Effect of Silicon Nitride and Graphene Nanoplatelets on the Properties of Aluminum Metal Matrix Composites

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Abstract

This research work aims at investigating the influence of a fixed content of silicon nitride (Si_3N_4) and varied contents of graphene nanoplatelets (GNPs) on the physical and mechanical properties of Al-Si_3N_4-GNPs composites. The composites were fabricated by a microwave-assisted powder metallurgy route. The Si_3N_4 concentration was fixed at (5 wt.%) while the GNPs concentration was varied between (0 wt.%) to (1.5 wt.%) in the Al-Si_3N_4-GNPs. The structural analysis indicates the formation of phase pure materials with high crystallinity. The microstructural analysis confirmed the presence of the Si_3N_4 and GNPs showing enhanced agglomeration with the increasing amount of GNPs. Moreover, the surface roughness of the synthesized composites increases with an increasing amount of GNPs reaching its maximum value (RMS = 65.32 nm) at 1.5 wt.% of GNPs. The Al-Si_3N_4-GNPs composites exhibit improved microhardness and promising load-indentation behavior during nanoindentation when compared to pure aluminum (Al). Moreover, Al-Si_3N_4-GNPs composites demonstrate higher values of compressive yield strength (CYS) and ultimate compressive strength (UCS) when compared to pure Al despite showing a declining trend with an increasing amount of GNPs in the matrix. Finally, a shear mode of fracture is prevalent in Al-Si_3N_4-GNPs composites under compression loading.

Methodology

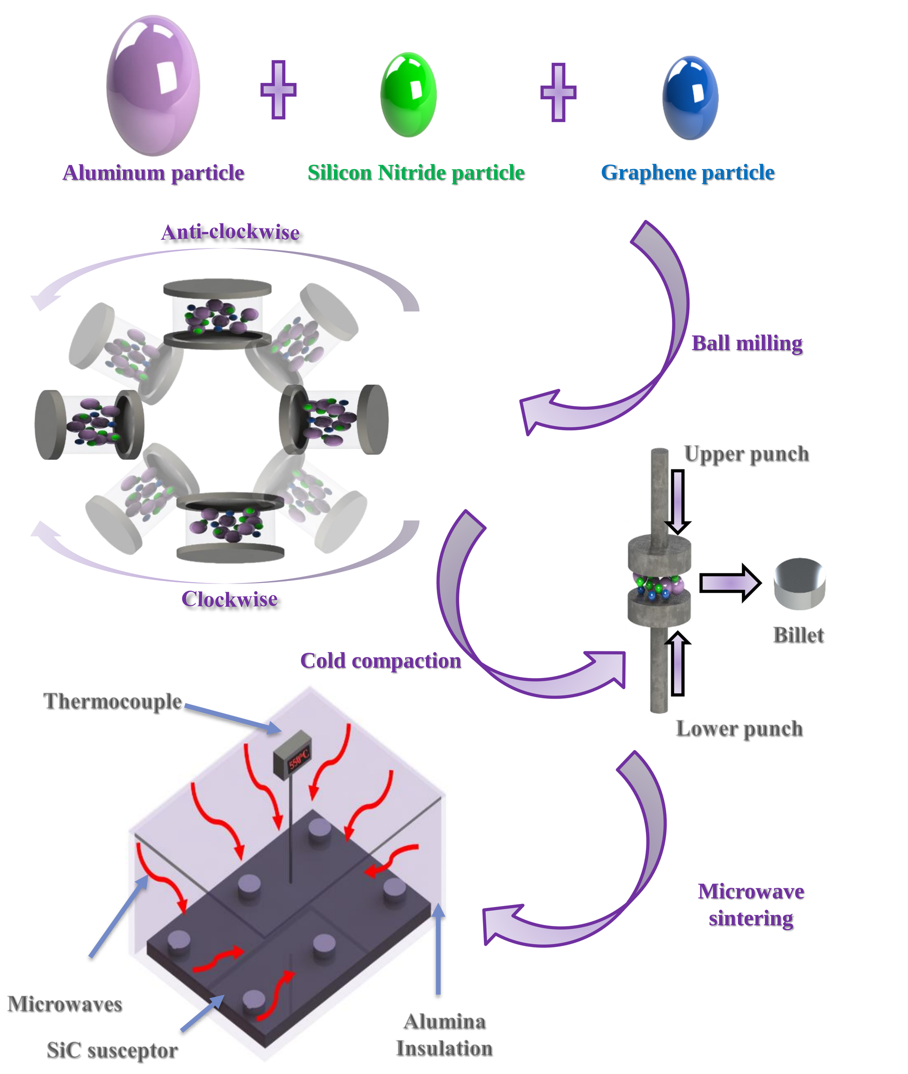

Figure 1. Schematic representation for the development of Al-Si_3N_4-GNPs composites.

Results

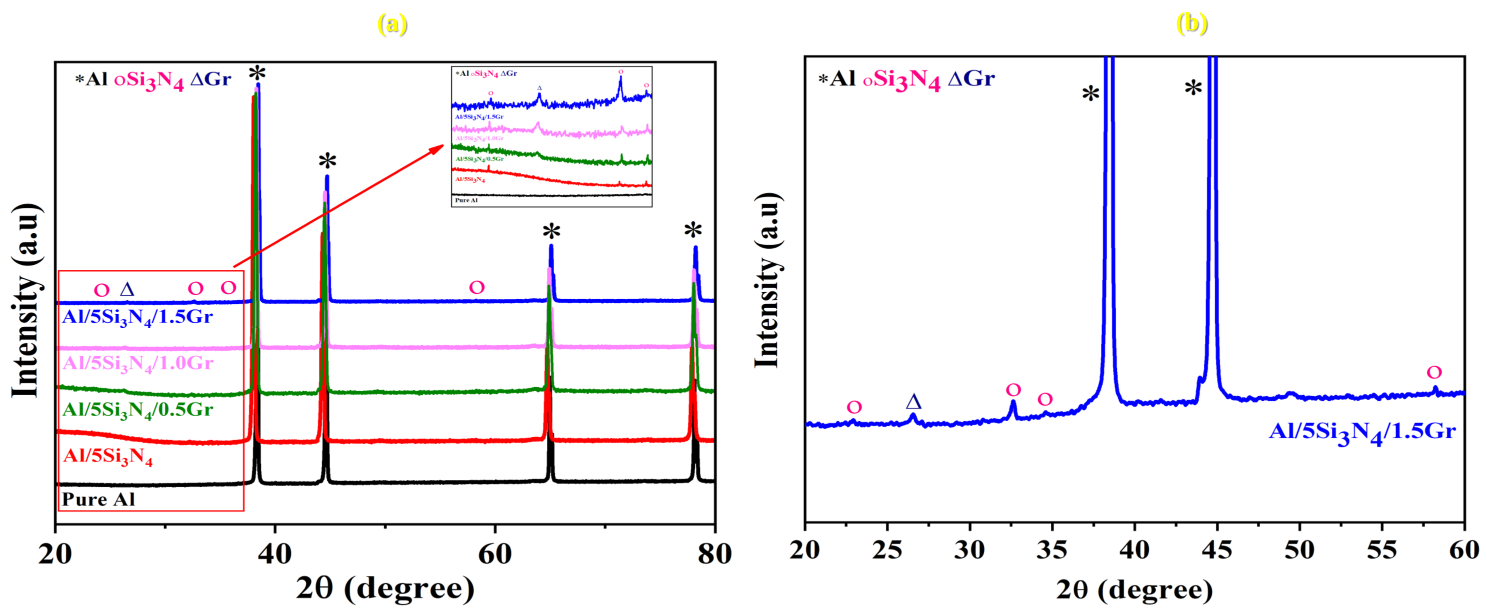

Figure 2. X-ray diffraction patterns of (a) Al-Si_3N_4-GNPs composites (inset graph shows the enlarged section that covers the 2θ range 20–35°) and (b) Magnified pattern of Al-5Si_3N_4-1.5GNPs composites.

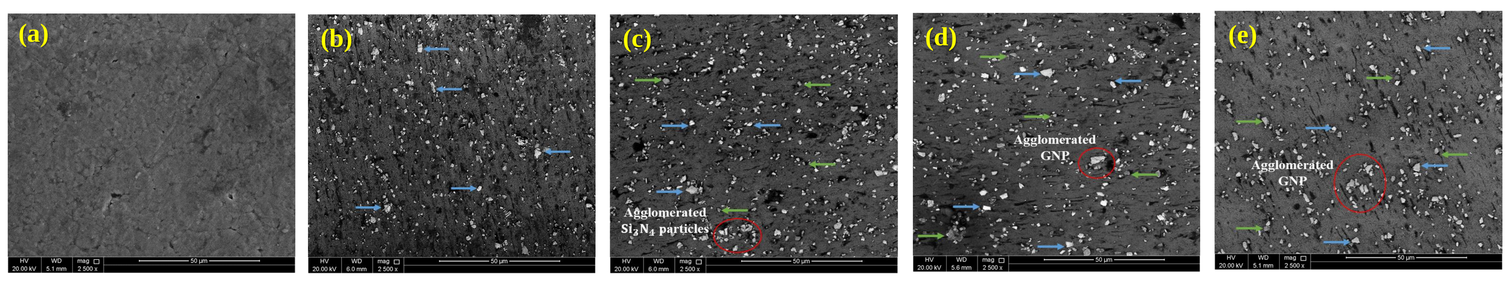

Figure 3. FE-SEM images of (a) Pure Al, (b) Al-5Si_3N_4, (c) Al-5Si_3N_4-0.5GNPs, (d) Al-5Si_3N_4-1GNPs and (e) Al-5Si_3N_4- 1.5GNPs composites.

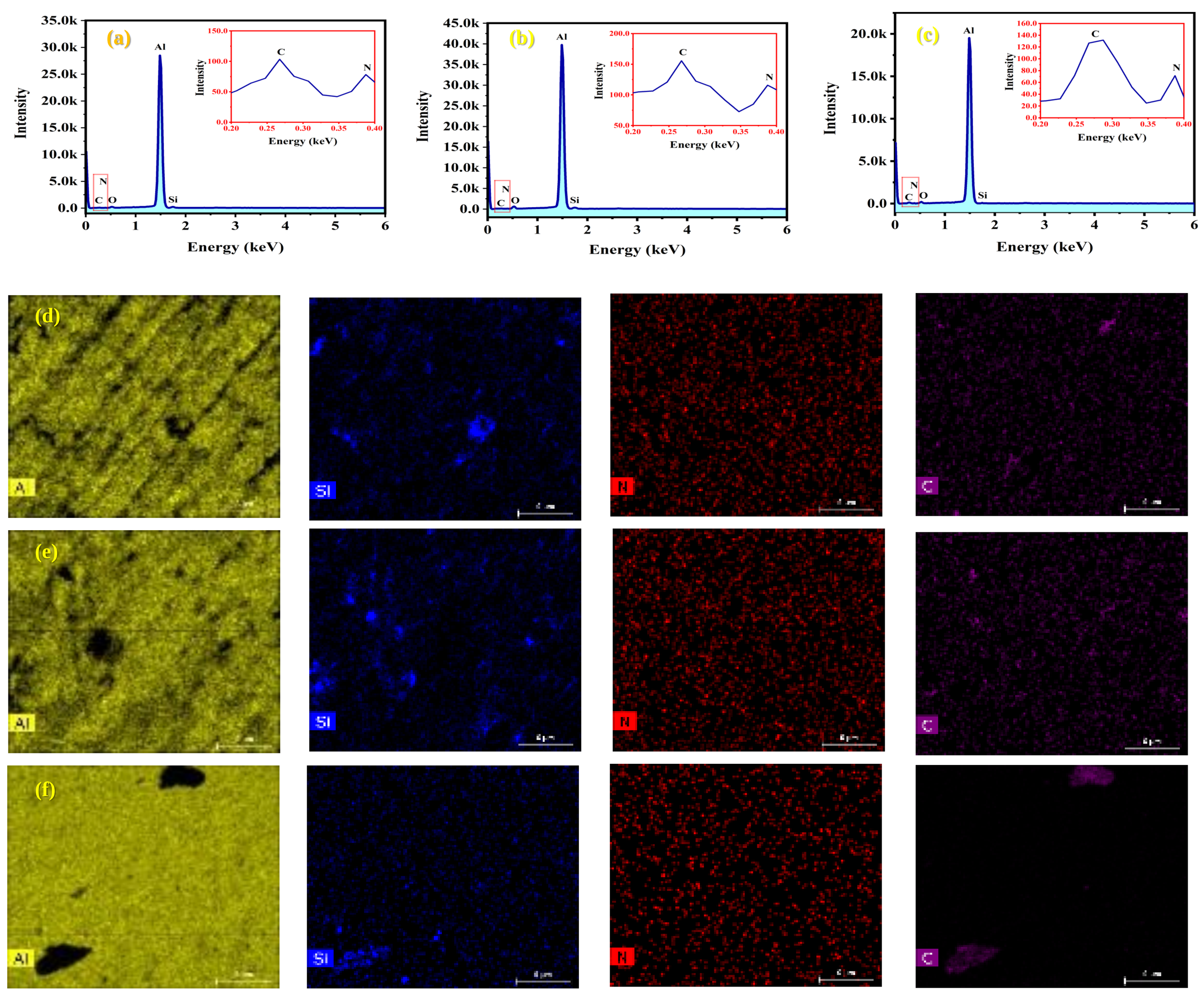

Figure 4. (a–c) Energy dispersive X-ray spectroscopy spectrum analysis and (d–f) elemental mapping images of Al-5Si_3N_4- 0.5GNPs, Al-5Si_3N_4-1GNPs and Al-5Si_3N_4-1.5GNPs composites (scale-6 μm).

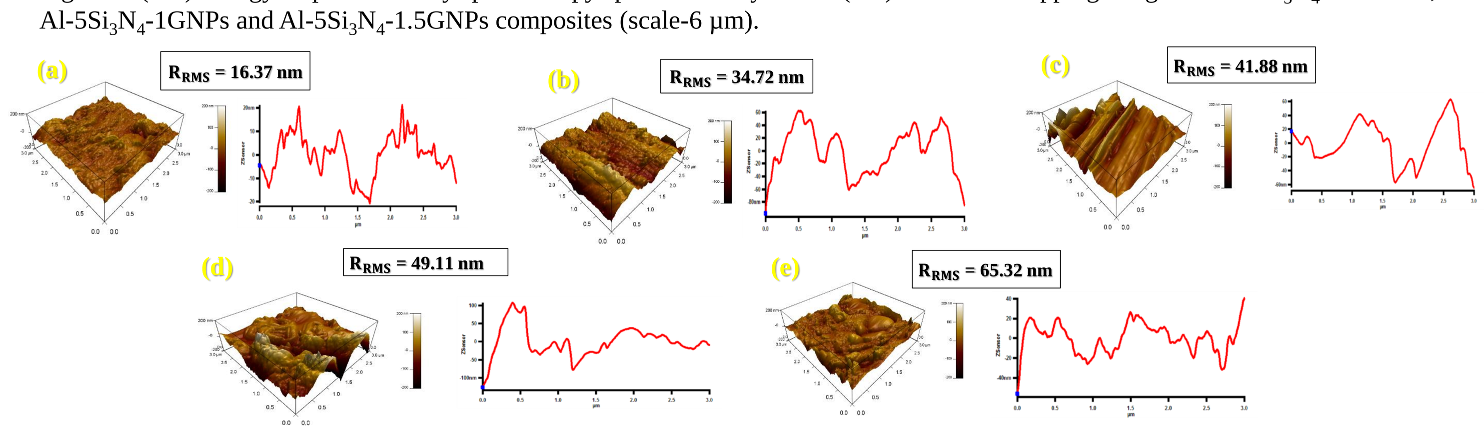

Figure 5. 2D and 3D atomic force microscope images of (a) Pure Al, (b) Al-5Si_3N_4, (c) Al-5Si_3N_4-0.5GNPs, (d) Al-5Si_3N_4- 1GNPs and (e) Al-5Si_3N_4-1.5GNPs composites.

Discussion

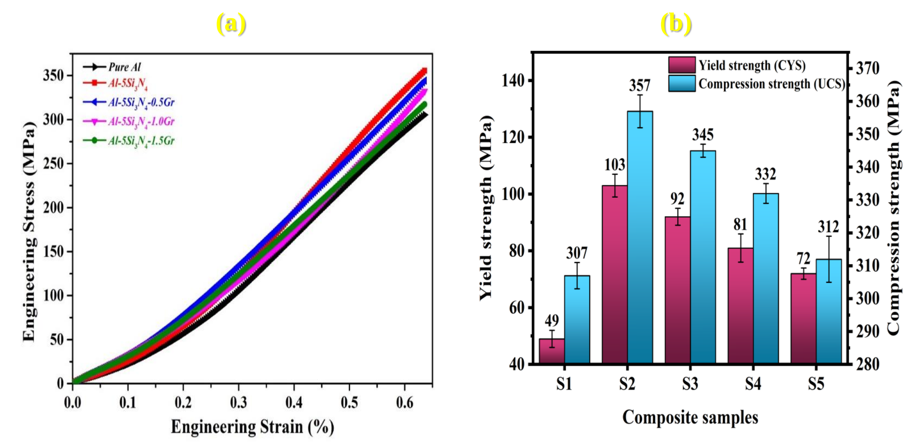

Figure 6. (a) Engineering stress-strain curve under compressive loading (b) Compressive yield strength (CYS) and ultimate compressive strength (UCS) values of Al-Si_3N_4-GNPs composite samples.

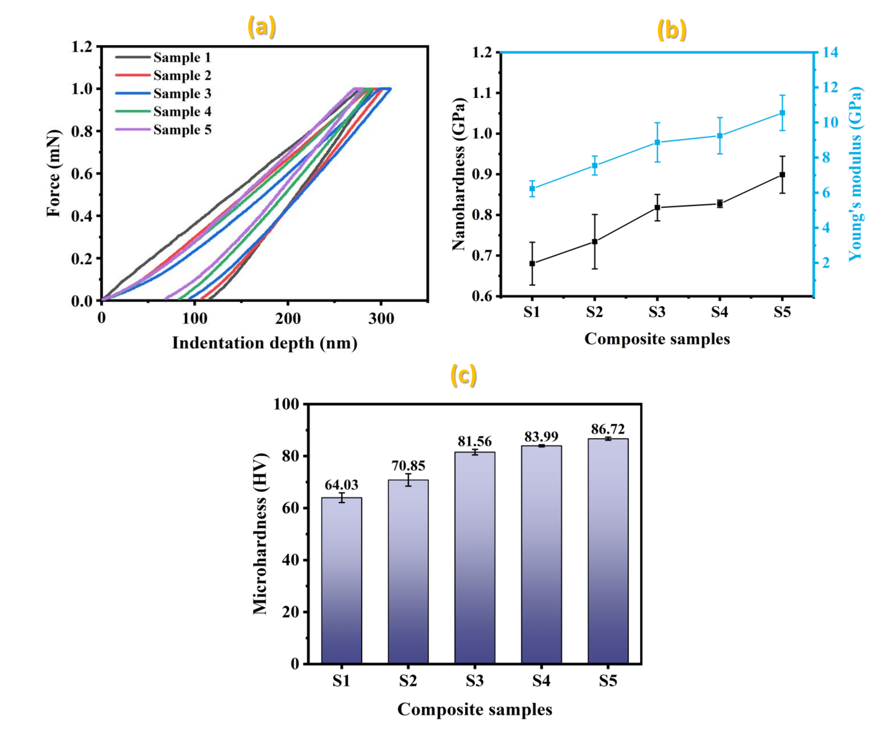

Figure 7. (a) Load-indentation depth curves, (b) Nanohardness and Young's modulus and (c) Microhardness values of Al-Si_3N_4-GNPs composites.

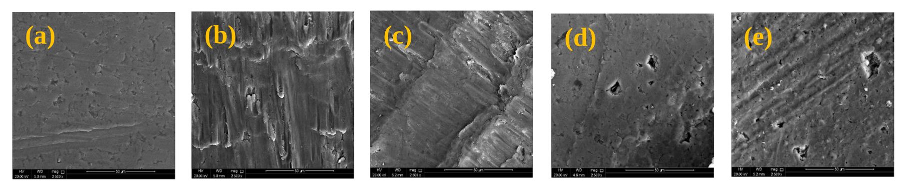

Figure 8. Compression fracture images of (a) Pure Al, (b) Al-5Si_3N_4, (c) Al-5Si_3N_4-0.5GNPs, (d) Al-5Si_3N_4-1GNPs and (e) Al-5Si_3N_4-1.5GNPs composites

Conclusion

In this study, Al-Si_3N_4-GNPs composites containing different concentrations of GNPs were successfully synthesized using the microwave-assisted powder metallurgy method. The structural (XRD) and compositional analyses (EDX) confirm the formation of phase pure Al-Si_3N_4-GNPs composites having an agglomeration effect with increasing concen- tration of GNPs. The density of the prepared composites decreases with the increasing amount of GNPs, while the porosity follows an opposite trend. The surface roughness of the Al-Si_3N_4-GNPs composites increases with the exhibit promising hardness as compared to pure Al. Although, the values of CYS and UCS of Al-Si_3N_4-GNPs composites decrease with the increasing amount of GNPs but remain higher than the pure Al justifying the motivation of their development. A shear mode of fracture is prevalent in Al-Si_3N_4-GNPs composites under compressive loading.

Acknowledgement

The authors would like to appreciably acknowledge Qatar University's Central Laboratories Unit (QUCLU) for their assistance with the FE-SEM and EDX analysis of the samples.