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Processing and mechanical properties of aluminium-silicon carbide metal matrix composites

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Abstract. In this study, aluminium-silicon carbide (Al-SiC) metal matrix composites (MMCs) of different compositions were prepared under different compaction loads. Three different types Al-SiC composite specimens having 10%, 20% and 30% volume fractions of silicon carbide were fabricated using conventional powder metallurgy (PM) route. The specimens of different compositions were prepared under different compaction loads 10 ton and 15 ton. The effect of volume fraction of SiC particulates and compaction load on the properties of Al/SiC composites were investigated. The obtained results show that density and hardness of the composites are greatly influenced by volume fraction of silicon carbide particulates. Results also show that density, hardness and microstructure of Al-SiC composites are significantly influenced depending on the compaction load. The increase in the volume fraction of SiC enhances the density and hardness of the Al/SiC composites. For 15 ton compaction load, the composites show increased density and hardness as well as improved microstructure than the composites prepared under 10 ton compaction load. Furthermore, optical micrographs reveal that SiC particulates are uniformly distributed in the Al matrix.

1. Introduction

In recent times, there is an increasing demand for developing advanced engineering materials which are multi-functional and these materials are gaining popularity for high performance applications. Metal matrix composites (MMC) are new generation engineering materials to fulfil multiple functions in many engineering fields and substantial progress in the development of metal matrix composites has been achieved so that these composites can be used for high performance structures such as in aerospace, automotive and armor industries [1,2]. The desired properties of metal (ductility and toughness) and ceramics (high hardness, high strength and high modulus) are combined in the metal matrix composites production, leading to greater strength in compression and shear as well as higher service temperature capabilities. Nowadays, aluminium based metal matrix composites are very popular due to high modulus, stiffness, strength-to-weight ratio, corrosion and wear resistance. These composites exhibit better mechanical properties over conventional metals/alloys [3,4].

Aluminium alloy-alumina silicate particulate composites exhibited longer fatigue lives than the unreinforced aluminium alloy in lower stress state but showed reduced fatigue lives at elevated stress state regardless of their reinforcement fractions [5]. Wear and friction behavior of sand cast brake rotor made of A359-20 vol% SiC particle composites sliding against automobile friction material were

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investigated [6]. Results showed that the wear resistance of the composites is much related to the hardness and strength of the SiC particles. Microstructure and properties of aluminium based metal matrix composites reinforced with ZnO whiskers were investigated [7]. Microstructure and thermal conductivity of aluminium oxide particulate reinforced aluminium composites were investigated [8] and it was found that the thermal conductivity of the composites was significantly influenced by the aluminium oxide volume fraction.

In the present study, aluminium-silicon carbide composites containing 10%, 20% and 30% volume fractions of silicon carbide particulates were prepared under different compaction loads 10 ton and 15 ton. The effects of volume fraction of SiC particulates and compaction load on the properties of Al/SiC composites were investigated. The properties such as density, hardness and microstructure of the composites were analyzed.

2. Experimental

Aluminium/silicon carbide (Al/SiC) composite specimens of different compositions were prepared using conventional powder metallurgy (PM) route. Aluminium powders were used as matrix material and silicon carbide particulates were used as reinforcement. In the composition, 10%, 20% and 30% volume fractions of silicon carbide powder materials were added to 90%, 80% and 70% volume fractions of aluminium powder respectively to prepare three types of composites. In processing the specimens, the main three steps are blending, compacting and sintering. At first, the weights of aluminium and silicon carbide powders were measured based on their molecular weight. After mixing and blending of the powders, a good homogeneous mixture was achieved, so that SiC particulates were uniformly distributed into the aluminium matrix. Different compositions of mixed Al/SiC powders were cold compacted in a cylindrical steel die. After that, the powders were pressed at room temperature using a hydraulic press machine (TOYO: Model TL30, capacity 30 Ton). The specimens of three different compositions were prepared under different compaction loads 10 ton and 15 ton. The cohesive strength of these green compact specimens is very low and these green compacts are very fragile. The green compact specimens were then sintered using a sintering furnace (Nabertherm: Made in Germany). During sintering process, two cycles of heating were applied. In the first cycle, with a heating rate of 5^{o}C/min, the temperature reached to 400^{o}C and a holding time of 30 minutes was maintained. In the second cycle, with a heating rate of 5^{o}C/min, the temperature reached to 500^{o}C and a holding time of one hour was maintained. After that, the specimens were allowed to cool in the sintering furnace to reach the normal room temperature. After the sintering process, all the specimens were prepared for characterization and hardness testing. Microstructural analyses of the samples were carried out using a metallurgical microscope (OLYMPUS BX51M, Made in Japan). Vickers hardness measurements of the samples were carried out using microvickers hardness tester (Wilson Hardness: Model 402 MVD, Made in USA). Standard test method was followed according to ASTM E384 standard for the microvickers hardness testing of the specimens. The specimens were cut along the transverse direction. Then the specimens were prepared for cold mounting. Vickers hardness (HV) was measured under test load of 300 gf (2.94 N) along the longitudinal axis of the test specimen. For each test specimen, 10 measurements were made with an interval of about 1 mm to avoid any effect by the neighboring indentations. For each test specimen, the differences in the measured vickers hardness (HV) values were very small and the average value of these hardness measurements was taken into consideration.

3. Results and discussion

Figure 1 shows the density variations of different percentage compositions of aluminium/silicon carbide composite specimens before and after the sintering. These specimens were prepared using 10 ton compaction load. The measured density variations are shown for 10%, 20% and 30% volume fractions of silicon carbide in the composites. Before the sintering process, aluminium-silicon carbide composites containing 10, 20 and 30 vol.% of SiC particulates exhibited densities 1.95, 2.14 and 2.23 g/cm^3 respectively. On the other hand, after the sintering process, aluminium-silicon carbide composites containing 10, 20 and 30 vol. % of SiC particulates exhibited densities 2.02, 2.2 and 2.29 g/cm^3 respectively. It is apparent that with the increase in SiC particulate volume fraction, the density of the composite increases. It has been found that after the sintering, the density of the composites increases 3.6, 2.8 and 2.7% due to the content of SiC particulate volume fraction 10, 20 and 30% respectively.

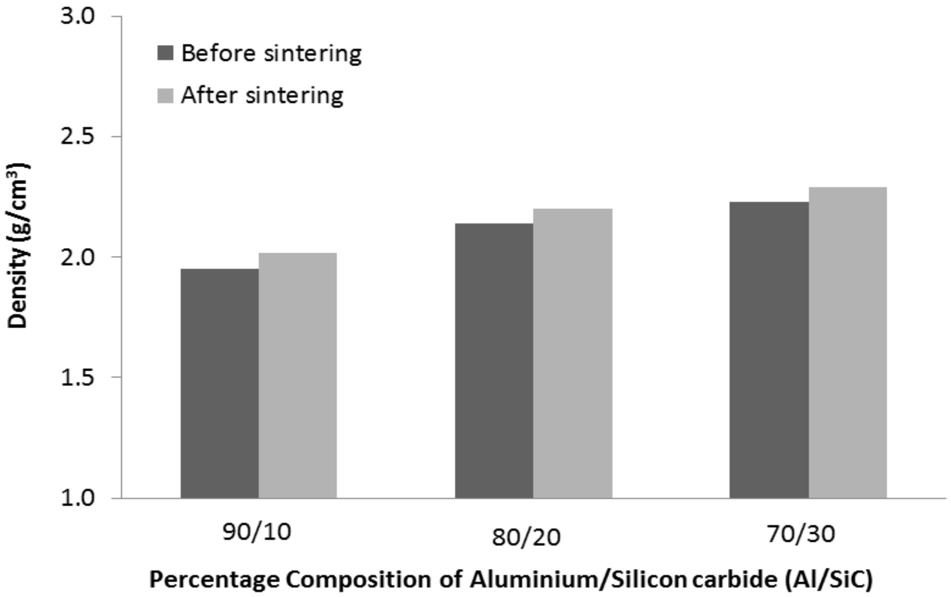

Figure 1. Density variations for different percentage compositions of aluminium/silicon carbide composites before and after sintering (Compaction load: 10 ton)

Figure 2 exhibits the density variations of different percentage compositions of aluminium/silicon carbide composites before and after the sintering. In this case, all the specimens were prepared using 15 ton compaction load. Before the sintering process, the measured densities of aluminium-silicon carbide composites containing 10, 20 and 30 vol. % of SiC particulates are 2.17, 2.21 and 2.28 g/cm^3 respectively. After the sintering process, the measured densities of the composites are 2.23, 2.26 and 2.33 g/cm^3 for the 10, 20 and 30 vol.% of SiC particulate contents respectively. The effect of SiC particulate volume fraction on the density variations are studied and the density increases 2.7, 2.3 and 2.2% for the 10, 20 and 30 vol.% of SiC respectively which means that increased SiC reinforcements enhance the density of the composites. As a comparison, it can be observed that the densities of the composites are higher for 15 ton compaction load than the densities obtained for 10 ton compaction load. Furthermore, comparing these results with the results obtained for 10 ton compaction load (figure 1), it can be seen that in this case (figure 2), after the sintering process the percentage increase in the density of the composites somewhat less than that of the sintered Al/SiC composites prepared under 10 ton load and containing three different volume fractions of SiC.

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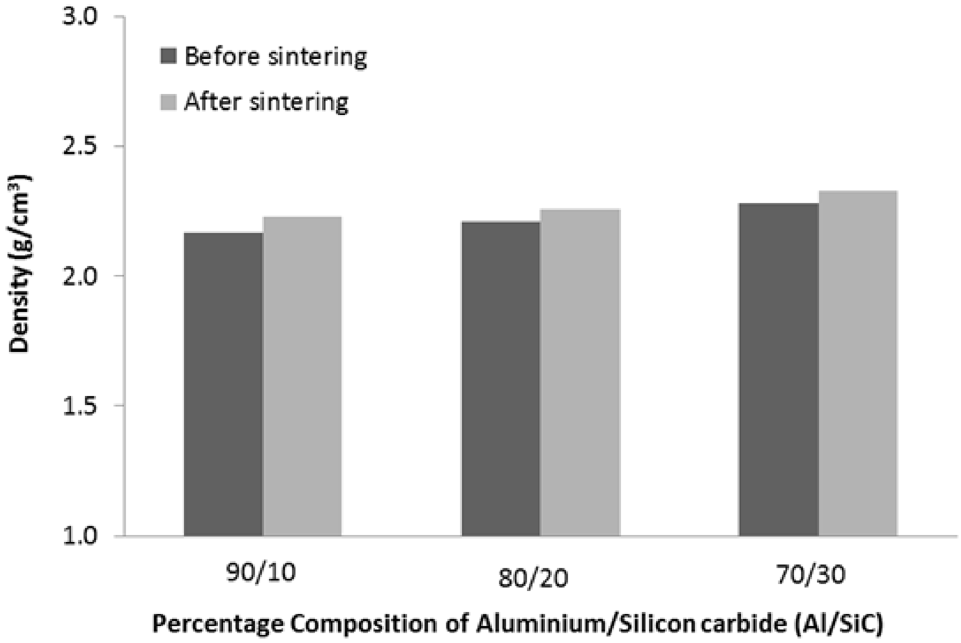


Figure 2. Density variations for different percentage compositions of aluminium/silicon carbide composites before and after sintering (Compaction load: 15 ton)

Figure 3 shows the hardness variations of different percentage compositions of aluminium/silicon carbide composites. These composites were prepared using the compaction load 10 ton. Microvickers hardness testing was carried out under a test load of 300 gf (2.94 N) for all the Al/SiC composite specimens containing 10, 20 and 30% volume fractions of silicon carbide. The hardness measurements were made along the depth of the specimen and the measured average values of vickers hardness of the composites are 20.8, 22.2 and 23.7 HV for the 10, 20 and 30 vol.% of SiC particulates respectively. From the figure it can be observed that the increase in the volume fraction of SiC reinforcement results in an increase in the hardness of Al/SiC composites. Furthermore, it is found that the increase in average hardness of the composite is about 6.7% and 13.9% for the 10% and 20% increase in the SiC volume fraction.

The effect of SiC particulate volume fraction on the hardness variations of the composites is also shown in figure 4. These composites were prepared using the compaction load 15 ton. The measured average values of vickers hardness of the composites are 21.7, 22.9 and 24.9 HV for the 10, 20 and 30 vol.% of SiC particulates respectively. It is found that the average hardness increased by 5.5% and 14.7% for the 10% and 20% increase in the SiC volume fraction. It is believed that the improvement in the hardness of the Al/SiC composite, observed in the present investigation is due to the high hardness of SiC and a strong interfacial bonding between the Al matrix and SiC particulates. When these hardness results are compared with the results obtained for 10 ton compaction load (figure 3), it is very clear that in this case (figure 4), due to the higher compaction load, the average hardness of Al/SiC composites of all the compositions is somewhat higher than the average hardness of the composites prepared under 10 ton compaction load.

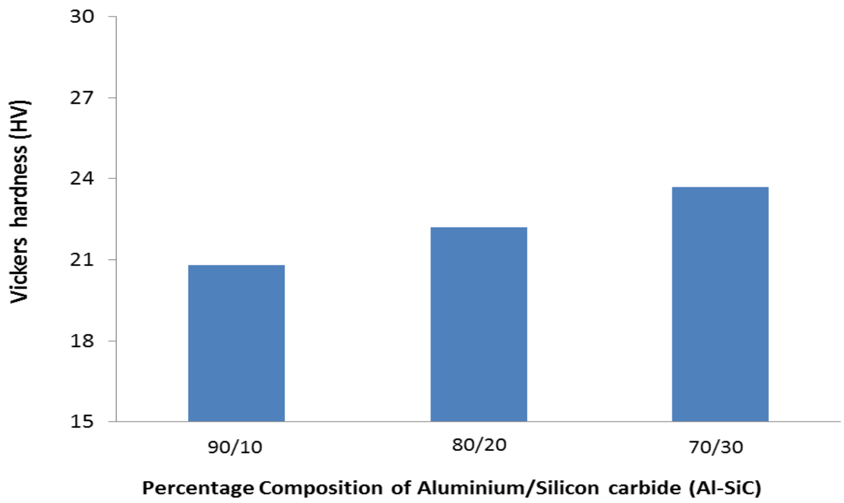


Figure 3. Hardness variations for different percentage compositions of aluminium/silicon carbide composites (Compaction load: 10 ton)

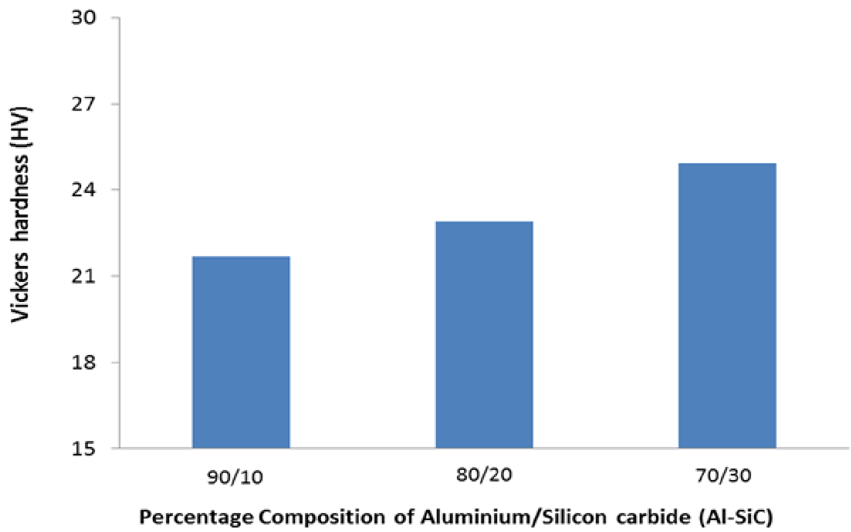
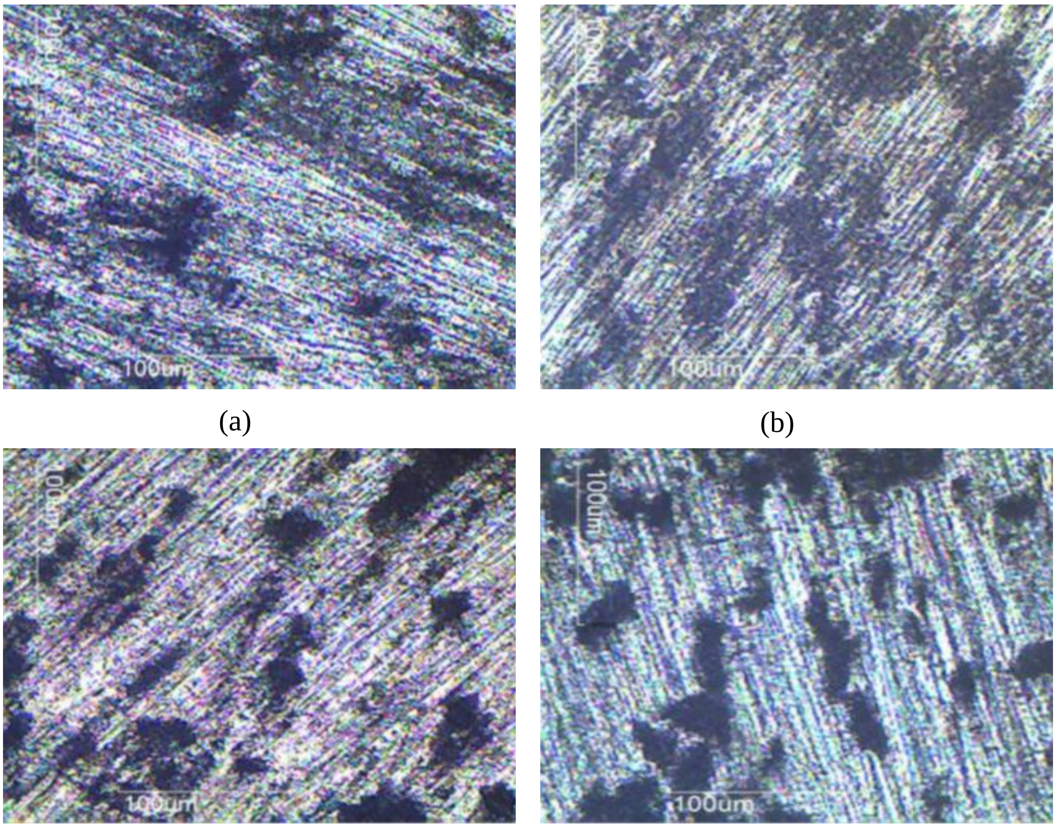


Figure 4. Hardness variations for different percentage compositions of aluminium/silicon carbide composites (Compaction load: 15 ton)

Figures 5(a)-(d) show the photomicrographs of Al/SiC composites of different compositions. Figure 5(a) shows the micrograph of 90%Al-10%SiC composite prepared under 10 ton compaction load. In the micrograph, the whitish part is the aluminium matrix and the blackish part is the SiC particles. The micrograph shows reasonably uniform distribution of SiC particles in the aluminium matrix, but in qualitative measurement or the sharpness of the microstructure is not good enough. Figure 5(b) shows the micrograph of 80%Al-20%SiC composite prepared under 10 ton compaction load. The micrograph shows the SiC particles are distributed uniformly in the Al matrix but the sharpness of the microstructure is poor. Figure 5(c) shows the micrograph of 80%Al-20%SiC composite prepared under 15 ton compaction load. From the micrograph, it is apparent that the distribution of the SiC particles in the aluminium matrix is uniform. It is believed that Al matrix and

SiC particulates are properly bonded during the fabrication process. It can be also observed that the sharpness of the microstructure is very strong. Figure 5(d) shows the micrograph of 70%Al-30%SiC composite prepared under 15 ton compaction load. In the micrograph, the whitish part is the aluminium matrix and the blackish part is the SiC particulates. It can be observed that SiC particles are almost uniformly distributed in the aluminium matrix. It is believed that strong particle-matrix interfacial bonding is achieved during fabrication. From the figure it is also apparent that the sharpness of the microstructure is very strong. As a comparison, the composites prepared under 15 ton compaction load clearly show improved microstructure (figures 5(c) and 5(d)) than the composites prepared under 10 ton compaction load (figures 5(a) and 5(b)).



(a) (b) (c) (d)

Figure 5. Optical micrographs of Al/SiC composites (a) 90%Al+10%SiC ; Compaction load: 10 ton (b) 80%Al+20%SiC, Compaction load: 10 ton (c) 80%Al+20%SiC, Compaction load: 15 ton (d) 70%Al+30%SiC, Compaction load: 15 ton

4. Conclusion

The effects of compaction load and volume fraction of SiC particulates on the properties Al/SiC composites were investigated and the following conclusions are drawn:

1. Density of the composite specimen increases with the increase in SiC particulate volume fraction and the densities of the composites are higher for 15 ton compaction load than the densities obtained for 10 ton compaction load. For 15 ton compaction load, after the sintering process, the percentage increase in the density of the composites somewhat less than the percentage increase in the density of the composites prepared under 10 ton load.

2. In general, the increase in the volume fraction of SiC particulates results in an increase in the hardness of Al/SiC composites. Under 15 ton compaction load, the average hardness of Al/SiC composites of all the compositions is somewhat higher than the average hardness of the composites prepared under 10 ton compaction load.
3. Al/SiC composites prepared under 15 ton compaction load certainly exhibit improved microstructure than the composites prepared under 10 ton compaction load.

5. References

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