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Mechanical Characterization of Graphene Reinforced Al2024/Albite Hybrid Composites by Powder Metallurgy

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Abstract

Aluminum copper alloys reinforced with naturally occurring or synthesized ceramic particulates are widely used for producing various automobile components and as structural supports by the aerospace industries. For improving their performance these composite materials have been further refined by the addition of nano materials. Nano sized graphene has played a significant role in this direction. In this present work an attempt has been made to refine Al2024/Albite composite in which the predominant primary reinforcement Albite of 5% by weight has been maintained constant and by addition of graphene as secondary reinforcement with varying content (0.25,0.50,0.75, 1, 1.25 and 1.5Wt%) the composite material was fabricated by adopting powder metallurgy. SEM images of the processed hybrid composites revealed the presence of primary reinforcement Albite and secondary reinforcement graphene reinforcements equitably distributed throughout the Al2024 alloy with very less presence of voids. An appreciable increase in compression strength and hardness has been observed with increase in addition to secondary reinforcement up to 1.25%Wt of graphene, but tends to decrease with further addition of graphene reinforcement.

Keywords: *Al2024, Albite, Graphene, Powder Metallurgy Mechanical Properties.*

1.0 Introduction

Aluminum alloys with predominant presence of copper reinforced with ceramics have been used for aerospace, automobiles, and home appliances applications. The use of Aluminium-copper alloys possess good properties such as process forming, machineability, low ratio of mass to volume, corrosion resistant, heat dissipation, vibration damping capability etc. [1–3]. Aluminium matrix composites (AMC) processed byadopting powder metallurgy route are being increasingly used to fabricate parts of various shapes and sizes which is generally not economically feasible by other forms of processing. The composites so developed forms an integral part of temperature sensitive encasings which house microchip-based devices and their helps in the functional parameters by using these types of composites.Graphene reinforced hybrid composites possess excellent heat dissipation and low coefficient of thermal expansion (CTE) facilitate the process of heat dissipation as heat sinks [4]. Composites reinforced with ceramics adopting powder metallurgy technique are being increasingly used for structural applications of aircrafts, automobile components and nuclear reactors, due to its inherent low weight, high strength and excellent damage tolerance are required [5].

Graphene is a two dimensional lattice of carbon atoms which almost resembles a honey comb like structure which

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possess superior mechanical, thermal and electrical properties. It is outstanding property is its structural stability and when used as a reinforcements in AMC's substantially enhance the mechanical properties. Graphene possess distinctive wear resistance properties as it serves as solid and colloidal lubricant and also superior mechanical properties. Research articles reveal of late, graphene has been extensively used as secondary reinforcement to refine a wide range of metal matrix composites.

This work has been carried out to study the influence of graphene as refining element in Al2024/5% albite composites when used secondary reinforcement [6-8]. Aluminium-copper alloy based hybrid AMC's with 5% of albite as primary reinforcement and graphene content varying from 0.25 to 1.5% Wt as secondary reinforcement were processed by adopting powder metallurgy technique. The hybrid composites were subjected to a series of mechanical tests preferably compression and hardness tests as per ASTM standards. The test results would unveil the influence of secondary reinforcement graphene on mechanical properties of Al2024 based hybrid composites. The hybrid composites would be subjected to structural analysis. Investigative techniques namely EDAX, XRD and scanning electron micrography (SEM) would be carried out to corroborate the mechanical characterization of the aforesaid hybrid composites.

2.0 Experimental Details

In this present work graphene has been used a secondary reinforcement to refine Al2024/albite composites, to fabricate the aforesaid composites, powder metallurgy technique has been adopted. The fabricated composites were subjected to compression and hardness tests as per standards. Investigative techniques such EDAX, XRD and SEM analysis were carried out to investigate the influence of graphene on Al2024/albite composites. The chemical composition of aluminium 2024 alloy powder used for this present work is shown Table 1.

Albite the primary reinforcement with an average particulate size of 30 microns has been used and nano sized graphene powder as secondary reinforcement. The powder metallurgy route adopted to fabricate the hybrid composites. It has been carried out by blending the matrix and reinforcement powders by ball milling, the blended mixture were subjected to compaction and finally the resulting green compacts are subjected to sintering. A split die was fabricated to produce green compacts of 20mm diameter and 30 mm height to carry out tests in accordance with ASTM standards [9-11].

To study theinfluence of reinforcing nano sized graphene on hardness and compression properties, the secondary reinforcement graphene powder with varied weight percentages (0.25, 0.50, 0.75, 1, 1.25 and 1.5 wt %) was added to the previously blended mixture of Al2024 and 5wt% albite and further subjected to ball milling for obtaining a uniform blend of all the constituents. The green compacts were prepared compacted using split dies and a hydraulic press, and the resulting green compacts were sintered. The mechanical tests were carried out on Vickers hardness tester and UTM.

Matrix details

Among the various commercially available various types of Axxx alloy powders, for the present work Al2024 alloy has been preferred due to considerable high presence of copper 4.5%, and notable presence of magnesium, manganese and silicon. This alloy due to its higher strength and load bearing capabilities has been chosen, the alloy composition is shown in Table 1.

Reinforcements

Albite (sodium aluminium silicate $NaAlSi_3O_8$) particulates of 50 microns size has been used as the primary reinforcement, which is a naturally occurring plagioclase feldspar. It is composition is mainly made of silicates, it is abundantly available in the Earth's crust in the form of natural rocks. Albite a naturally occurring mineral is available various shades white to dark grey colors, possess a Moh hardness of about 6.5, light in weight, specific gravity of 2.6, low coefficient of thermal expansion of 2.3 x 10^{-6} K^{-1}, density 2550 kg m^{-3}, albite tends to soften at temperatures in the range of 1140-1280°C thereby used and excellent substitute for commercially synthesized silicon carbide and alumina. In the present work, the weight fraction of 5 Wt% albite particulates have been used to process the hybrid composites per cent.

With the advent of graphene and subsequent industrial scale of production new avenues have opened for using graphene in various applications. It is superior properties such as mechanical, thermal and electrical properties make it an excellent candidate material to be used as reinforcement in

Table 1: Chemical Composition of AL2024 alloy

Al	Cu	Mg	Fe	Mn	Si	Zn	Ti	Cr
Remaining	4.50	0.86	0.19	0.68	0.20	0.024	0.011	0.001

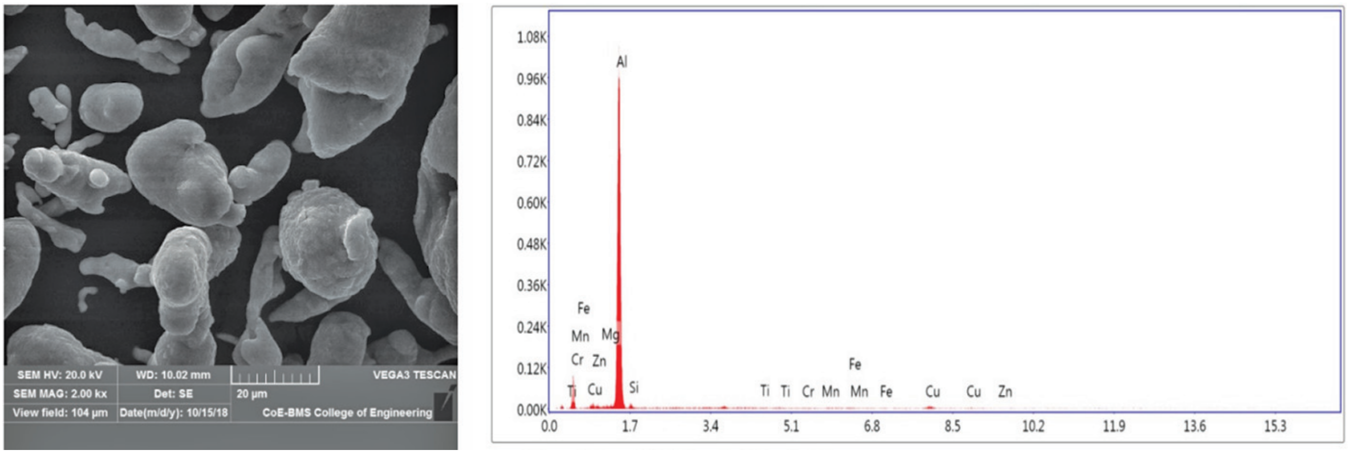

Figure 1: EDAX of Al2024 Powder particles

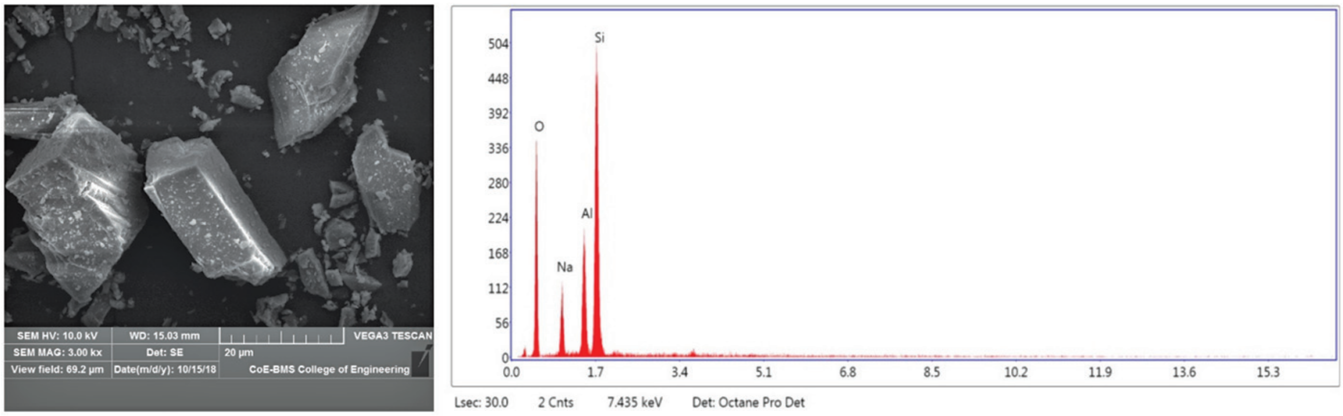

Figure 2: EDAX of Albite Powder particles

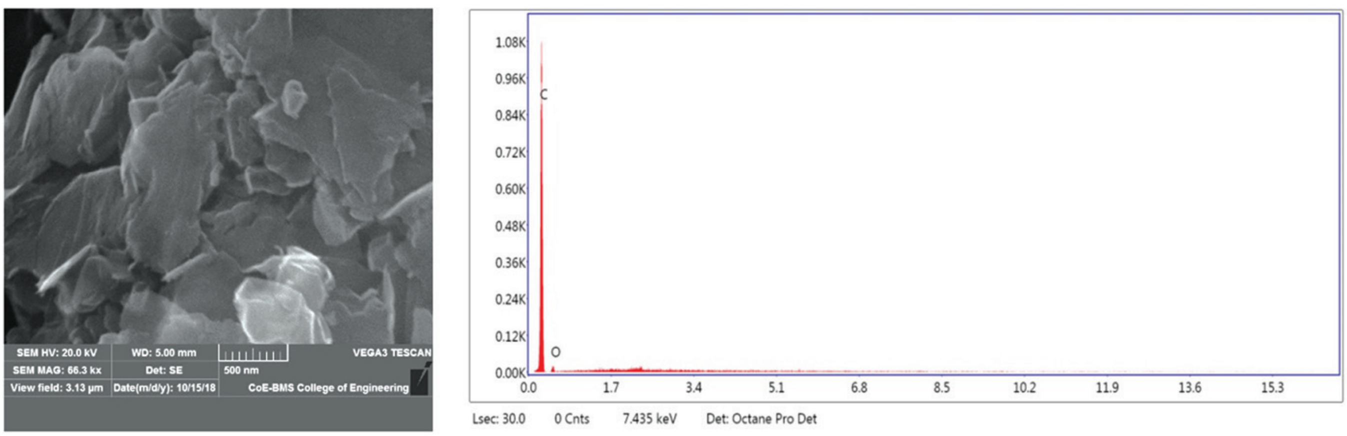

Figure 3: EDAX of Graphene Powder particles

the fabrication of metal matrix composites. Graphene is a two-dimensional material whose two-dimensional lattice of carbon atoms resembles a honeycomb structure. It has excellent mechanical properties notable among them are fracture strength of 125 GPa, high young's modulus modulus of 1 TPa and strength 125 GPa has attracted a lot of attention for improving the mechanical properties of existing range of aluminium alloys. Commercially available nano sized graphene powder has been used as the secondary reinforcement to refine Al2024/Albite composites in the present work.

3.0 Powder Metallurgy Technique

The Al2024 based hybrid composites were processed by adopting the powder metallurgy route. Mechanical alloying is the process of blending the powders to achieve a homogenous distribution and also to reduce the average size of the powder particles. The powders of Al2024 alloy matrix reinforced with 5 wt% of albite and 0-1.5 wt% of graphene were mechanically blended using a high energy ball mill, the AISI 420 stainless steel balls of diameter 20 mm and operating speed 700 rpm. The mixing time was 1.5 h. Batch wise mixing of the powders with albite weight percentage kept constant at 5% and varying the graphene content ranging from 0-1.5 wt% were prepared and adequately segregated for further preparation of green compacts.

Compaction

The mechanically alloyed powders of Al2024/5% albite with varying content of graphene were filled manually into a split die and compacted at high pressure to achieve a cylindrical shape specimen as desired for testing. The die walls were coated with thin layer of zinc stearate powder lubricant over the punch face and the cavity of the die. A split die made up of stainless steel with a bore diameter of about 20 mm and permissible height of 30mm were used. The blended mixtures were compacted by using a 20-tonne hydraulic press. The applied optimized pressure was 160MPa. The split die facilitates easy removal of the green compacts without any damage.

Sintering

The green compacts were sintered which generally is a heat treatment process to remove the moisture content and facilitates solidification process, the sintering temperature has a bearing influence on the properties of composite and the inert environment also influence on specimen properties. Sintering process which is carried out at temperatures much lower temperatures than that of the matrix alloy consolidates the interfacial bonding between matrix and reinforcements thereby changing the base alloy Al2024's microstructural and other related mechanical properties. The specimen green compacts produced after compaction in a uniaxial hydraulic press, were sintered in argon medium at 500ºC for 6 hrs. A muffle furnace connected to a continuous supply of argon unit to maintain an inert atmosphere was used, subsequently after the sintering cycle, in a constrained atmosphere all the specimens were allowed to cool to room temperature.

4.0 Results and Discussion

The Al2024/5% albite composites reinforced with secondary reinforcement graphene with varying content of 0.25 to 1.5wt% in steps of 0.25wt% were subjected mechanical tests post sintering process has been discussed.

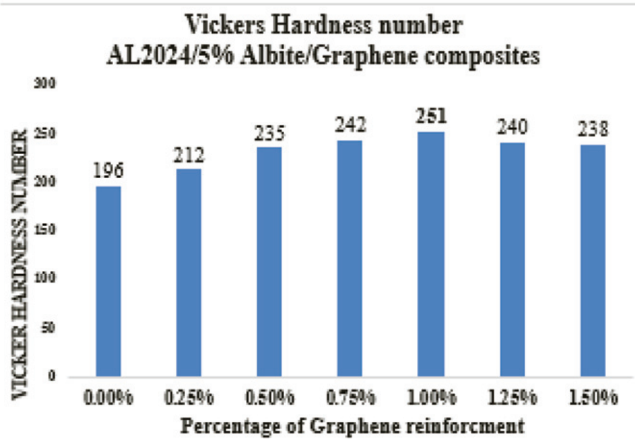

Figure 4: Average Hardness values of Hybrid composites

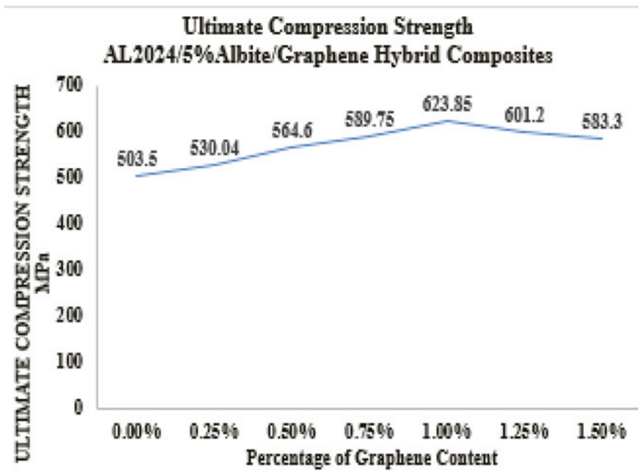

Figure 5: Compression strength values of Al2024/5% Albite/ Graphene Hybrid composites

Hardness

The sintered composites were subjected hardness tests using Vickers hardness tester as per IS 1501-2011 testing standards.The presence of graphene reinforcements has influenced the hardness values of Al2024/5% albite composites an observed incremental increase in micro hardness values with an incremental increase of graphene addition as shown in Figure 4, which reflects excellent bonding of Al2024 matrix alloy and reinforcements [1]. Madhusudhan et.al, [1] reported the hardness of Al2024 matrix alloy with addition of 5% albite substantially increased from 89 to 196 VHN an increase of 120%, but with addition of nano based graphene at an incremental rate of 0.25 wt%, the observed increase wasabout 28% when compared to that of Al2024/5% albite composite hardness value. The notable increase in hardness is due to the presence of graphene content and the formation carbide compounds during the sintering process. The test results also define the saturation limit on addition of graphene as hardness tends to decrease on addition of graphene powder beyond 1wt%, this is due to the formation of agglomerates of reinforcements resulting in enlargement in voids and decrease in interfacial bonding due to the presence intermittent carbide compounds.

Compression Strength

The ultimate compression strength (UCS) of Al2024 alloy reinforced with albite and graphene reinforcements was carried out by maintaining a constant 5wt% of primary reinforcement albite and by incrementally varying the weight % of secondary reinforcement graphene in steps of 0.25 wt% up to 1.5%. The compression tests of hybrid composites were carried out on 40 tonne hydraulically operated universal testing machine as per ASTM C-29 standards. The composite test specimens of circular cross-section measuring 20mm in diameter and 30 mm in height was used for testing purpose.

Al2024/albite composites with 5wt% of Albite possessing the maximum compression strength was reinforced with secondary reinforcement graphene with varying weight percentages of 0.25 to 1.5 wt %. Figure 5 reveals the UCS values have increased with every incremental addition of graphene, the observed increase is due to the effective interfacial bonding of added reinforcements and effective load transfer during the test process and also added graphene inhibit the grain growth formation leading to formation of finer grains. Madhusudhun et.al, [1] have reported the compression strength of the base alloy Al2024 with addition of 5% albite substantially increased from 320MPa to 503MPa an increase of 57% but with subsequent inclusion of graphene to the parent composite (Al2024/5% albite) the observed marginal increase was about 25% more. The compression test results also reveal UCS values tend to decrease with further addition of graphene beyond 1wt%, this is due to the interfacial failure at the boundaries encompassing the reinforcements at the matrix/reinforcement interface.

EDS Analysis

Al2024/5% albite/graphene composites were subjected to Energy Dispersive X-Ray Analysis (EDX), referred to as EDS or EDAX, an x-ray technique used to identify the elemental composition of composites. Figure 6 illustrates the predominant elements in the composites Cu,Al, and Si associate to the base matrix alloy Al2024, the peaks of Na and O represent the presence of albite primary reinforcement and C indicates the presence of graphene secondary reinforcement in the hybrid composite.

SEM analysis

SEM images reveal magnified surfaces of sintered composite samples possessing 0.25,0.75 and 1wt% of

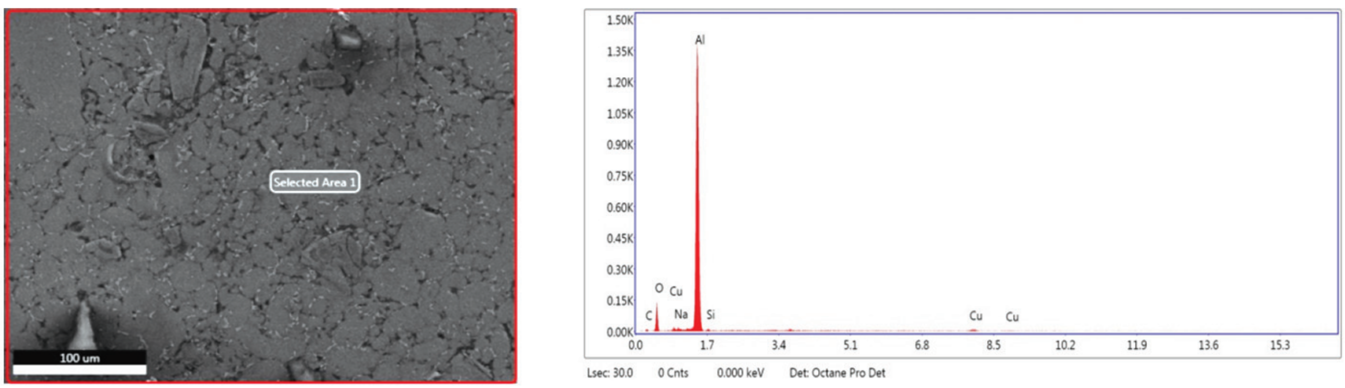

Figure 6: EDAX of Al2024/Albite/Graphene Composites

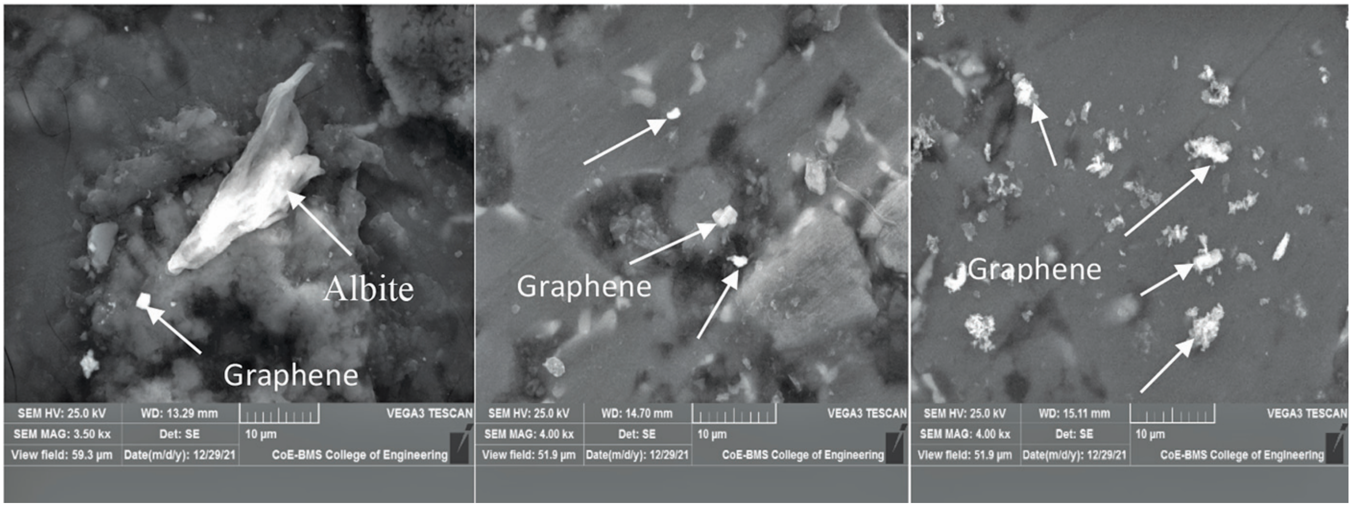

Figure 7: SEM's of (a) Al2024/5% Albite/0.25% Graphene, (b) Al2024/5% Albite/0.75% Graphene, (c) Al2024/5% Albite/1.00% Graphene

graphene along with 5Wt% of Albite is shown in Figure 7a-c. From the imagesthe reinforcing albite particles and graphene were found firmly embeddedin the base alloy Al2024 matrix, it can be observed that there exist fewer voids between the reinforcements and matrix alloy, visible enhancement of interfacial bonding as the Wt% of reinforcing graphene content increases.

5.0 Conclusions

Graphene has been successfully used as the secondary reinforcement in enhancing the compression and hardness properties of Al2024/5% albite/graphene hybrid composite by powder metallurgy technique. Al2024 based composites with 5% albite content was processed successfully. An optimum composition of Al2024 with 5% of albite has been further refined by the addition of graphene as secondary reinforcement. The SEM images of graphene reinforced Al2024/albite composites shows uniform distribution of primary reinforcement Albite particulates and nano sized graphene secondary reinforcement in the processed hybrid composite.

The following conclusions are drawn from the microstructural and mechanical analysis:

1. The Al2024/5% albite/graphene hybrid composites specimens with 0.25,0.50,0.75 and 1.0 wt%'s of graphene reinforcements the mechanical properties in terms of hardness and compression strength show a considerable increase because of the presence of secondary reinforcement graphene in the base composite material of Al2024/albite.
2. SEM's shows the presence of deeply embedded albite particles and graphene in the matrix with fewer voids clearly indicating the compaction and sintering process were adequate.
3. Graphene as a secondary reinforcement can be used to increase the existing mechanical properties, but test results in the present work indicate a saturation limit of 1% by weight, beyond which the strength and hardness tends to decrease.

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