An Investigation into the Mechanical Properties and Microstructures of Graphene Reinforced Aluminum Composites

Mahmut Can ŞENEL, Mevlüt GÜRBÜZ and Erdem KOÇ

***Abstract*— Aluminum based metal matrix composites (AL-MMC) can be used in automotive, aircraft, space, automotive, agricultural and building industries due to their high strength, good stiffness, low density, good thermal and electrical properties. SiC, Al_2O_3, WC, TiC as well as graphene nanoplatelts (GNPs) can be used as reinforcement element in Al-MMC. In this study, graphene reinforced aluminum composites with various graphene content (0.1wt.%, 0.3wt.%, 0.5wt.%) were fabricated by powder metallurgy (PM) method. The crystal structure and microstructure of fabricated composites were analyzed with X-Ray diffractometer (XRD) and scanning electron microscopy (SEM). Vickers hardness and compressive strength were tested by micro Vickers hardness tester and universal test machine. The best hardness (57 HV) and compressive strength (118 MPa) were obtained at 0.1wt.% graphene reinforcement. As a result, mechanical properties of Al-GNPs composites increased up to 0.1%GNPs content. After %0.1 GNPs addition, the mechanical properties of Al-GNPs composites decreased due to the agglomeration of GNPs.**

***Keywords*—Aluminum, composite, graphene, powder metallurgy.**

I. Introduction

Aluminum and its alloys are used very frequently in the automotive, electronics, aerospace and aeronautical industries due to their important performance and traits including good electrical and thermal conductivity, good workability, high strength to weight ratio, high ductility and superior corrosion strength [1]-[3].

Over the last two decades, there has been a high demand for improving the strength of aluminum and its alloys [3]. Hence, aluminum-based metal matrix composites with nanoparticles have attracted many researchers. Carbon-based materials like carbon nanotubes (CNTs), graphite and graphene nanoplatelets (GNPs) have been among the extensively researched materials due to their superior mechanical [4], electrical [5], thermal properties [6] and tribological behaviors [7]-[8]. Graphene is the most preferred material among carbon based materials due to its extraordinary properties.

Graphene is a single layer of graphite, two dimensional consisting of sp^2-hybridized carbon atoms [9]. It has extraordinary mechanical, electrical, thermal properties and tribological behaviors which makes a great reinforcement in metal matrix composites due to its honeycomb lattice of single sheet structure [10]-[13].

In recent years, the mechanical properties of graphene nanoplatelets (GNPs) reinforced aluminum metal matrix composites have been studied [14]-[20]. Bastwros et al. researched the flexural strength of graphene-reinforced aluminum nanocomposites produced by PM method. A development of 47% in strength was determined when compared with the Al6061 alloy [18]. Rashad et al. reported the effect of graphene on the hardness, tensile and compressive strength of aluminum composites. Compared to pure aluminum, the tensile strength (+11.1%) and Vickers hardness (+11.8%) for 0.3wt.%GNPs addition increased, but compressive strength (-7.8%) reduced [19]. Wang et al. fabricated graphene-reinforced aluminum composites by PM method. The tensile properties of aluminum composites with only 0.3wt.% GNPs addition is 62% higher than pure aluminum [20].

Although some valuable researches have been concentrated on Vickers hardness and tensile strength of GNPs reinforced aluminum composites, there are rare studies on the Vickers hardness and compressive strength of GNPs reinforced aluminum composites.

In this study, graphene reinforced aluminum composites with various GNPs content (0.1%, 0.3%, 0.5wt.%) were fabricated by powder metallurgy method. This study aims to investigate the effect of graphene addition on Vickers hardness, compressive strength, and microstructure of aluminum composites.

II. Materials And Methods

A. Materials

In this study, pure aluminum (99% purity, (theoretical density of 2.7 g/cm^3 and 8–15 µm particle size) and GNPs powders (theoretical density of 2.25 g/cm^3, 5–8 nm thickness with a typical surface area 120–150 m^2/g) were purchased from Alfa Aesar (United Kingdom) and Grafen Chemical Industries (Turkey), respectively.

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The morphology of aluminum and GNPs powders was shown in Fig. 1. Aluminum powders have nearly spherical form and the particle size of Al is ~10µm. On the other hand, GNPs have the flake form, few-layered morphology which the layers were stacked upon each other with less than 10 nm thickness.

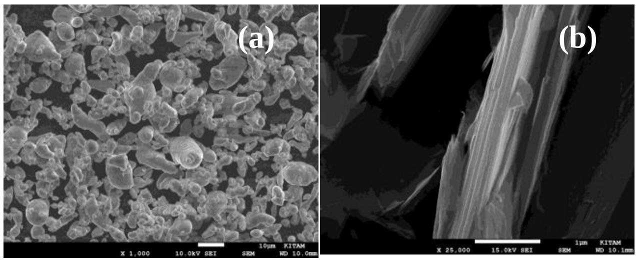

Fig.1. The morphology of aluminum (a) and GNPs (b) powders.

The X-Ray diffraction patterns of pure aluminum and GNPs powders were represented in Fig. 2. X-ray diffractions from pure Al and GNPs were expected at 2θ=~48°, 54°, 75° and 2θ=~26.5° peaks, respectively.

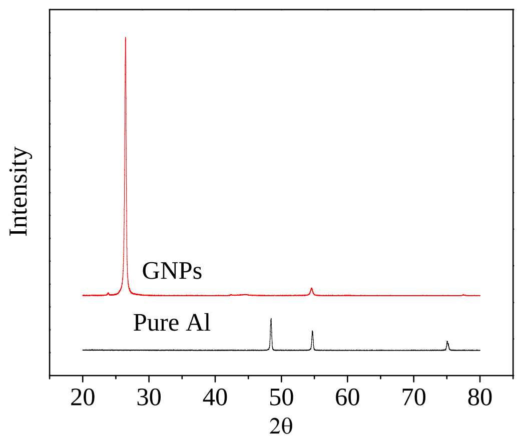

Fig. 2. XRD patterns of Al and GNPs

The particle size distribution of aluminum particles was measured by Malvern Mastersizer 3000 laser particle size analyzer. As seen in Fig. 3, average particle-size distribution of aluminum is nearly 10 µm. This analysis confirms the SEM results.

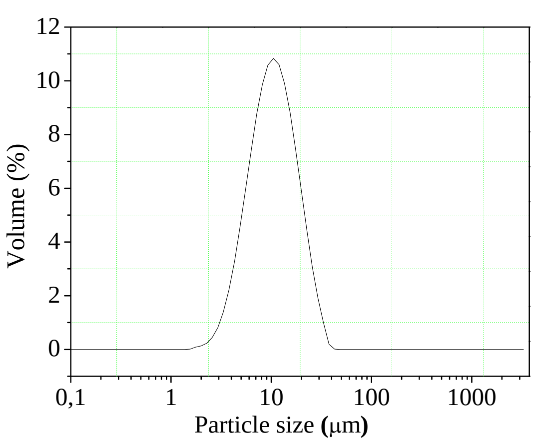

Fig. 3. Particle size distribution of Al powder

B. Methods

Graphene reinforced aluminum composites were fabricated by powder metallurgy method as given in Fig. 4. In this method, Al powders were blended in an ethanol medium using a mixer. Simultaneously, dispersion of GNPs (0.1, 0.3, 0.5wt.%) was carried out for 1 hour using ultrasonic homogenizer. GNPs slurry was added drop by drop into the aluminum-ethanol mixture. Mixing was performed until a homogeneous slurry was obtained. The prepared mixture was ground for 18 hours until homogeneous slurry obtained. The mixture was filtered and then dried overnight at 50^{o}C under vacuum. The composite powder was pressed in a mold under 600 MPa to form green cylindrical samples 130x30 mm in size. After pressing, the samples were sintered under vacuum in the tube furnace at the constant sintering time and temperature (t_S= 3 h and T_S=630 °C).

A micro-Vickers hardness tester (HV1000B micro Vickers hardness tester) under a load of 200 g was used to measure the hardness of the samples. The average values of at least six measurements at polished cross-sections for various areas of each sample were considered. Compressive tests were performed by the universal test machine (Mares Test-10 tons).

The particle size distribution of the powders was determined by particle size analyzer (Malvern Mastersizer 3000). The microstructure evaluation of powders and fracture surface of the composites were characterized by scanning electron microscopy (SEM, Jeol JSM-7001F). X-ray diffraction analysis (XRD, Rigaku Smartlab) was used to examine the phase analysis after sintering.

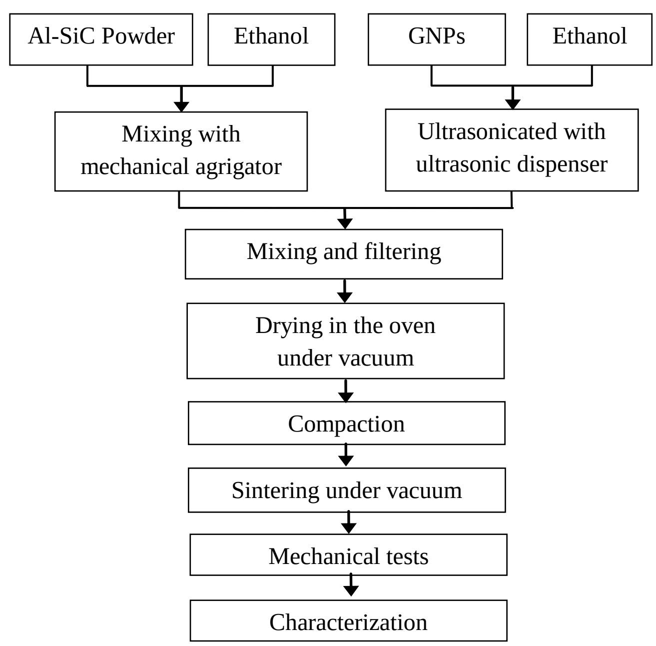

Fig. 4. Fabrication scheme of aluminum based composites [21]-[22]

III. Results And Discussions

The variation of Vickers hardness for pure Al and Al-GNPs composites was shown in Fig. 5. The maximum hardness value was obtained at Al-0.1%GNPs (57 HV). The hardness of these composites reduces with the addition of graphene above 0.1wt.% due to the agglomeration tendency of graphene. The interaction between aluminum and GNPs particles during shaping reduces with agglomeration of GNPs. It causes the higher porosity and the lower hardness results.

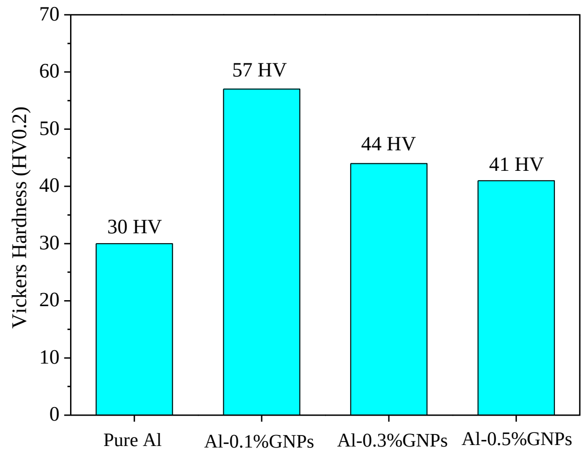

Fig. 5. Vickers hardness of Al-GNPs composites.

Fig. 6 illustrated the variation of compressive strength for pure Al and Al-GNPs composites. The compressive strength of pure Al and Al-GNPs composites increased from 90 MPa to 118 MPa. After 0.1wt.% GNPs addition, the poor interface between aluminum and graphene formed due to the large agglomerated graphene clusters which can lead to the higher porosity and the lower compressive strength.

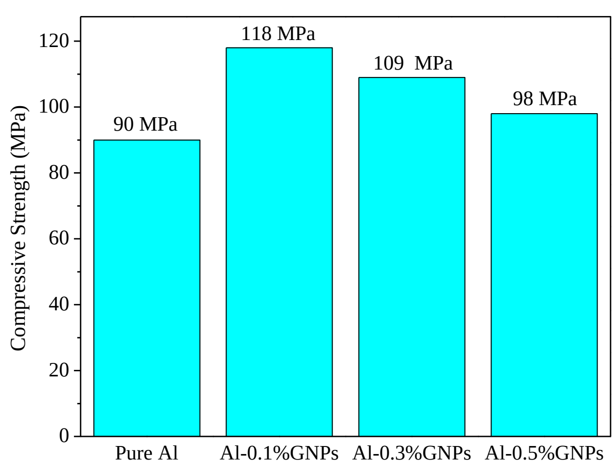

Fig. 6. Ultimate compressive strength of Al-GNPs composites.

Fig. 7 represented the morphology of pure Al and 0.1%, 0.3% and 0.5%GNPs reinforced aluminum matrix composites by scanning electron microscope. Better bonding between the particles and good neck formation was observed at Al-0.1%GNPs composite. On the other hand, the agglomeration was determined at Al-0.3%GNPs and Al-0.5%GNPs composite.

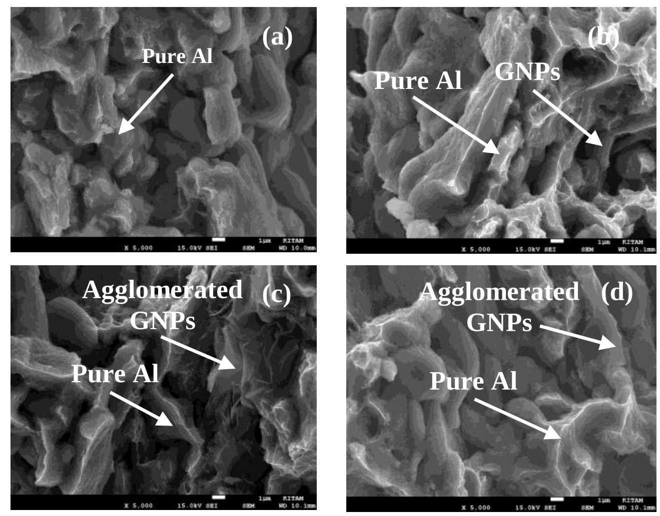

Fig. 7. Pure aluminum (a), 0.1% (b), 0.3% (c) and 0.5%GNPs (d) reinforced aluminum matrix composites

The XRD patterns of pure Al and Al-GNPs composites were given in Fig. 8. As shown in the figure, graphene peaks (2θ=26.5°) are not detected in these composites which may attribute to the low detection limit of XRD and the low content of GNPs and. Also, undesired secondary phase formation (Al_4C_3) is not detected in any Al-GNPs composition.

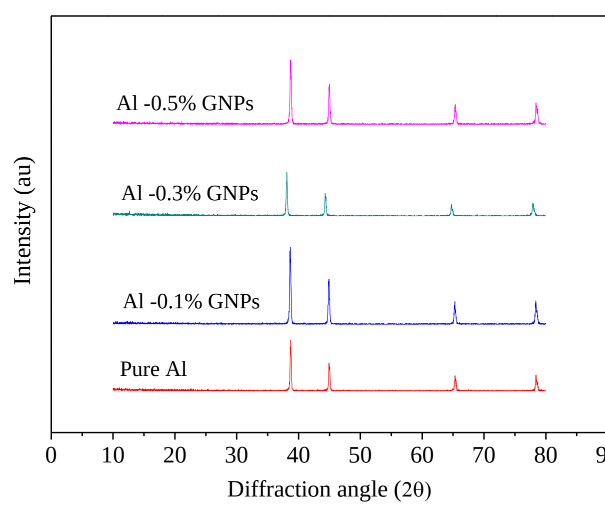

Fig. 8. X-ray diffraction patterns of pure Al and Al-GNPs composites

IV. Conclusion

In this study, GNPs reinforced aluminum composites were successfully fabricated by using powder metallurgy method. From the results, the following conclusions can be drawn:

- The hardness of Al-GNPs up to 0.1wt.%GNPs content increased from 30 HV to 57 HV. Similarly, the ultimate compressive strength of Al-0.1%GNPs increased to 118 MPa when compared to pure aluminum (90 MPa).
- XRD analysis shows that graphene peaks were not seen in these composites owing to the low content of GNPs and the low detection limit of XRD analyzer.
- From the SEM analyses, bonding between the particles and good neck formation were observed.
- As a result, the mechanical properties of Al-GNPs composites enhanced up to 0.1%GNPS addition. After 0.1wt.%GNPs content, the mechanical properties of these composites decreased due to the agglomeration of GNPs.

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