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Abstract

In the present study the effect of SiC amount on structural, physical and mechanical properties of Al matrix composite (AMCs) was investigated. Al6061 alloy and three composites were fabricated by powder metallurgy technique (0, 7.5, 10 and 13 wt.% of SiC). The prepared composites were characterized by X-ray diffraction, optical microscopy and Vickers hardness. Physical properties (Density) of the prepared Al6061-SiC composites were measured. The microstructures show a homogeneous distribution of SiC nanoparticles into the aluminium matrix. We have found a significant increase of hardness and density of the composites with the increase of silicon carbide quantity. However, it is noticed that the porosity of Al-SiC composites decreases with the increase of SiC amount.

Keywords: Al matrix composite (AMCs), silicon carbide SiC, powder metallurgy, properties of Al6061 Matrix.

1. Introduction

Metal matrix composites (MMCs) are combinations of two or more chemically non-reactive materials to form a new material system with enhanced material properties, in which titanium, aluminium and magnesium are popularly used as matrix metals and some non-metallic materials, commonly ceramics such as silicon carbide (SiC, aluminium oxide(Al2O3), graphite or fly ash may be used as reinforcing materials[1,2]. Advanced composites are replacing metal components in many uses such as aerospace industry and automobile applications (diesel engine pistons, piston rings, connecting rods, drive shafts, brake disc, etc). SiC is widely used due to physical and chemical compatibility with aluminium matrix in wide range of available grades [3,4]. The physical and mechanical properties of the aluminium based reinforced with ceramic particles are better than the properties of unreinforced materials, because thermal expansion, thermal diffusivity, tensile and compressive behaviour, creep, and tribological behaviour are improved [5].

Aluminium Metal Matrix Composites (AMMCs) are fabricated by liquid state fabrication methods (Stir casting, compo-casting, squeeze casting, spray casting and in-situ (reactive) processing, solid state fabrication methods (Powder Metallurgy, friction stir processing, diffusion bonding, and vapour deposition technique) and deposition processes. To fabricate AMCs, among the various manufacturing technologies powder metallurgy is one the most advantageous techniques to fabricate isotropic distribution of particles in matrix, good dimensional accuracy, complex, net shape lightweight components can be produced cost effectively. [2,6] Powder Metallurgy is a material processing technique in which particulate materials are consolidated to semi-finished and finished products. It consists of blending of powders, compacting of powders in a die and sintering [7].

Sattari et al. [8] have studied the effect of volume fraction of reinforcement and milling time on the microstructure, relative density, hardness, and compressive strength of reinforced aluminium alloy. The Al7075 and SiC powders were mixed by a planetary ball mill. They reported that with increasing milling time and volume fraction of the reinforcement phase, the hardness and compressive strength increased. Habibur et al. [9] investigated the microstructures, mechanical properties, and wear characteristics of as-cast reinforced aluminum matrix composites with various SiC content. They reported that introducing SiC reinforcements in aluminum matrix increases hardness, tensile strength and wear resistance. However, high incorporation in matrix of the SiC particles induces clustering and non-homogeneous distribution of SiC particles, as well as porosities

The objective of the present investigation is to fabricate by powder metallurgy route three different aluminium composite reinforced with different SiC amount: 7.5, 10, and 13 wt. % of SiCp. Microstructure, hardness, density, and porosity are studied.

2. Experimental procedure

2.1. Materials

Al6061 alloy with average size 63 um as matrix material and SiC with average size 50 nm is used as reinforcement material in the preparation of composites. The chemical composition of matrix material is shown in Table 1. The Al6061 and SiC powders were supplied by good fellow Cambridge limited Huntington PE29 WR, England.

Table 1. Chemical composition of matrix alloy Al6061.

Elements	Al	Si	Fe	Cu	Mg
(Wt. %)	97,5	0,6	0,5	0,4	1.0

2.2. Preparation methods

Three different composites with: 7.5, 10 and 13 wt. % of SiC were prepared by powder metallurgy. The Al6061 and SiC powders were mixed by a planetary ball mill for 2 h, with milling speed of 300 rpm in order to get a homogenous mixture. The powders were compacted under 10 tonne uniaxially in cylindrical mould with compacting machine named HERZOG. Zinc stearate (ZnO) was used in compacting process for easy removal of green compact specimen. Then, the samples were sintered at 600°C in sintering furnace (primary vacuum) at a rate of heating up to 4oC /min, equipped with argon and hydrogen gas.

2.2. Characterization methods

Microstructures of the composites were observed to reveal the distribution of SiC particles in Al matrix. The sintered samples were polished in automatic polishing machine (STRUER) by using emery papers of different grades. Then the samples were etched with HF reagent and examined under a digital HIROX Kh-8700 microscope, equipped with display screen. The phase analysis was conducted using X-ray diffractometer Siemens model (BRUKER D-5000) with Cu Kαradiation, in 2θ range from 10° to 90°. For microstructural observations and chemical analysis, a scanning electron microscope (SEM HITACHI SU8020 model) equipped with an energy dispersion spectrometer (EDS) with a high resolution was used.

Theoretical density was calculated by applying the rule of mixtures according to the weight fraction of reinforcement. The experimental density was measured using Archimedes principle according to Eq (1). and % of porosity was determined using Eq. (2).

$$\rho_e = \frac{w_a}{w_a - w_a} \quad (1)$$

$$P = \left[1 - \frac{\rho_e}{\rho_t}\right] * 100 \quad (2)$$

Where ρt and ρe are theoretical and experimental (measured) densities of the composite respectively, wa is the mass of the cylindrical sample in air, ww is the mass sample in water. The sample was weighed using a digital balance with an accuracy of 0.1 mg and P is percentage of porosity in the composites.

Mechanical characterisation tests consisted of hardness measurements by using a Vickers tester (EMCO-M4U025) under an applied load of 5kg.

3. Results and discussion

3.1. Microstructure observations

Figure 1 shows the microstructures of Al6061 and Al-SiCp composites with 7.5, 10, and 13wt. % SiC. Micrographs indicate the nearly uniform distribution of the SiCp particles in the aluminum matrix and no clustering of SiC particles was observed in the matrix. This enhances the properties of the composites. A similar result is achieved by Kumar et al.[10].

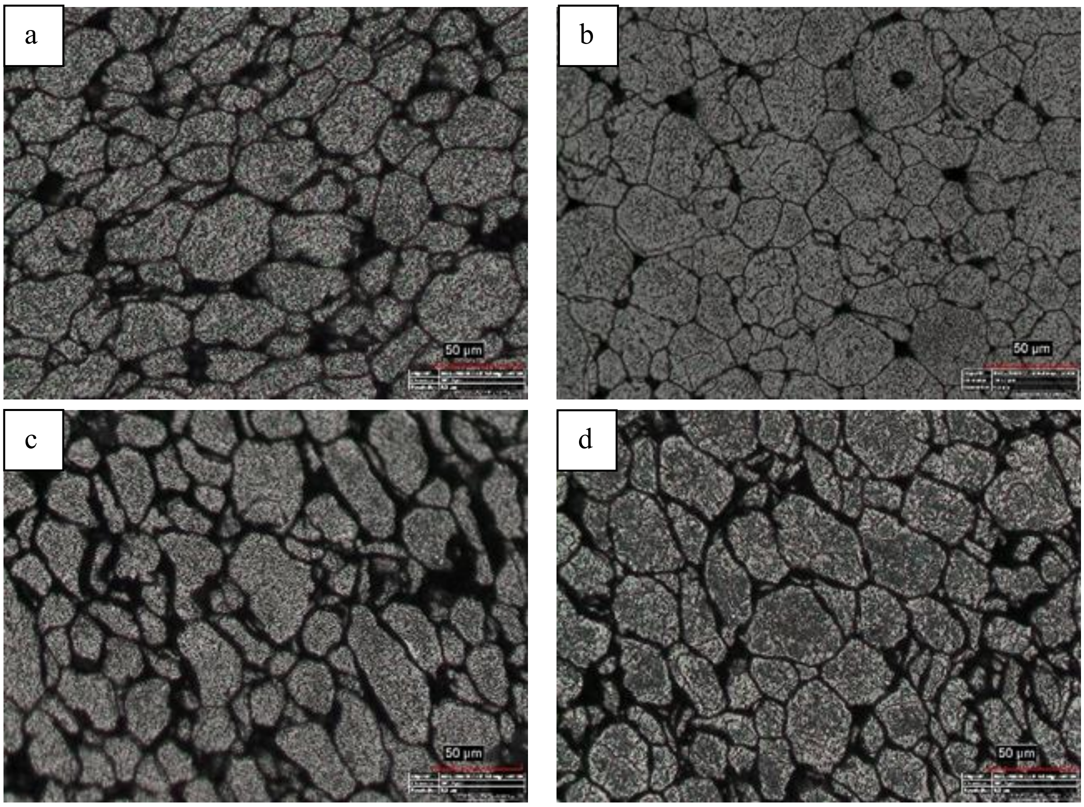

Fig. 1. Microstructures of Al6061 and its composites: a: Al6061, b: 7.5 wt. % SiC, 10 wt. %, and c: 13 wt. %. SiC

3.2 X-ray diffraction

X-ray diffraction patterns of aluminum composite reinforced with different SiC amount and sintered at 600°C are shown in Figure 2. The XRD results reveal that the main elements present in the developed composites are Al (largest peak) and SiC (shorter peak). The intensities of SiC peaks increase with increasing wt .% of SiC nanoparticles. In addition, all XRD patterns did not reveal any presence of secondary phases. Our result is in agreement with the work of M. Penchal Reddy [10], because they found that during the sintering process of the aluminum composite reinforced with different SiC amount, no solid-state reaction took place between the matrix and reinforcement to form any other undesired phases.

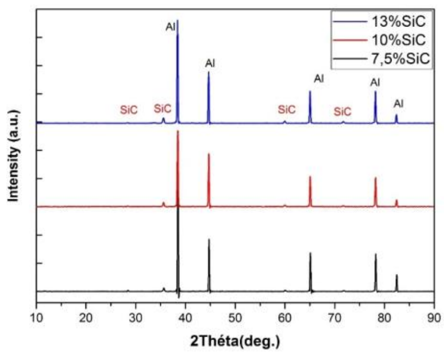

Fig. 2. XRD patterns of sintered aluminum composite reinforced with different SiC amount.

3.3 Hardness

The variation of the Vickers hardness of the composite as a function of SiC amount is presented in Figure 3. It is clear that with increasing SiC amount, hardness of the composite increases. The highest value of hardness was obtained for sample reinforced with 13 wt.% SiC due to the stiffness of the matrix material. The incorporation of particles in the matrix results in an increase in work hardening because of the lower matrix volume. It has been reported that the mechanical behavior of the composite is also very much dependent on the relationship between particle/ matrix interface strength and particle strength. [12]. The increase in hardness is to be expected, since SiC particles being a hard dispersoid positively contribute to the hardness of the composite. Increased content of reinforcement in the matrix alloy leads to higher dislocation densities during solidification due to the thermal mismatch of the matrix alloy and the reinforcement. Enhancement in dislocation densities results in higher resistance to plastic deformation and responsible for additional increase in hardness of composites. [13]

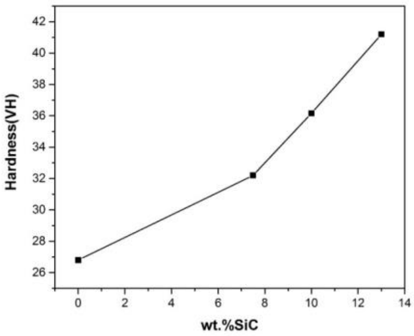

Fig. 3. Vicker's hardness curve of composites with various wt.% of SiC reinforcement.

3.4 Density and porosity

The measured density value by experimental and theoretical density for composites are compared and presented in Figure 4. The density of the base metal (Al6061) is relatively low comparing to addition of reinforced composites. Density increases by increasing the percentage of SiC reinforcement material in Al6061matrix; while the porosity decrease (Fig.5). From Figure 4 it can clearly seen that experimental and theoretical density values are not much more differences and this confirms the suitability of powder metallurgy process for composite preparation.

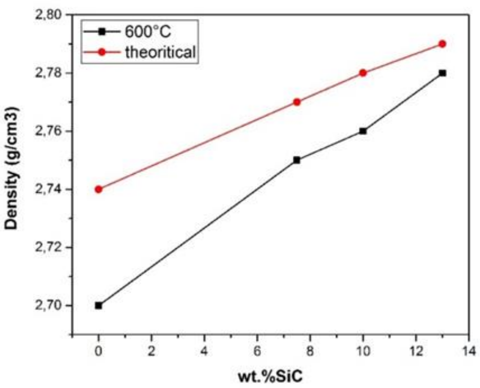

Fig.4. The changes in experimental and theoretical density of the material with percentage of SiC.

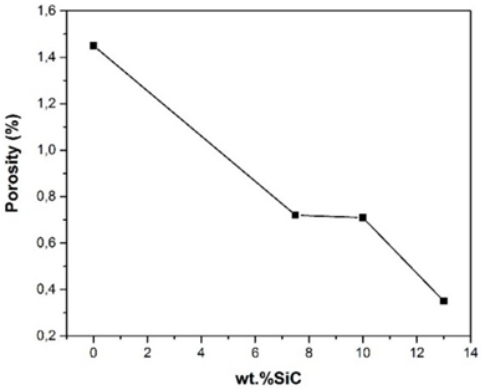

Fig. 5. The variation of porosity with wt.% of SiC reinforcement

4. Conclusion

In this paper, Al6061 alloy and three composites were fabricated by powder metallurgy technique (0, 7.5, 10 and 13 wt.% of SiC). The results reveal following conclusions:

- The Al6061–SiC composite was successfully fabricated by powder metallurgy process
- The microstructural observations revealed a uniform distribution of reinforcing particulates in the aluminum matrix
- The presence of SiC in matrix was verified by XRD analysis
- The hardness of the composite increased with increasing SiC amount.
- Increasing SiC amount in the Al matrix, leads to increase of the density and the decrease of the porosity of the composite.

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