Properties of Aluminum Metal Matrix Composites Reinforced by Particles of Silicon Carbide using Powder Metallurgy

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Abstract
In wide choice of materials, it is challenging for engineers to select the right material and manufacturing process for different engineering application. The development of hybrid metal matrix composites has become an important area of research interest in materials science. Light weight metal alloys reinforced with hard carbide particle to enhance their mechanical properties. Aluminum alloys are increasingly seen among them as alternative to the conventional materials particularly in the aerospace, automotive and defence engineering. Reinforcing of aluminum alloys with hard phase of carbide particles offers higher strength, higher modulus, superior wear resistance, good workability and desirable thermal expansion. In the present study, an attempt has been made to fabricate five different types of Al-Mg-SiC composite by powder metallurgy (PM) route. The samples of different compositions were prepared under compaction load of 250MPa at room temperature. The effect of volume fraction of SiC-Mg particulates on the properties of Al-Mg-SiC composites was investigated. The results show that density and hardness of the composites are greatly influenced by volume fraction of particulates. An optimum content of SiC and Mg addition to aluminum was found to be 12-16 wt% of SiC and 1-1.5 wt% of Mg, at which the composites exhibited good mechanical properties.
Key words: METAL MATRIX COMPOSITE, ALUMINUM ALLOYS, REINFORCEMENT, POWDER METALLURGY

Introduction

Composites are the combination of two or more constituent materials with significantly different physical and chemical properties with characteristics different from individual components [5]. They commonly consist of a continuous phase called matrix and discontinuous phase in the form of fibers, whiskers, or particles called as reinforcement.

In recent years, stringent requirements of material quality in aerospace and automotive industries have necessitated the development of lightweight metal alloys due to their excellent mechanic performance, high strength, wear resistance, high working temperature etc.

Among light weight metal alloys aluminum alloy matrix attracts much more attention towards manufacturing the components, due to their lightness, high thermal conductivity and moderate casting temperature [9]. Reinforcing of aluminum alloys with carbide phase of hard particles offers high strength, high modulus, superior wear resistance, good workability, desirable thermal expansion and isotropy [2].

A wide range of production techniques have been developed for aluminum matrix composites, the objectives of all processing techniques are to homogeneously distribute the reinforcement phases, to achieve a defect free micro-structure and economical efficient component. Primary industrial manufacturing processes of AMMCs can be classified into liquid phase and solid state processes. Choosing the appropriate manufacturing process is an important consideration at the early stages of metal matric composite design. The selection of the processing route depends on many factors including type and level of reinforcement loading and the degree of micro structural integrity desired [2].

Powder metallurgy (PM) techniques have emerged as promising routes for the fabrication of particulate reinforced aluminum metal matrix composites. Due to the fact that the process enables close dimensional tolerance, efficient material utilization and complex parts can be produced with specified level of porosity [2]. In the present study, an attempt has been made to fabricate five different types of Al-Mg-SiC composite by powder metallurgy route. The specimens of different compositions were prepared under compaction load of 250MPa.

The process mainly covers blending fine powdered composite, compacting or pressing into a desired shape and then finally sintering composite. The effect of volume fraction of SiC-Mg particulates on the properties of Al-SiC-Mg composites was investigated.

Experimental method

Material

Pure aluminum powder (99.9%) with average particle size of 400 mesh was obtained from Hunan ningxiang jiweixin metal powder limited company and used as test material along with magnesium and silicon carbide particle (Table 1). To improve the wettability of SiC particles 0.5-2.5% wt. % of magnesium (Mg) gray color was added along with the reinforcement.

Table 1. Raw material

Sample No	Raw material	Average particle size	Purity
1	Aluminum	400 mesh	99.9%
2	Magnesium	325 mesh	99.7%
3	Silicon carbide	325 mesh	99.7%

Sample Preparation

Five categories of samples were prepared as show in Table 2. Equal weight of 300 g aluminum and reinforcement powder were taken by varying the percentage for varies sample.

Experimental procedures

Aluminum metal matrix composite (Al-Mg-SiC) specimens of different compositions were prepared using conventional powder metallurgy route.

Table 2. Sample preparation

Sample	Aluminum		Magnesium		Silicon carbide	
	Weight (g)	Percentage	Weight (g)	Percentage	Weight (g)	Percentage
1	286.50	95.50	1.50	0.50	12.00	4.00
2	273.00	91.00	3.00	1.00	24.00	8.00
3	259.50	86.50	4.50	1.50	36.00	12.00
4	246.00	82.00	6.00	2.00	48.00	16.00
5	232.50	77.50	7.50	2.50	60.00	20.00

Manufacturing of the specimens starts with preliminary preparation of the reinforcement which includes crushing, grinding and classification silicon carbide particles. Die wall lubrication was applied by brushing a thin layer of graphite powder over die cavity and the top punch.

The Al-Mg-SiC composite powder of weighed amount was blended with the reinforcement in a drum with a cylindrical mixer at speed of 1200 rpm for 40 min. Different compositions of Al-Mg-SiC powders samples (Table 2) were poured in to the hardened steel die and compacted to diameter of 300 mm (160 mm long) using manually operated hydraulic press with pressure of 250 MPa.

The green compact samples were sintered using a sintering furnace supplied from Harper International Company. During sintering process, two cycles of heating were applied.

In the first cycle, with a heating rate of 10 ^{o}C/min, the temperature reached to 400 ^{o}C and a holding time of 40 minutes was maintained.

In the second cycle, with a heating rate of 10 ^{o}C/min, the temperature reached to 500 ^{o}C and a holding time of one hour was maintained. After that, the samples were allowed to cool in the sintering furnace to reach the normal room temperature. After the sintering process, all the specimens were prepared for testing.

The steps are summarized as follows and shown in Figure 1:

- Aluminum metal matrix and reinforcement preparation.
- Blending. The matrix and the reinforcement powders are blended or mixed to produce a homogeneous distribution.
- Small amount of solid lubricant introduced during blending are driven out by low temperature heating cycle.
- Mixed powders are placed in a die and compacted by pushing a punch under pressure to produce a part called green body.
- The green compact samples were then sintered.

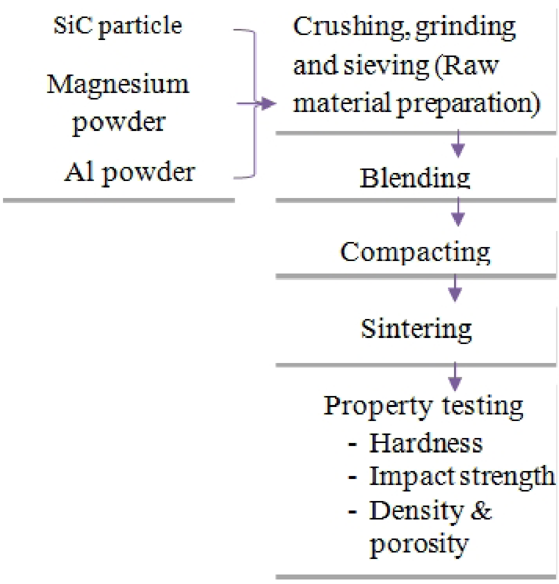

Figure 1. Experimental procedure

Result and discussion

Density and porosity

The density was measured by measuring the weight and volume of the specimens [8]. The vo- lume was determined by measuring the accurate dimensions of the specimen. Porosity of the sintered composite was determined by Archimedes principle [4].The compacts were first weighed in air and then tied with string and weighed while hanging in water. Density of sintered samples determined using the following equation:

$$\rho s = \frac{m_a \times \rho_w}{m_a - m_w} \quad (1)$$

Where, ρs = Density of sintered specimen (g/mm^3)

ρ_w = Density of water (g/mm^3)

m_a = Weight of sample in air (g)

m_w = Weight of sample in water (g).

The theoretical density was determined by comparing the sum of volume (weight divided by the density) of constituents and the volume of composite. For example, the theoretical density of composite in which 95.5 wt % of Al, 4 wt. % of SiC and 0.5 wt. % of Mg was determined as follows:

Density of SiC = 0.00321g/mm^3 density of aluminum = 0.0027g/mm^3, density of Magnesium = = 0.00177g/mm^3.

$$\rho_t = \frac{100}{\sum_{i=1}^{n} \frac{x_i}{p_i}} \quad (2)$$

Where ρ_t is the theoretical density x_i is the fraction of component *i* in mixture (*i* being Al, Mg, and SiC); ρ_i is each components density, *i* is in (g/mm^3).

$$\rho_t = \left(\frac{100}{\frac{4}{0.00321} + \frac{0.5}{0.00177} + \frac{95.5}{0.0027}} \right) = 0.002709 \text{ g/mm}^3$$

Similarly the theoretical densities of other compositions of Al-Mg-SiC composites were determined and tabulated (Table 3).

From the theoretical and actual densities, porosity of the composites can be estimated by using equation.

$$E\,(\%) = \left(1 - \frac{\rho s}{pt}\right) \times 100 \quad (3)$$

Where, E = Porosity (%)

ρs = Density of sintered sample (g/mm^3)

ρt = Theoretical density (g/mm^3)

The result showed that, the theoretical densities of Al-Mg-SiC composite improved with the increment weight percent of SiC from 4 to 20 compared to pure aluminum.

Theoretical density of Al-Mg-SiCp composite was closer to the experimental values, which indicate that the interface between matrix and reinforcement was almost bonded and pores formed by irregular shape of matrix material were filled by powders of reinforcement. However, as the particulates content was increased beyond 16 wt% of SiC and 2 wt% Mg, the higher porosity (Fig. 2) in the composites results from poor wettability between matrix and particulates. An optimum content of SiC and Mg addition to aluminum was found to be 12-16 wt% of SiC and 1-1.5 wt% of Mg, at which the composites exhibited good mechanical properties.

Impact testing

Impact Strength is used to measure the energy absorbing capacity of the material subjected to sudden loading but also to determine the transition temperature from ductile to brittle behavior [7].

The Impact tests were performed with an Izod Test. The samples were cut from the manufactured composite and milled to the standard size (Fig. 5).

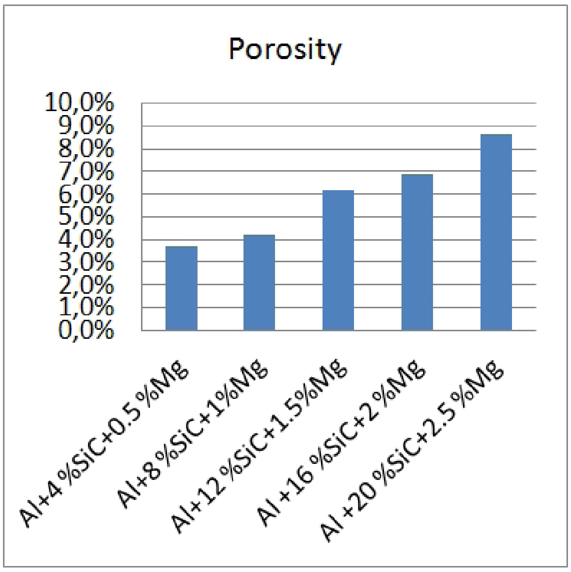

Figure 2. Porosity of composite

Table 3. Porosity and hardness of composite

Sample	Content			Hardness (HBR)	Impact strength (Joules/mm^2)	Theo. Density (gm/mm^3)	Exp. Density (gm/mm^3)	Porosity (%)
	% SiC	% Mg	Balance (Al)					
1	4	0.5	95.5	64	14	0.002709	0.00261	3.663
2	8	1	99	69	16	0.002516	0.00241	4.209
3	12	1.5	86.5	72	13	0.002728	0.00256	6.156
4	16	2	82	76.5	12	0.002737	0.00255	6.845
5	20	2.5	77.5	77	8	0.002747	0.00251	8.624

The Izod impact test was carried out using Tinius Olsen **(**Model IT 406**)** impact tester as per ASTM standard. Five samples with identical dimensions of 55 mm x 10 mm x 10 mm were prepared for composite testing and average result was derived. The specifications of impact tester (Fig 3) and testing conditions are given below.

Maximum pendulum capacity = 25 J

Maximum impact velocity = 3.46 m/s

The test specimen (Fig 4) was supported as a vertical cantilever beam and broken by a single swing of a pendulum. The pendulum strikes the face of the sample and total of 5 samples were tested; the mean value of the absorbed energy was taken.

Energy absorbed *(U)* by the specimen is calculated using the following equation:

$$U = \frac{W}{2g} (\mathcal{U}1 - \mathcal{U}2) \quad (4)$$

Where W is the weight of striking head

$\mathcal{U}1$ the velocity of striking head before impact;

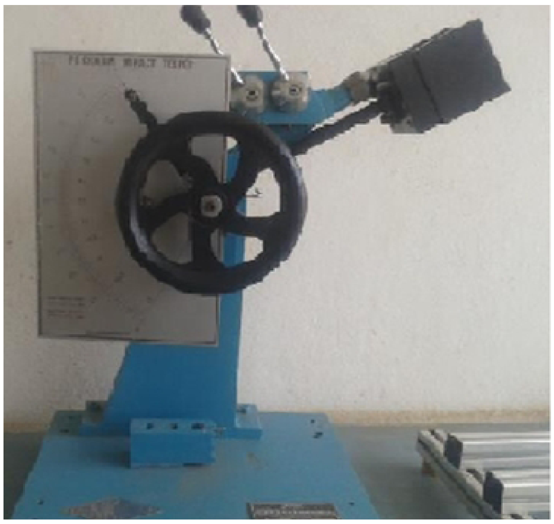

Figure 3. Impact testing machine

$\mathcal{U}2$ - the measured velocity of striking head after impact;

g - the acceleration due to gravity; and H, the drop height.

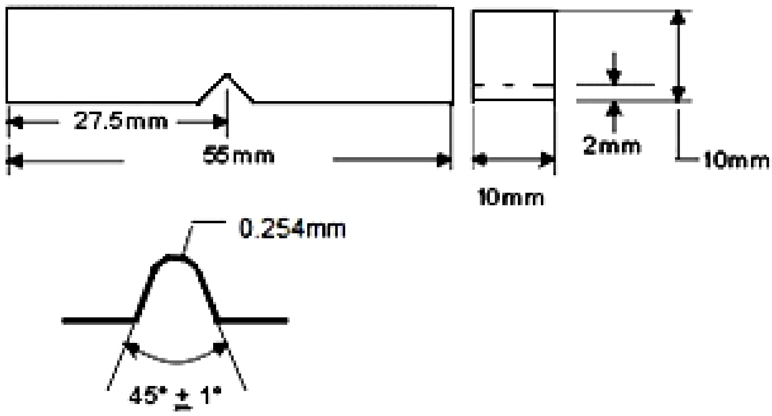

Figure 4. Composite specimen for impact test

The brittle nature of the reinforcing materials (SiC) plays a significant role in degrading the impact energy of the composite. Fig.5 shows the effect of reinforcement content on the hardness and impact energy of Al-M-Si metal matrix composite. It can be seen that as the content of reinforcement increase, the impact energy of the composite material decreases.

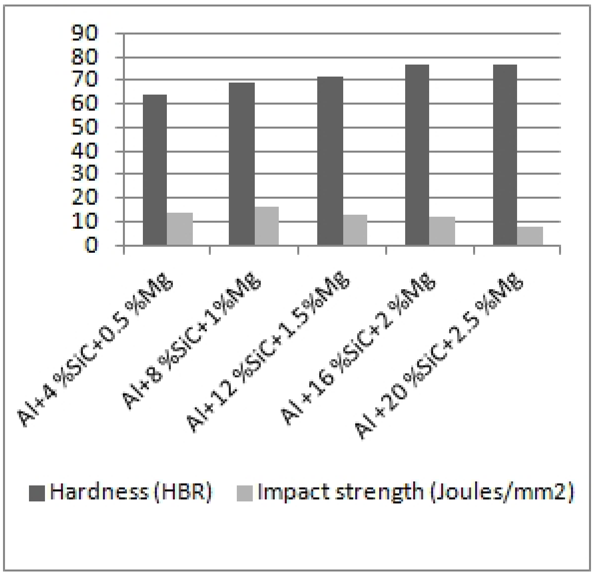

Figure 5. Hardness and impact strength result

Hardness test

Rockwell hardness was measured on the polished surfaces of the Al-Mg-SiC composite samples. A diamond indenter with fixed indentation load of 150 kg was used for all tests. The effect of weight percentage of particulates (Si-Mg) on the hardness values of aluminum metal matrix composite measured using Rockwell hardness testing machine. The result shows that hardness of Al-Mg-SiC composites increases with increase in weight % of Mg from 0.5 to 2.5 and wt. % of SiC from 4-20. High variation hardness values also measured at different positions of the sample due to the presence of porosity, which results from increment in percentages of hard and brittle phase of ceramic body in matrix composite.

Conclusion

In the present study, an attempt has been made to fabricate five different types of Al-Mg-SiC composite by powder metallurgy route. The results show that density and hardness of the composites are greatly influenced by volume fraction of silicon carbide particulates.

- Rockwell hardness and porosity of powder metal Al-Mg-SiC composites increase with the increasing in the weight percentages of reinforcements.

- High variation hardness values were measured at different positions of the sample due to the presence of porosity, which results from increment in percentages of hard and brittle phase of ceramic body in matrix composite.

- Experimental density and impact strength of composites decreased by increasing the wt. % of the reinforcement. This is due to the brittleness nature of SiC particles, which act as micro void initiator.

- Optimum content of SiC and Mg addition to aluminum at which the composites exhibited good mechanical properties was found to be 12-16 wt% of SiC and 1-1.5 wt% of Mg.

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