Effect of Reinforcement Type and Amount on Electrical Conductivity in Carbon Nanomaterial Reinforced Al 2024 Alloy

Rüstem Yılmazel [1], Mustafa Yasin Erten [2*], Muharrem Pul [3]

[1] *Kırıkkale Vocational School, Department of Control and Automation, Kırıkkale University, Kırıkkale, Turkey*
[2]*Kırıkkale University, Electrical-Electronics Engineering Department, Kırıkkale, Turkey*
[3]*Kırıkkale Vocational School, Department of Electricity and Energy, Kırıkkale University, Kırıkkale, Turkey*

[*]*(mustafaerten@kku.edu.tr) Email of the corresponding author*

Abstract **–** In this experimental study, composite structures were obtained by reinforcing graphene nanoplate and carbon nanotube in different proportions by stir casting method into Al 2024 alloy in the first stage. Then, the microstructures of the composites were examined, and measurements were made to determine their electrical properties. It was observed that the GNP reinforcement material exhibited a more stable distribution in the Al2024 matrix, and MWCNT caused aggregation and porosity in the structure and negatively affected the structural integrity. In both GNP and MWCNT reinforced composites, it was determined that the conductive values increased up to 1% reinforcement rate and started to decrease at higher rates after that. It was determined that 1% of GNP supplemented in Al 2024 increased the electrical conductivity by approximately 20% and MWCNT by 12%. The GNP reinforcement material exhibited a slightly higher conductivity value than MWCNT. It was concluded that the unstable structure due to porosity in MWCNT reinforced composites had a negative effect on conductivity and that the shape changes and specific surface area differences between MWCNT and GNP also affected the conductivity values.

Keywords – Al 2024 Composite, GNP, MWCNT, Microstructure, Electrical Properties

I. Introduction

Due to their low density and high mechanical properties, aluminum alloys are increasingly used in many essential production areas, such as the automotive, aerospace, and defense industries. 2024 Al-alloy, also known as duralumin, is one of the most complex aluminum alloys, with the highest modulus of elasticity and strength. As a result of the widespread use of aluminum and its alloys, it has become one of the most widely used metals in the production of metal matrix (based) composites, a type of composite material. Aluminum and its alloys are this composite's main elements (matrix). The reinforcements are other elements that are as important as the matrix material in composites. Reinforcement materials are the most crucial element that determines the technical properties of the composite. In recent years, nano-sized materials have begun to be reinforced in addition to ceramic-based reinforcements such as Al_2O_3, SiC, B_4C, TiB_2, TiC, WC, W, C, and MgO into composite structures. Among the most important of these nanomaterials, carbon-based graphene and carbon nanotubes are counted [1].

Graphene and carbon nanotubes are forms of graphite in different geometrical structures. Graphene has a honeycomb-shaped braided structure. This hexagonal structure forms a single layer of the layered shape of graphite (Figure 1).

Graphene is a one-atom-thick layer of carbon. It is calculated that it consists of 3 million layers on top of each other and is close to 1 mm thick. It is an excellent conductor of electricity, and its melting point is around 3000 °C. Graphene has recently attracted attention in both academic and industrial fields due to its excellent performance in mechanical, electrical, and thermal applications.

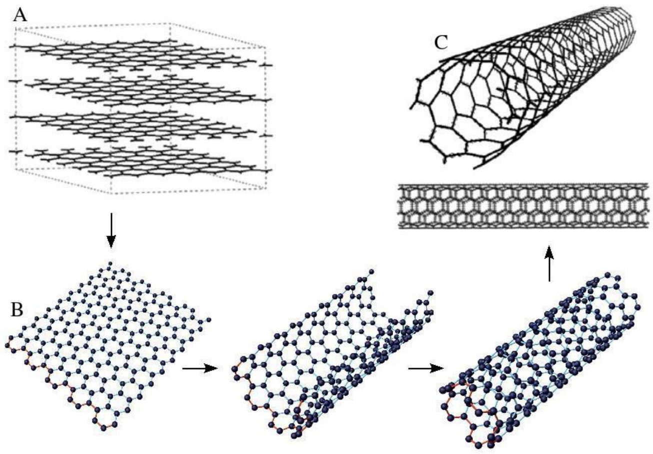


Fig. 1. (A) graphite, (B) graphene sheet, and (C) carbon nanotube [1]

CNTs are of great importance in nanomaterials. CNTs are tubular structures in nanoscale diameter, microns in size. CNTs can be thought of as a hollow cylinder made up of one or more graphene sheets (Figure 1). CNTs are the strongest fibers known today, with outstanding properties [2].

In many studies in the literature, it is seen that the mechanical properties of Al2024 matrix composites are examined [3-8]. However, it is vital to know the electrical properties of aluminum composite structures, which are outstanding conductors, in their use in different areas. For this purpose, this study was planned to investigate the electrical properties of multi-walled carbon nanotube (MWCNT), and graphene nanoplate (GNP) reinforced Al 2024-based composite structures with different carbon allotropes.

II. Materials and Method

Al 2024 aluminum alloy matrix material with the chemical composition of 0.5% Fe, 0.5% Si, 3.8-4.9% Cu, 0.3%-0.9% Mn, 0.25% Zn, 0.1% Cr in the production of composite materials was used as Some technical properties of reinforcement materials in composite structures and supplied from Nanograph Nano Technology [9]-Turkey is given in Table 1.

Table 1. Technical properties of nano reinforcement materials

MWCNT	
Purity	<96 (%)
Outer Diameter	8-18 (nm)
Inner Diameter	5-10 (nm)
Length	10-30 (µm)
Heat Conductivity	3000 (W/mK)
Electrical Conductivity	9800 (Sm^{-1})
Spesific Surface Area	220 ($m^2 g^{-1}$)
GNP	
Purity	99.9 (%)
Ticknes	3 nm
Length	1,5 µm
Heat Conductivity	5000 (W/mK)
Electrical Conductivity	6×10^5 (Sm^{-1})
Spesific Surface Area	800 ($m^2 g^{-1}$)

Stirred casting (vortex) method was applied to obtain composite materials with Al 2024 alloy matrix and carbon nano material reinforcement. 750 °C, liquid Al 2024 temperature, 500 rpm stirring speed, 10 min stirring time were used as production parameters. The matrix and reinforcement ratios of the composite structures produced are given in Table 2.

Table 2. Production parameters of composite materials

Sample No.	Al2024 %	GNP %
1	100	-
2	99.5	0.5
3	99.0	1.0
4	98.0	2.0
5	96.0	4.0
	Al2024 %	MWCNT %
6	99.5	0.5
7	99.0	1.0
8	98.0	2.0
9	96.0	4.0

Electrical measurements were started by preparing samples from the composite materials whose production was completed. A DC power source and two digital multimeters were used for electrical measurements. The DC power supply gives a constant DC supply to the material produced. Digital multimeters measure the electric current passing through the material and the voltage falling on it. The power supply is set to 4V. When this voltage value is applied to the produced material, the current value passing over it is measured. While measuring these currents,

measurements were taken in different parts of the material. The average value of the produced material was calculated by taking measurements from at least five different places. The reason for this is that the material produced is not homogeneous. Therefore, it was tried to calculate the most suitable current value for the material by taking measurements from different parts [10].
According to the current value obtained, the current values passing over the material were found against the voltage values given to the material from the DC power source. According to Ohm's law, the resistance value of the material was calculated. Then, the resistivity value of the material with resistance value is calculated. The electrical conductivity expression of the material after determining the resistivity is also presented in terms of (S/m).

III. RESULTS

A. *Microstructures*

Digital microscope images obtained from GNP and MWCNT reinforced composites in order to examine the microstructures of composite materials produced by the mixed casting method are given in Figure 2.

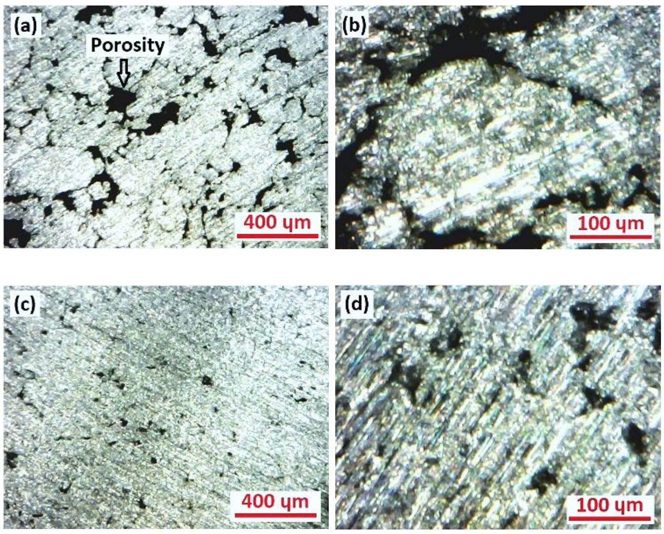


Fig 2. (a) and (b) 2% MWCNT reinforced composite structure, (c) and (d) 2% GNP reinforced composite structure

In order to make a better comparison, equal magnification, and equal reinforcement ratios were selected for both reinforcement materials in the microscope images in Figure 2. The first thing that draws attention to the images is the high porosity in the MWCNT-reinforced structure. It is understood that the reinforcing material MWCNT particles, which agglomerate and come together during production, form dense porous regions (Figure 2a). This situation is also evident from the image in Figure 2b, where the liquid Al 2024 matrix material disrupts its structural integrity and creates intermittent cracks and discrete regions.

B. *Electrical Measurements*

The electrical conductivity level, which is one of the essential properties of conductive materials, is the use of the advanced material's electrical and microstructure properties by developing it at the most optimum level according to the usage area [11]. Therefore, this study aimed to increase the electrical conductivity level of the Al2024 alloy without deteriorating the microstructure.

The graphs given in Figure 3 were created according to the resistivity and conductivity values obtained from the electrical measurements of the GNP and MWCNT-reinforced Al 2024 samples.

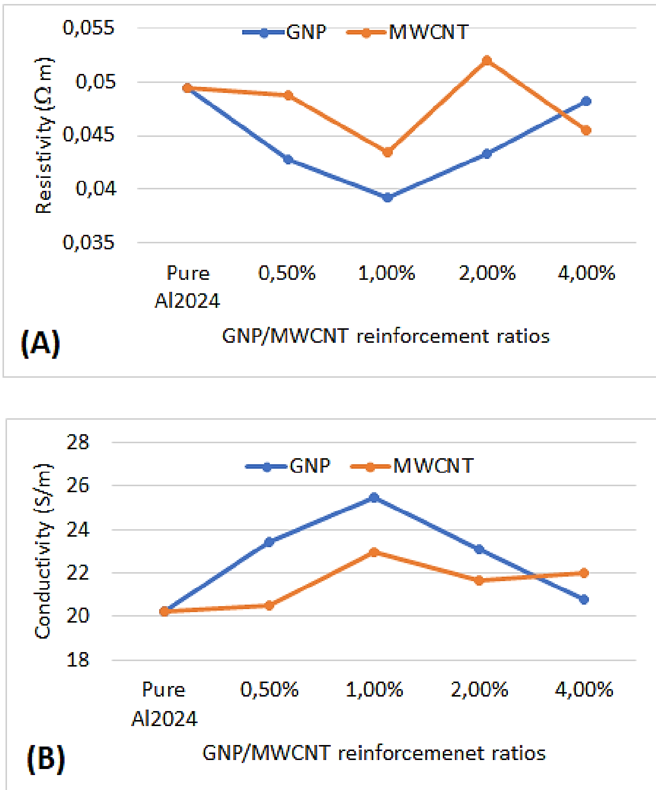


Fig 3. (a) Resistivity of GNP and MWCNT Al 2024 composite samples (b) Conductivity of GNP and MWCNT Al 2024 composite samples

When the graphs in Figure 3 are examined, it is seen that the resistivity decreases, and conductivity increases up to 1% reinforcement in both GNP and MWCNT reinforced samples. However, the electrical conductivity values obtained from composites with more than 1% additives showed a decreasing trend. The reason for this is considered to be the microstructure of the materials first and then the geometric structure of the reinforcement element nanomaterials. These possible reasons are interpreted in more detail in the discussion section.

IV. DISCUSSION

When the microstructures are examined, and the images in Figure 2 are examined in more detail, it is clearly understood that the GNP and MWCNT reinforcement materials exhibit different behaviour in the composite structure. It is known that the GNP nanomaterial of MWCNT is in the form of rounded and nested pipes (Figure 4). These tube-shaped and micron sized MWCNT particles enter each other during the production process, to be more precise, form agglomerated MWCNT masses.

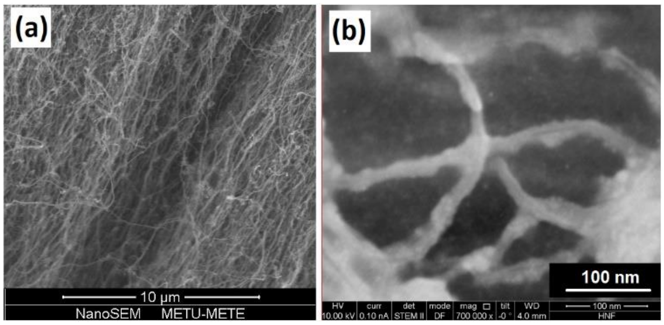


Fig 4. (a) 10000 x magnification, (b) 700000 x magnification MWCNT SEM images [9]

It is reputed to the mixed casting technique, which is the production method of the composite, also helps this situation. Because during the mixing of the liquid metal with the propeller, it is considered that the MWCNT particles are thrown toward certain regions and clump together in these regions. With this clumping, it is understood that dense pores occur in those regions. It is evaluated that it acts as a good insulator in the air spaces in these pores, thus interrupting or reducing the electrical conductivity. In addition, it is stated in the literature that there are some disadvantages of stirred casting among the production methods of such composites and that the reinforcement particles are difficult to wet by the liquid metal [12]. As a result of weak or no wetting, there is no bonding between the matrix and the reinforcement, and interfacial gaps are formed.

However, it is seen that the amount of MWCNT added into the composite structure is up to the order of 1%, the distribution in the liquid metal is more homogeneous, and the conductivity value of the composite structure increases. It is understood that with the increase of the MWCNT ratio, the nanomaterials in which this aggregation accelerates cling to each other and suddenly increase the porosity. With the increasing pore amount, the conductivity value started to decrease again.

This structural evaluation is also valid for the GNP nanomaterial. The same conductivity behaviour is also observed in these nanostructures. However, it was observed that the conductivity amounts in the GNP samples were slightly higher than in the MWCNT-reinforced samples. The most important reason for this is evaluated to the plate-shaped geometric structure of GNP (Figure 5).

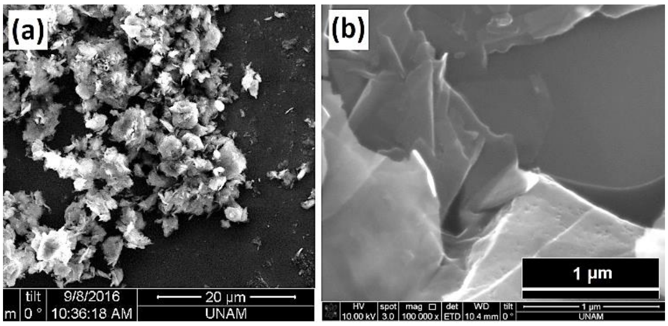
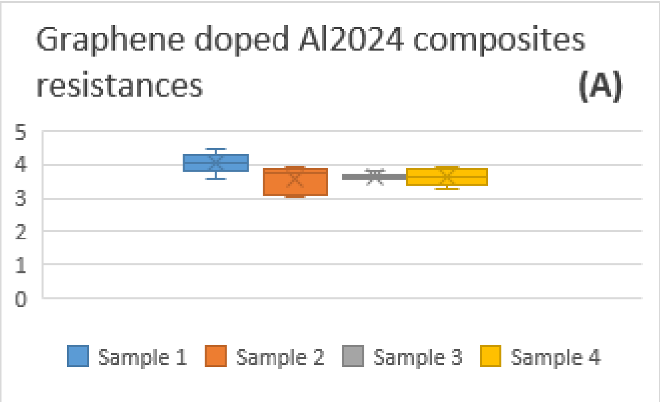


Fig 5. (a) 3000 x magnification, (b) 100000 x magnification GNP SEM images [9]

This structure positively affected both the distribution in the liquid metal and less pore formation. The plate-shaped structure of GNP caused the conductivity to occur more uninterrupted. In addition, the agglomeration and pore spaces being less than MWCNT affected measuring the conductivity somewhat higher. At the same time, the difference between the specific surface areas of both reinforcement materials affects the conductivity values (Table 1).

When the electrical conductivity of GNP and MWCNT-reinforced samples were compared, the measured electrical conductivity value of the GNP-reinforced sample gave better results than the electrical conductivity value of the MWCNT-reinforced sample. The electrical conductivity of the 1% GNP reinforced sample was 9.89% better than the 1% reinforced MWCNT reinforced sample. This is because the electrical conductivity of graphene is much better.



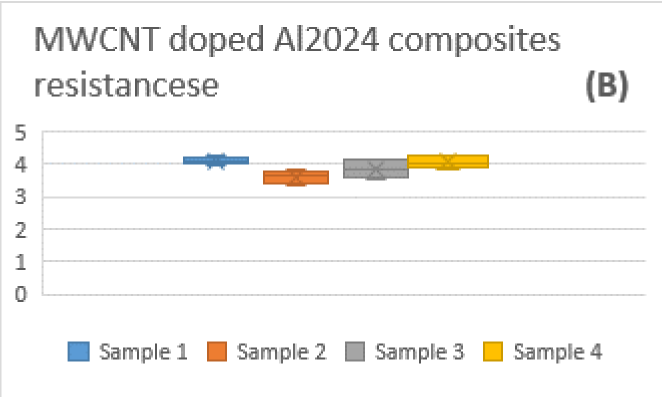


Fig 6. (a) Graphene doped Al2024 composites resistances, (b) MWCNT doped Al2024 composites resistances

V. CONCLUSION

Within the scope of this study, Al2004 composites were obtained by reinforcing graphene nanoplate and carbon nanotube in various ratios. When the microstructures of the obtained composites were examined, it was observed that GNP-reinforced composites exhibited a more stable and homogeneous distribution than MWCNT-reinforced composites. Considering the electrical conductivity properties, GNP and MWCNT supplements added by increasing from 0.5% to 4% increase the electrical conductivity up to 1%, 20%, and 12%, respectively. On the other hand, it was observed that the electrical conductivity of the higher reinforced composite materials decreased compared to the 1% reinforced composites. In addition, it was determined that the GNP reinforcement material increased the electrical conductivity properties of Al2024 alloy at a higher rate than MWCNT. It has been evaluated that the reason for this is that the specific surface area differences between GNP and MWCNT and the MWCNT reinforcement causing porosity on the composite, resulting in an unstable structure, has a negative effect on the electrical conductivity.

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