and healing of porosity caused by the compressive forces generated by interaction of the composite billet with the extrusion container and die, resulting in the flow of the matrix alloy into voids under the applied shear forces and also due to the strain remaining after incomplete dynamic process of recovery and recrystallization. The hardness of extruded composites increases with increasing addition of Al_2O_3 particles compare to base alloy up to 6 wt%, beyond this level of addition the average hardness decreases.

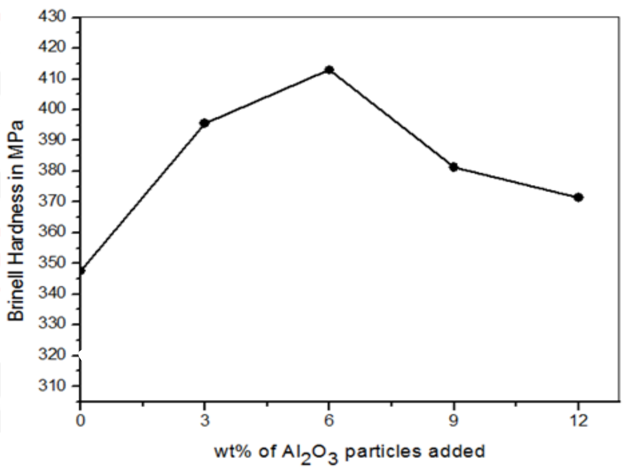

Fig. 2: Variation of average hardness extruded alloy and composites developed by increasing addition of Al_2O_3 powder.

C. Tensile properties in Cast and Extruded composites

Table 5 shows tensile properties of extruded alloy and composites

Table 5: Average tensile properties of extruded alloy and composites

Designation of alloy / composite	Yield strength (MPa)	Tensile strength (MPa)	Percentage Elongation (%)
AM	161.50	193.50	14.95
AMP3	178.30	217.25	16.45
AMP6	174.35	232.90	17.99
AMP9	112.85	162.5	11.85
AMP12	99.10	131.80	11.00

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The yield strength increases with increasing addition of Al_2O_3 powder up to 3 wt% in extruded composites, yield strength decreases with further increase in wt% of Al_2O_3 powder as shown in Fig. 3. The composite with 12 wt% addition of Al_2O_3 powder particles exhibited low yield strength this may be due to ineffective reduction in porosity and ineffective break up of particle agglomerates.

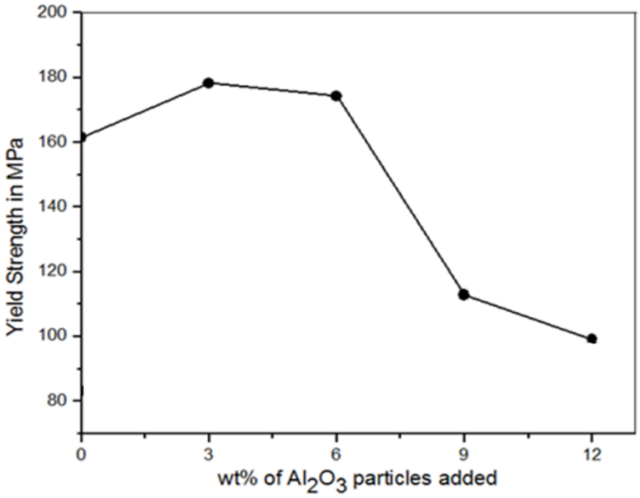

Fig. 3: Variation of yield strength in extruded composites with increasing addition of Al_2O_3 powder.

The tensile strength in extruded composites improves most with 6 wt% addition of powder as shown in Fig. 4. This may be due to the reduction of porosity content, reduction in grain size, uniform distribution of Al_2O_3 particles due to break up of particle agglomerates and improved bonding between matrix and reinforcement materials and also may be due to compressive strains involved in the extrusion process. The extruded composite improves most with 6 wt% addition, beyond the addition tensile strength decreases. The extruded composites with 9 wt% and 12 wt% addition of Al_2O_3 powder particles decrease, this may be due to ineffective reduction in porosity and ineffective break up of particle agglomerates.

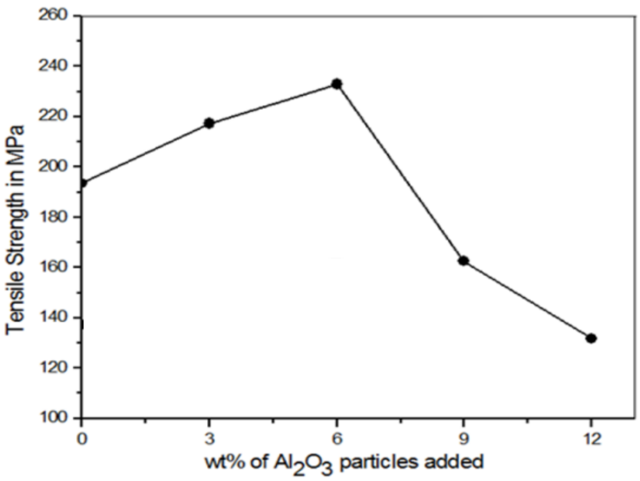

Fig. 4: Variation in tensile strength in extruded composites with increasing addition of Al_2O_3 powder.

Fig. 5 reveals the variation of percentage elongation in extruded composites with increasing addition of Al_2O_3 powder. The percentage elongation in extruded composites increases with the increase in the reinforcement content up to 6 wt% of Al_2O_3 and then percentage elongation decreases with 9 wt% and 12 wt% of reinforcement. This may be due to high porosity content in cast composites AMP9 and AMP12.

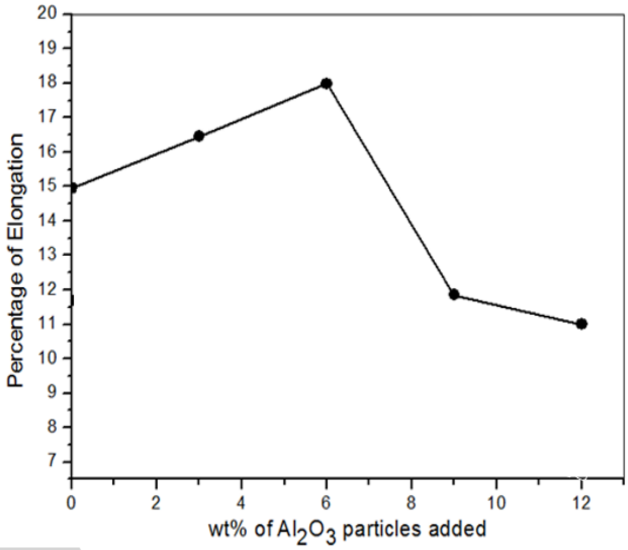

Fig. 5: Variation in percentage of elongation in extruded composites with increasing addition of Al_2O_3 powder.

Generally, in a composite, loss of strength and ductility is caused by early debonding of the particles due to shear stress generated by difference in flow behaviour across the interface between the matrix and the particle. The magnitude of the shear stress depends on the size of the particle. The larger is the particle, the larger is the shear stress and the debonding takes place at lower strain. If the debonding takes place in the elastic region of strain, there will be no improvement in the tensile strength of the composite but a lowering will be observed due to loss in the area of cross section. In the cast alloy it is presumed that the failure has been caused by debonding of the oxide inclusions generated due to oxidation during processing at high temperature.

IV. CONCLUSION

SEM analysis shows hot extrusion causes reduction in porosity content and matrix grain size, and more uniform distribution of particles due to break up of particle agglomerates is achieved. This may be due to the action of compressive forces in hot extrusion process.

The hardness and tensile strength of the composites is found to decrease beyond 6 wt% of Al_2O_3 may be due to increased porosity and improper bonding between matrix and reinforcement particles. The hardness and tensile

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strength of hot extruded composites exhibits higher value when compared with respective cast composites.

The 6 wt% composite developed after extrusion exhibited good yield strength of 161.50 MPa, tensile strength of 232.90 MPa and percentage of elongation around 17.99%.

It was observed that 6 wt % of Al_2O_3 with Al 1100 (Mg) is the optimum mixture of reinforcement and matrix material for extruded composites in the present investigation.

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