Silicon Carbide Effect as Reinforcement on Aluminium Metal Matrix Composite

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Summary: In the present study aluminium silicon carbide (Al/SiC) composites were prepared by powder metallurgical method. The mechanical and morphological evaluation were studied upon the variation of reinforcements percentages i.e.10, 15 and 20 wt.% of SiC powder were used as the reinforcements in aluminium matrix. The comparison of powder metallurgy method with stir casting method of Al/ (SiC) composites preparation was performed and the particle reinforcements were visualized through Scanning Electron Microscopy (SEM). The results demonstrated increased hardness with increasing wt. % of SiC particles. This was attributed to efficient stress transfer and dislocation strengthening. In addition, the densification behaviour of the composites was also studied and SiC particulates were found to exhibit profound effect on composites density.

Keywords: Powder Metallurgy; Metal Matrix Composite (MMC); Aluminium (Al); Silicon Carbide (SiC); Scanning Electron Microscope (SEM).

Introduction

Composites are not alone used for their physical properties, but also for thermal and wear applications. Advanced composite materials that are currently used worldwide employ a mixture of properties to achieve certain requirements for a given image of applications [1]. Metal matrix composites (MMCs) are basically engineered combinations of the metal (matrix) and reinforcement (hard particle/ceramic or else) to get tailored properties [2], they can provide higher tensile and fatigue bounds than their base metal counterparts and they can be customized to raise stiffness and strength. In an MMC, the matrix phase is usually a low-density nonferrous alloy i.e. monolithic alloy whereas the reinforcement involves metallic, high-performance carbon or ceramic additions [1].

The efforts to produce attractive MMC components have resulted in several innovative manufacturing techniques currently being employed in the manufacturing industry [3]. In general, the following two crucial types are possible (i) Pyro-metallurgical processes and (ii) Powder metallurgical processes [4]. The powder metallurgy method is highly efficient which provides rapid and high volume production of precision components [5]. It is widely used for the preparation of aluminium metal matrix composites due to its low processing temperature, which is beneficial for mitigating a harmful interface reaction [6]. Great precision is offered by powder metallurgy as it eliminates almost all of the finishing operations that are required generally after castings [5]. Low density combined with high strength, various production processes and considerable improvement in strength after heat treatment signifies the high demand of aluminium based MMC reinforced with particles, whiskers or fibres [7].

In recent past research has been carried out to incorporate the silicon carbide on aluminium and its alloys to improve their mechanical and tribological properties. Significant amount of work has been carried out by preparation of composites through stir casting route [8-11]. Silicon carbide particulates have proven to increase mechanical strength of aluminium and its alloys with increasing content and reduced particle size [12]. As preparation of Al-SiC reinforced MMCs through stir casting is reported to be problematic such as it yields undesirable reactions, dissolution of gases and difference in densities and thermal expansion coefficient that causes low wettability [5]. Thus, preparation of Al-SiC MMCs by powder metallurgy route is well documented and appropriate method. For example, powder metallurgical method is suitable for low wettability of the reinforcement phase by the molten metal [13]. Moreover, several studies could be found on preparation [14, 15] and optimization of process parameters for synthesis of Al-SiC MMCs using powder metallurgy technique [16]. Thus, the area remains an active field for research since lot more work need to be done in for optimal synthesis of Al-SiC MMCs. Therefore, present contribution is to develop an understanding of effects of the SiC in an aluminium metal matrix produced by powder metallurgy.

Experimental

The aluminium and SiC powder of mesh size 300 & 75 microns respectively were purchased

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from F.S Corporation Lahore. Aluminium powder used as a matrix has following composition; 98 wt. % aluminium with the minor elements such as Si, Zn and Fe.

Experimental procedure for this study involved the formation of composite samples. Four tablets samples having diameter of 20mm were prepared, one of which was of pure aluminium powder, while remaining 3 composite samples were reinforced with different wt.% of Silicon carbide (SiC), the table below comprises the details:

Table-1: Shows samples classification according to different weight fraction of reinforcements.

Name of constituent	Wt.%	Sample ID
Aluminium	90	A
Silicon Carbide	10	
Aluminium	85	B
Silicon Carbide	15	
Aluminium	80	C
Silicon Carbide	20	

Powders were initially sieved according to ASTM B 214-99 on mechanical sieve shaker to get appropriate small particle size as smaller particles has a larger pore/solid interfacial area which results in an increased driving force for sintering [5]. Silicon carbide and aluminium powders were heated inside vacuum to 120°c for 2 hours to remove any moisture and then mixed in assigned weight ratios, 0.5wt% of magnesium was added to each mix because magnesium serves as a sintering aid while sintering aluminium [17]. The powders were then ball milled under nitrogen atmosphere at 350 rpm for 6 hours, compacted on uniaxial compaction machine under 40MPa load and sintered under Nitrogen environment at 630°C for 6 hours. Precipitation hardening treatment was performed afterwards which includes heating to 500°C for 1 hour, followed by quenching and then artificial aging at 200°C for 8 hours to improve the overall properties of the composites [18].

Fig. 1: Showing prepared composites samples after sintering and Heat treatment. It can be seen that only a slight variation in diameter is observed after sintering and the samples have diameters around 18-19 mm contrary to 20 mm initial diameter.

Density measurements were carried out according to ASTM B962-15 standard procedure which is primarily based upon Archimedes method of density measurements. For measuring the green density of the composite tablets, the tablets were first weighted in air in grams (mass A), and oil impregnated with Silicon oil for 4 hours at 85°C afterwards to close surface pores. After immersion and cooling to room temperature excess oil is wiped out through lint free cloth and the mass of the samples after oil impregnation was calculated in grams (mass B). Samples were weighted in water subsequently and deionized water was used at room temperature around 28-32°C. The density of the sample was calculated by using equation 1;

$$D_g = \frac{A\rho_W}{B - F} \quad (1)$$

Here, D_g = Density of sample, A = the mass of the green part or test piece in air in grams, B = the mass of the oil-impregnated green part or test piece, F = the mass of the oil-impregnated part/test specimen in water with the mass of the specimen support teared, ρ_w = the density of the water, g/cm^3.

Hardness was found out using Vickers Hardness tester at a load of 3Kg and the dwell time was 10 seconds. The porosity content of the composites was also evaluated by using equation 2.

$$E = 1 - \left(\frac{\rho s}{\rho t}\right) \quad (2)$$

where E= porosity (%), ρt = theoretical density (kg/m^3), ρs= actual density (kg/m^3) found out using Archimedes method.

Results and Discussion

Density

Density measurements of the prepared composites were carried out under ASTM B962-15 standard test method. A significant change between un-sintered and sintered densities was observed with the addition of SiC particles and the trend continues with the increasing wt.% of SiC, it was attributed to shrinkage of pores during sintering [18]. The increase in density with the additions of hard reinforcement particles such as Silicon carbide (SiC) has been evident in figure 2 as the maximum density of 2.4 g/cm^3 was observed with addition of 20wt% of Silicon carbide (SiC).

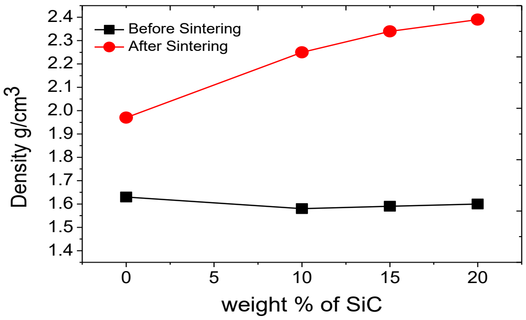

Fig. 2: Shows relationship between sintered and un-sintered densities of prepared composites.

Hardness

Hardness of the AL-SiC composites increased with increasing wt.% of SiC particles, it is due to the presence of well bonded SiC particles in Aluminium matrix that are hard in nature which causes the movement of dislocations to hinder resulting in increased hardness of composite [19]. Since the SiC particulates are hard in nature thereby resulting in resistance to the applied load causing pinning effect or dislocations pileup and ultimately enhanced hardness. The maximum value of 51 HV-3 is observed with the sample that has been reinforced with 20wt% of Silicon carbide (SiC) which shows that Silicon carbide (SiC) is beneficial in increasing the hardness of Aluminium based metal matrix composites.

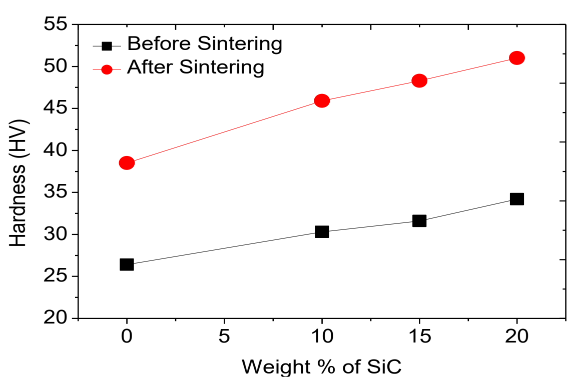

Fig. 3: Relationships between un-sintered and sintered HV3 hardness.

In addition to this these hardness values were compared with Silicon carbide (SiC) reinforced Aluminium composites through literature available and it was found that powder metallurgy method has more profound effect on the hardness as compared to stir casting method of composite preparation.

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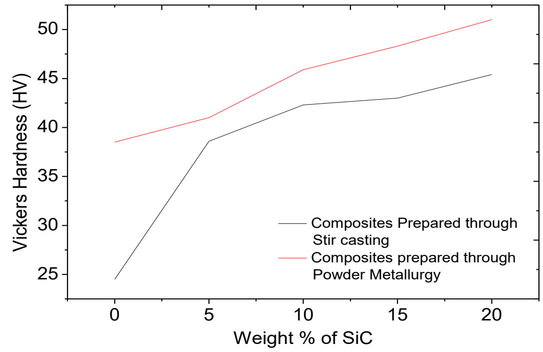

Fig. 5: Comparison between Vickers hardness achieved with composites prepared from powder metallurgy and stir casting method, the hardness values for stir casting are taken from literature [19].

Porosity Content

Parts produced by powder metallurgy exhibit some porosity which cannot be neglected and same was observed in Al-SiC composites produced in this study as shown in Table-2. It appears very clear from the table that the porosity content was significantly reduced after sintering. The major reduction in porosity was obtained with 20wt% reinforcement. This is attributed to settling of small particles into interstitial sites.

Table-2: Table showing porosity content in un-sintered and sintered Al-SiC composites.

Sample condition	Porosity Content			
	Pure Aluminium	10wt%	15 wt.%	20wt%
Un sintered	40.07	42.35	42.39	42.44
Sintered	18.38	17.88	15.21	14.02

SEM analysis

Reinforcements distribution inside the matrix are essential to the final properties of composites prepared through powder metallurgy, to investigate distribution of reinforcements on composites SEM analysis was performed and it showed that particles were homogenously distributed, and porosity was reduced considerably after sintering. The mark difference between the un-sintered and sintered micrographs is the reduced porosity in later. The morphology observed by the incorporation of SiC particles exhibits irregularly shaped grains and while after sintering the particles exhibited agglomeration this was attributed to the liquid phase sintering due to addition of magnesium (Mg) as a sintering aid.

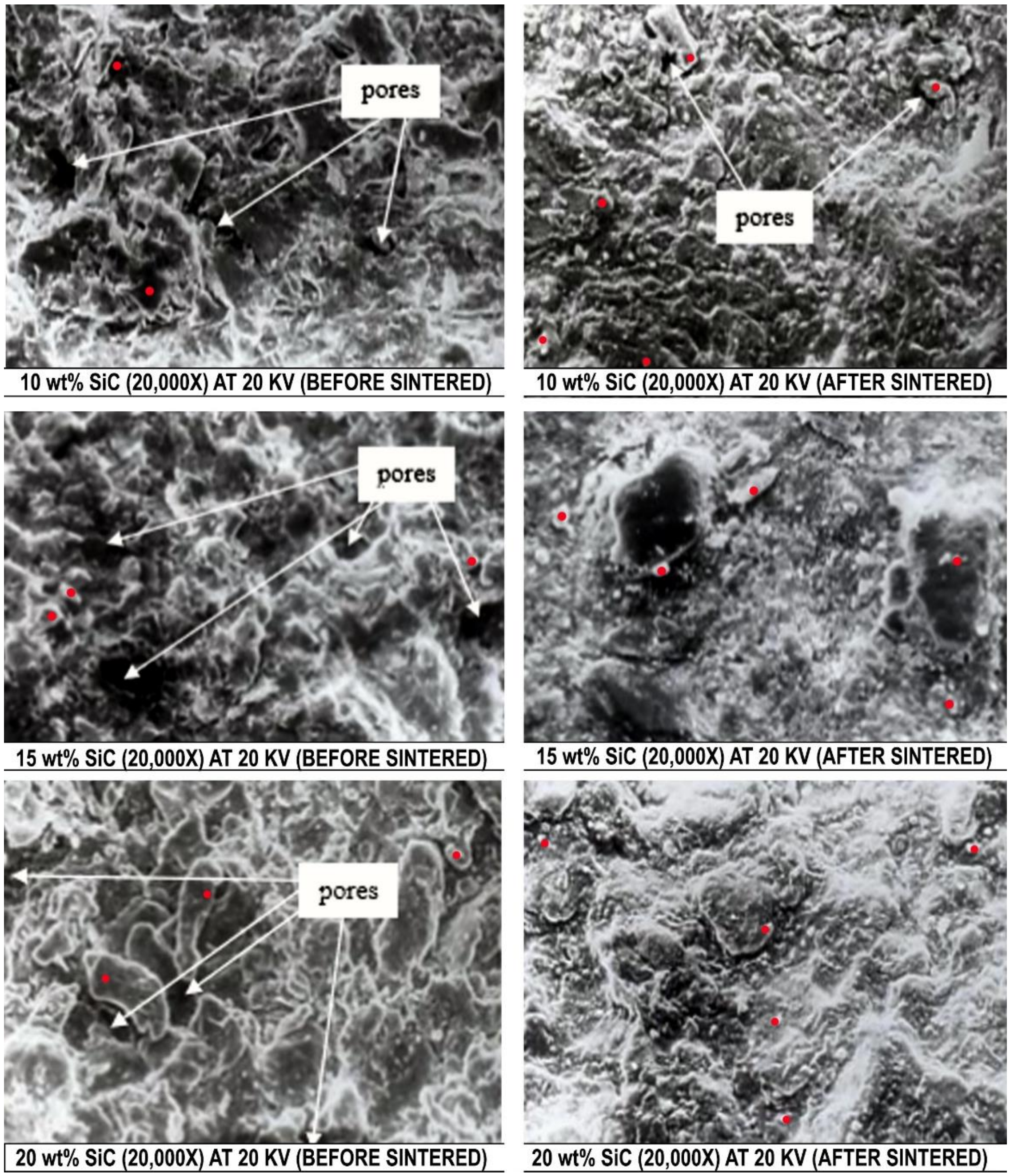

Fig. 4: Showing SEM micrographs of Al-SiC reinforced MMCs. The SiC particles are highlighted with red dots to show their appearance.

Conclusions

Knowing the invaluable impact of mechanical alloying on properties of aluminium matrix composites and keeping in mind the draw backs of preparing Al-Silicon carbide MMCs through stir casting method, Al–SiC metal matrix composite was produced by powder metallurgy and the effects of silicon carbide as a reinforcement was studied. The following are the concluding remarks based on present experimental conditions.

- The results of stir casting and powder metallurgical route were compared wherein later exhibited improved properties.
- Mechanical alloying of aluminium and silicon carbide powders for 6 hours by milling results in fine and homogeneous

mixture of Al-SiC composite at sintering temperature of 630ºC.

- Moreover, magnesium (0.5 wt. %) was used as sintering aid which resulted in bond formation subsequently enhanced densification was observed. One of the major impacts of SiC addition was increased hardness.

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