Hindawi
Advances in Materials Science and Engineering
Volume 2020, Article ID 1893475, 7 pages
https://doi.org/10.1155/2020/1893475

Research Article

Microstructural and Mechanical Analysis of Sintered Powdered Aluminium Composites

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Received 18 February 2020; Accepted 23 March 2020; Published 21 April 2020

Academic Editor: Francisco Javier Fernández Fernández

The present material world needs strong research studies for producing varieties of composite materials which have light weight and high strength with better performances. This leads to the introduction of materials through powder metallurgy technique. The main objective is to discover an aluminium matrix composite having enhanced characteristic performances and properties beyond the currently available materials. The current study has been carried out to develop an attractive composite having high strength, light weight, easy machinability, appreciable density, and low manufacturing cost. Aluminium powders of 99.55% purity and 325 mesh sizes are mixed with alloying metals such as copper, magnesium, silicon, and silicon carbide powders in a precisely controlled quantity. The result was found with better mechanical properties, and the XRD patterns were studied in the matrix at different intensities, showing the interfacial bonding of elements gives rise to increase in strength.

1. Introduction

A metal matrix composite like aluminium is a better and high-performance material for industrial applications due to its acceptable properties over the presently available aluminium or its alloys [1–5]. The composite is used in the fabrication of different components in automobile sectors, electronics, aerospace applications, defense, window frames, irrigation, tubing, and petro chemical industries. The composites have unique properties over the individual metal characteristics. The researchers are focused upon the aluminium composites for their better advantages. Aluminium matrix metal composites (AMMC) will be helpful towards fabrication of different fields in engineering applications. AMMC is having elements such as copper, silicon, magnesium, and silicon carbide showing better hardness, stiffness, and tensile strength [6–8]. The interfacial relations between matrix, its reinforcement, and nature of bonding determine the structure and properties of the composites [9–11]. Powder metallurgy is a technique used for its particular characteristics such as lower sintering temperature, low cost, and uniformly homogeneous distribution of the reinforcements inside the matrix elements [12–16]. All preparations of the composite material by the powdered process can efficiently prevent the unfavorable interfacial chemical reactions at low temperatures, and the product quality is adequate with volumetric fraction of the each particle present inside the composite. The process is very easy to control. The present study described the Al-composite material preparations through the powder metallurgy route, and the metal matrix composites were studied with microstructures, XRD analysis, hardness, density, and porosity.

2. Methodology

In the present experiment, the powder metallurgy [17–21] method was adopted for processing of AMMCs and the reinforcement of metal powders were added into the matrix. The aluminium used here as a main raw material known as matrix material and was reinforced with Cu, Mg, Si, and SiC. The composite material was prepared with the process beginning with the selection of metal powders, weighing, mixing/blending, compacting, and sintering. The AMMCs was reinforced with 5% and 10% SiC weight basis separately. The Cu powder of 325 mesh particle sizes having purity 99.77%, Si powder of 325 mesh particle sizes with purity 99.87%, Mg powder of 100 mesh particle sizes with purity 99.80%, and SiC powder of 325 mesh particle size with purity 99.55% are mixed and blended with Al powder of 325 mesh particle sizes with purity 99.55%. The SiC particles of volume fraction 5% and 10% are mixed separately in the mixture of Al-Mg-Si-Cu [22] with the volume fractions of (91.5-0.5-0.5-2.5) %, respectively. The mixed/blended powder was compacted using a C-45 steel die in a digital compression testing machine with a loading rate of 0.208 KN/sec and up to 250 KN (521.02 MPa). The green compacted specimens were removed and sintered in a muffle furnace. The sintering temperature was taken as 620°C and was annealed for 24 hours.

3. Results and Discussion

3.1. Microstructure Test. The examination of microtexture was to investigate the shape morphology, grain size, and distribution of aluminium, copper, silicon, magnesium, and especially silicon carbide particles. The microstructures of the composite were studied by utilizing inverted metallurgical microscope and SEM. The microstructures showed the uniformly distribution of silicon carbide powder particles inside the aluminium composite, and some clustering of silicon carbide aroused the reinforcement in it.

Silicon carbide distributions in the composites affected the performance of the materials directly [23]. It was observed that very few particles of silicon were heterogeneously nucleated on the particle of SiC. If the separation of SiC occurs between the particles due to contact with each other, it will result in the formation of porosity in the material. The microstructures of the aluminium composites are shown in Figures 1 and 2. SiC particles were considered to avoid the possibility of particle fracture and debonding under severe stress at the interface of the particulate matrix. Due to high pressure during the powder compaction process, a dense microstructure was obtained which was helpful for the improvement of material strength and heat conduction capacity. The mechanical properties were enhanced with a uniform dispersion of reinforcement particles in composites manufactured. The irregular shapes of most particles in the composite were found. The particles of the filler materials were found randomly oriented in most locations. They were incorporated and packed closely in the matrix, which improved the mechanical properties. Scanning electron images revealed that the typical microstructure had low levels of porosity and better distribution of SiC. Another important observation was the segregation and agglomeration of SiC at the composite interfaces. The SEM showed the presence of the dispersed phase, that is, the silicon carbide is distributed homogeneously in the aluminium matrix phase and on the surface of the composites.

3.2. XRD Test. The samples, for X-ray diffraction analysis, were prepared according to the standard sizes. Figures 3 and 4 showed an X-ray diffraction pattern (XRD) obtained for Al, Cu, Si, Mg, and SiC powders in composites to verify their quality and standard in the XRD pattern.

Composites with 5% and 10% SiC reinforcements prepared by the powder metallurgy technique were subjected to X-ray diffraction analysis for the constituents present and the results obtained. The X-ray diffraction pattern received higher intensity peaks that were clearly visible for aluminium, while many peaks are visible for SiC powder. Different constituents, such as aluminium, copper, silicon, magnesium, and SiC, were identified after combining the experimental peaks obtained with those of the standard peaks. It was observed that the peak height increases and then decreases with the 2-theta scale [24]. It was found that the intensity was higher at 44.76 degrees (deg) on the 2-theta scale for 10% SiC. The higher the intensity, the greater the numbers of atoms in that position shown. Therefore, 10% of SiC in the composites was predicted with a better uniform distribution of the reinforcement; therefore, the mechanical properties were improved as compared with the previous research studies.

4. Material Characterization

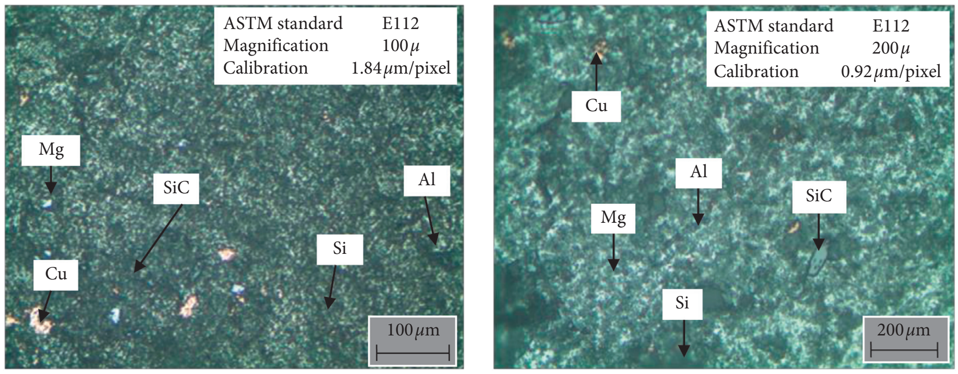
4.1. Hardness Test (Rockwell). The Rockwell hardness tester (Fuel Instruments and Engineers Pvt. Ltd.) determined the composite hardness [25] by penetration of the depth made by the indenter. The hardness was measured by a steel ball indenter with spherical diamond cone shape of diameter 1/16″ with 120° angle. The hardness was measured in Rockwell scale B.

The major benefits of Rockwell hardness test was its ability to display the hardness values directly and the calculation of hardness of the composites involved, i.e., shown in Table 1 due to the application of a minor load followed by a major load.

By adding higher weight percentage of silicon carbide in AMMCs, higher BHN values in the composites were found (Figures 5 and 6), which provide better hardness to the materials. Furthermore, the research will continue to find out different machinability aspects of the sintered products.

4.2. Density and Porosity Test. The calculation of sintered density was explained by application of the law, i.e., "rule of mixture" which is shown in Tables 2 and 3. The actual density of the composites was found out to be 2.597419 gm/cm^3 and 2.688894 gm/cm^3 in weight percentage of SiC 5% and 10%, respectively, which is less than the densities calculated from the rule of mixtures. It indicated that lower the density of composites leads to light weight of materials.

The density of sample-I (SiC 5 wt %):



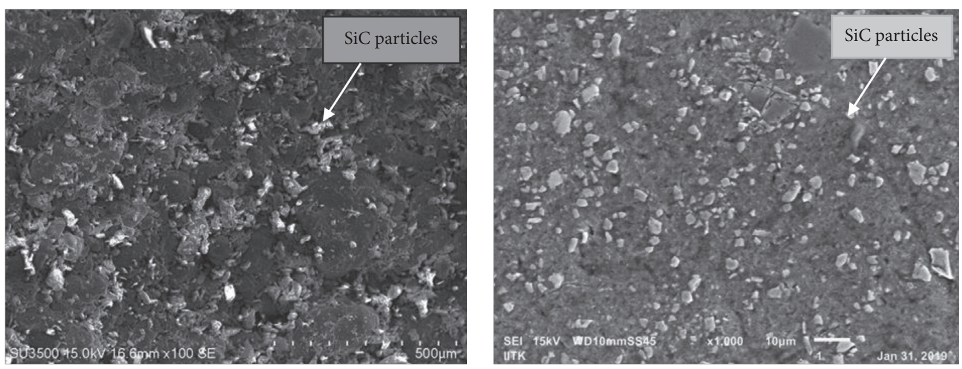
5% SiC in AMMCs

(a)

10% SiC in AMMCs

(b)

Figure 1: Microstructure of Al-composite with Cu, Si, Mg, and SiC.



5% SiC in AMMCs

(a)

10% SiC in AMMCs

(b)

Figure 2: Microstructure of Al-composite with Cu, Si, Mg, and SiC.

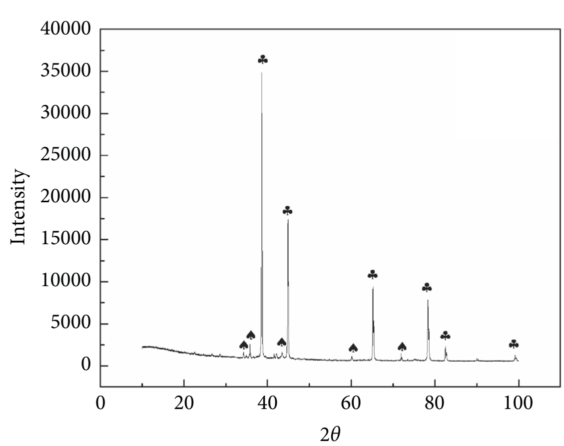


Figure 3: XRD pattern of Al composite with 5 weight % SiC.

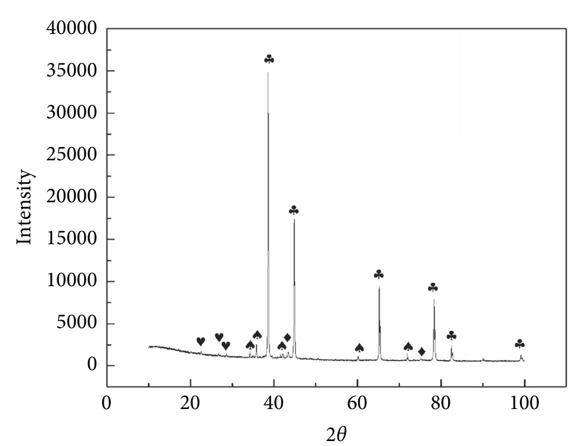


Figure 4: XRD pattern of Al composite with 10 weight % SiC.

Table 1: Samples of SiC reinforcement.

Sample nos.	Compacted samples (silicon carbide: 5 wt %) $x = SiC\ wt\%$	Hardness test (HRB)	Compacted samples (silicon carbide: 10 wt %) $x = SiC\ wt\%$	Hardness test (HRB)
1	5	46.0	10	52.0
2	5	46.5	10	51.5
3	5	46.0	10	51.5
4	5	47.0	10	52.5
5	5	46.5	10	51.5
6	5	46.0	10	52.0
7	5	46.5	10	51.5
8	5	46.5	10	52.0
9	5	47.0	10	53.0

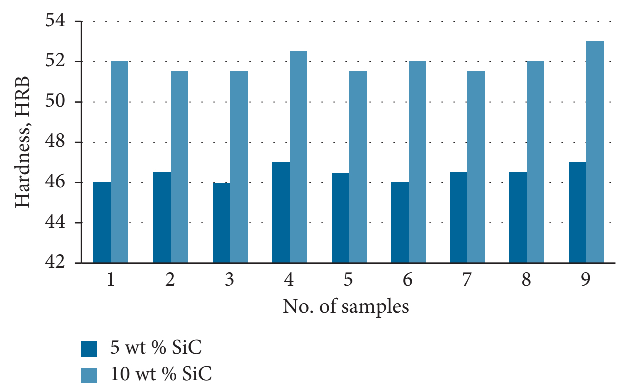


Figure 5: Samples vs. hardness.

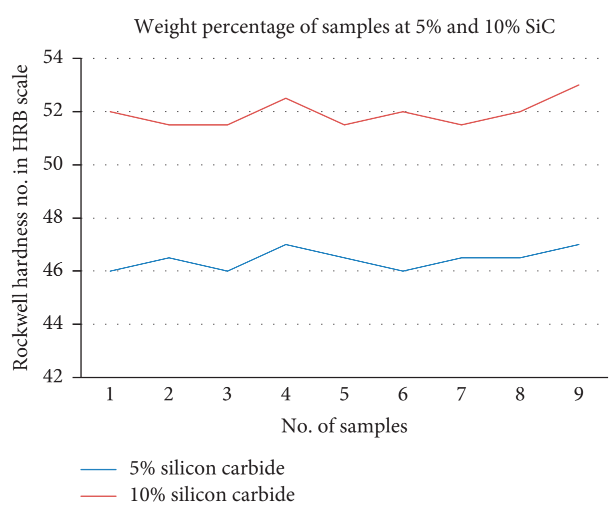


Figure 6: Samples at different compositions of SiC.

Table 2: Samples of 5% SiC reinforcement.

Raw metal powders	Atomic number	Density (ρ) in gm/cm^3	Weight percentages (%) in mixture (x)	Rule of mixture ($\rho \times x$) in gm/cm^3
Aluminium (Al)	13	2.70	91.5	2.4705
Copper (Cu)	29	8.96	2.5	0.224
Magnesium (Mg)	14	1.738	0.5	0.00869
Silicon (Si)	12	2.329	0.5	0.011648
Silicon carbide (SiC)	—	3.21	5	0.1605
Total			100	2.875338

Table 3: Samples of 10% SiC reinforcement.

Raw metal powders	Atomic number	Density (ρ) in gm/cm^3	Weight percentages (%) in mixture (x)	Rule of mixture ($\rho \times x$) in gm/cm^3
Aluminium (Al)	13	2.70	86.5	2.3355
Copper (Cu)	29	8.96	2.5	0.224
Magnesium (Mg)	14	1.738	0.5	0.00869
Silicon (Si)	12	2.329	0.5	0.011648
Silicon carbide (SiC)	—	3.21	10	0.321
Total			100	2.900838

$$\begin{aligned} D &= \text{Diameter of Sample} = 2.0\text{cm}, \\ R &= \text{Radius of Sample} = 1.0\text{cm}, \\ H &= \text{Height of Sample} = 7.5\text{cm}, \\ V &= \text{Total Volume of the Sample} = \pi r^2 H = \pi \times (1.0)^2 \times 7.3 = 22.942\text{cm}^3, \\ \text{So, Density of Sample}\,(\rho) &= \frac{\text{Mass}}{\text{Volume}} = \frac{59.59\text{gm}}{22.942\text{cm}^3} \\ &= 2.597419\text{gm/cm}^3. \end{aligned} \tag{1}$$

Porosity of sample-I (SiC 5 wt %):

$$\begin{aligned} \text{The theoretical density of the material} &= 2.875338\text{gm/cm}^3, \\ \text{Theactual/experimentaldensity of the material} &= 2.597419\text{gm/cm}^3, \end{aligned}$$

$$\text{Porosity} = \frac{\rho_{\text{(Theoretical)}} - \rho_{\text{(Experimental)}}}{\rho_{\text{(Theoretical)}}} \times 100 = \frac{2.875338 - 2.597419}{2.875338} \times 100 = 9.66\%. \tag{2}$$

The density of sample-II (SiC 10 wt %):

$$\begin{aligned} D &= \text{Diameter of Sample} = 2.0\text{cm}, \\ R &= \text{Radius of Sample} = 1.0\text{cm}, \\ H &= \text{Height of Sample} = 7.1\text{cm}, \\ V &= \text{Total Volume of the Sample} = \pi r^2 H = \pi \times (1.0)^2 \times 7.1 = 22.314\text{cm}^3, \\ \text{So, Density of Sample}\,(\rho) &= \frac{\text{Mass}}{\text{Volume}} = \frac{60.0\text{gm}}{22.314\text{cm}^3} = 2.688894\text{gm/cm}^3. \end{aligned} \tag{3}$$

Porosity of sample-II (SiC 10 wt %):

$$\text{The theoretical density of the material} = 2.900838\text{gm/cm}^3,$$

$$\text{Theactual/experimentaldensity of the material} = 2.688894\text{gm/cm}^3,$$

$$\text{Porosity} = \frac{\rho_{(\text{Theoretical})} - \rho_{(\text{Experimental})}}{\rho_{(\text{Theoretical})}} \times 100 = \frac{2.900838 - 2.688894}{2.900838} \times 100 = 7.306\%. \quad (4)$$

The abovementioned calculation shows that increasing of compaction pressure up to 521.02 MPa decreased the porosity and improved the tensile properties of the composites. If the compaction pressures decrease the percentage of the porosity and the density will decrease [26]. Also, it decreases the grain size of α-Al.

5. Conclusions

AMMC was prepared by metallurgical powdered technique which was a low-cost efficient method. The different mechanical properties of the aluminium composites were studied as the reinforcement particles obtained in the composites with proper ratios. Both industrial and academic researchers have displayed their interest in AMMCs because it had been observed due to following conclusions:

(1) Hardness of AMMC showed the best results when SiC was reinforced with 5 weight % and 10 weight % were maximum 47 and 53, respectively, in Rockwell HRB scale.

(2) Hardness increases with the increase in silicon carbide but decreases with the decreases in silicon carbide. To obtain an optimum hardness the reinforced material can be used in proper proportions.

(3) Reinforcing the matrix element with silicon carbide was found to be very negligible in pores when the mixture was done properly.

(4) Addition of Cu improves hardness, UTS, and reduces impact toughness of the composites.

(5) The AMMC provides the wear resistance due to addition of silicon.

(6) Wetability and light weight were found due to addition of magnesium in AMMC.

(7) Apart from the mechanical properties, the XRD pattern showed the matrix at different intensities where the interfacial bonding of the matrix directly affects the strength of the composite.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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