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Original Research Article

Development of a Graphene-Carbon Composite: An Alternative to Metals and Plastics used in the Production of Pyramidal Satellite Horn Antenna

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ABSTRACT

A radio wave is collected and transmitted in space using a pyramidal horn antenna. It is a waveguide horn with a pyramidal form that gathers radio waves and causes them to spread out like a beam. Although they are composed of plastic and metal, this pyramidal satellite antenna horn is beneficial for wide bandwidth applications. Finding an alternative to materials employed in the production of a pyramidal satellite horn antenna spurred the interest of this study. Graphene and carbon powders composite was considered and investigated to determine the mechanical and microstructural properties. The graphene percentage was varied while the carbon powder remained constant. The graphene-carbon composite materials were prepared using the open mold technique. Testing of the materials followed subjecting the samples to curing for 24 hours. The study showed that samples with higher graphene content exhibited better mechanical and microstructural properties. It was observed that the graphene content influenced the density and strength of the composite material. Graphene-carbon composite materials can make an excellent candidate for the production of a pyramidal satellite horn antenna.

1. INTRODUCTION

It is important to note that graphene is the building block of graphite, a flaky soft material used in making the lead of pencils. Graphene has single layers of carbon atoms in its crystal lattice in a honeycomb pattern (Zan et al., 2013). Composites of carbon are reinforcements of carbon fibers and carbon obtained from resins and organic gas through pyrolysis, and they have favorable thermomechanical properties like low density, low thermal expansion, high thermal conductivity, and shock resistance (Bahl and Dhami, 2005).

In addressing the significance of horn antennas, horn antennas are microwave antennas that focus radio waves into a narrow beam. Materials used for horn antennas include steel and plastics. Horn antennas are used in numerous applications such as astronomical studies, satellite communication, and radars (Kapade and Deshpande, 2017; Nor Arman et al., 2021). Graphene-carbon composites have high electrical conductivity, thermal stability, and strength hence making them more suitable than plastics and metals for producing horn antennas meant for higher frequency service conditions.

Graphene-carbon composites make horn antennas lighter in weight, have reduced volume, and improve the radiation performance of horn antennas, which make it a considerable composite material (Nor Arman et al., 2021; Sharma and Suthar, 2019). Some antennas manufacturers have a long tradition of producing satellite antenna horns with metallic materials or plastics but metallic antennas have higher weight compared to plastic antennas, and have easy affinity to corrosion, and electromagnetic interference (EMI), and plastic antennas have issues arising from electromagnetic compatibility (EMC), short service life due to chemical attacks, and progressive loss of function during operation in service (Avşar, 2021). It is therefore important to note that graphene-carbon composite materials are very useful materials that can conquer the limitations of using either metals or plastics because of their outstanding properties (Yang et al., 2023).

Therefore, this research constitutes a relatively new area which has emerged from the current trend to shift attention from heavy metals and polymers to composites, which are more available, affordable and easy to form. The study focuses on the application of graphene-carbon composite as a suitable material for producing pyramidal satellite horn antennas. The objective of this research is to investigate the properties of graphene-carbon composites and the ultimate goal is to produce composite materials that are useful in improving the performance of horn antennas.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this study include graphene, carbon powder, epoxy resin, epoxy hardener and stirrer.

2.2. Methods

2.2.1. Production of samples

The graphene and carbon powder materials were obtained from the Materials/Mechanical testing laboratory in the Materials and Metallurgical Engineering Department, University of Ilorin, Ilorin, Kwara State, Nigeria. The epoxy resin and hardener were purchased from a supplier in Lagos state of western Nigeria and were added to the composite in a 2:1 ratio. The samples were fabricated with molds subjected to standards (ASTM D638 for tensile tests and ASTM D790 for flexural tests)(Kovtun et al., 2019; Oun et al., 2022).

Figure 1: Tensile and flexural test samples (the first three samples at the right were prepared for tensile testing while the first three on the left were prepared for flexural testing)

For easy removal of the samples from the molds, the samples were, overlaid with butter. Measurement of the required matrix proportions and reinforcing components was carried out and open technique was used to produce the samples. The epoxy resin and hardener were, mixed for about five minutes before adding the carbon and graphene reinforcements to it. To attain a homogeneous mixture, the mixing were continued for another five minutes. Thereafter, the composite samples were, produced in three different percentages (0.25%, 0.5%, and 1%) of graphene while carbon content were, kept constant at 1%. Finally, the samples were, removed from the molds after curing at a conditioned room temperature of about 23 ^{o}C. As presented in Figure 1, the three samples produced for tensile testing are separate from the ones used for flexural testing (David and Kolawole, 2021).

2.2.2. Tensile testing

To determine the tensile strength, yield strength, and Young's modulus of the composites of graphene-carbon, the samples were subjected to a tensile test by using a Universal Instron Testing Machine (model 3369) at the Department of Mechanical Engineering, University of Ilorin. The samples were prepared according to the ASTM D638 standard (Laureto and Pearce, 2018). Tensile test has its significance in this study because of its suitability in determining the strength of the samples produced before constructing the satellite horn antenna. This is to ensure that the satellite horn antenna can withstand various stress and load configurations during its operation.

2.2.3. Flexural testing

To obtain the flexural strength and the modulus of the graphene-carbon composites, the samples were subjected to flexural test. Determining the flexural strength of the composite material is important in order to guarantee the integrity of the resulting antenna and its ability to withstand bending forces which the satellite horn antenna will be subjected to under service conditions. The test was carried out at the Department of Mechanical Engineering, University of Ilorin according to ASTM-D790 standards (Oun et al., 2022). The data obtained are compared with those obtained from using other materials.

2.2.4. Water absorption test

To determine the rate of moisture adsorption over time, the graphene-carbon composites were subjected to water absorption testing. It is important to note that this test has to be carried out to prevent the final product from failing structurally because absorbed water in the composite will weaken the composite. The testing was, carried out in agreement with ASTM D570 standard (Nor Arman et al., 2021). To carry out this test, first, the composite specimens were sawn into smaller parts, then, the weight was measured, and then an immersion of the samples in water at room temperature for seven days. To determine the amount of water that was absorbed, the soaked samples were weighed every 24 hours. The formula in Equation (1) was used to obtain the percentage of water absorption:

$$\text{Water absorption} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \times 100 \tag{1}$$

2.2.5. Microstructural analysis using SEM

In order to describe the distinctive nature of the structure and morphology of the graphene-carbon composites, the scanning electron microscopy (SEM) was used. SEM produces very high-resolution images of the surface of the samples by focusing beams of electrons. The resulting SEM images were analyzed at the University of Ibadan, Ibadan, Nigeria.

3. RESULTS AND DISCUSSION

3.1. Tensile Test Results

Sample A contains 0.25% graphene and 1% carbon, sample B has 0.5% graphene and 1% carbon and sample C has 1% graphene and 1% carbon. Also, each of the samples was bonded by epoxy resin and hardener and when subjected to tensile testing, it was observed that the more the graphene in a sample, the more the tensile strength (Figure. 2). Sample A was able to support a maximum stress of 25.244 MPa, sample B could support 57.587 MPa, and C was able to support 85.277 MPa. However, a sample without any graphene was created and it was able to support a maximum stress of 11.674 MPa. These findings demonstrated that sample C supported a higher amount of stress before starting to fracture compared to samples B and A and the sample that does not contain graphene. As such, sample C has a higher tensile strength than samples B and A and the one without graphene. Conversely, amongst the samples containing graphene, sample A that has the least graphene content has the highest elongation under strain and will result in a product being plastically deformed before fracturing, if considered. Therefore, the graphene content plays a significant role in formulating the composite sample, which is in agreement with literatures (Nicola et al., 2019; Castilho et al., 2019).

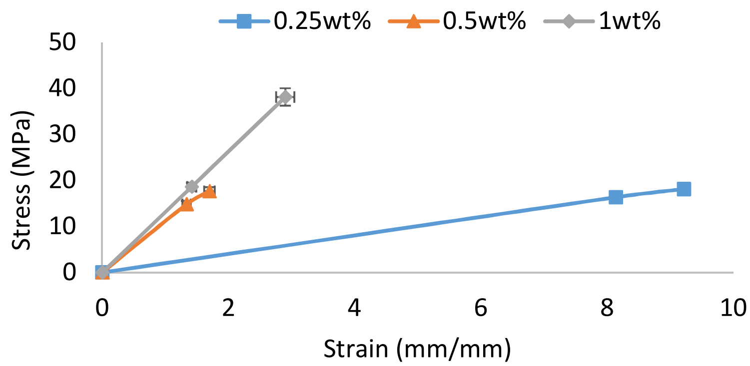

Figure 2: Graph of stress against strain of samples containing graphene

3.2. Flexural Test Results

When a material is subjected to bending, there is a bending stress acting on the depth of the material. This stress acts perpendicularly to the cross-section of the material. Figure 3 shows the maximum stresses recorded for the composite samples with and without graphene when subjected to bending during flexural testing. The sample without graphene has a flexural strength of 4.45 MPa. The sample containing 0.25 wt% of graphene has a flexural strength of 12.13 MPa, the sample with 0.5 wt% has a flexural strength of 42.63 MPa and 1wt% sample has a flexural strength of 54.7 MPa. It is evident that flexural strength of the samples increases as the graphene is increased. Sample C with 1 wt% has the highest flexural strength. Therefore, the graphene content plays a significant role in formulating the composite sample, which is in agreement with literatures (Nicola et al., 2019; Castilho et al., 2019).

3.3. Water Absorption Test Results

Figure 4 is a graph showing the effect of graphene on water absorption performance of the composite samples after a 7-day immersion. As reported in the graph, the 1wt% graphene-carbon composite absorbs water the least. This is followed by the 0.5wt% composite which has a lower absorption value compared to 1wt%. It is important to note that from the trend line of the 0.5wt% composite, as the time increases, there seems to be a reduced water absorption for the next 48 hours. At the 144th hour, there is an observation of a sharp slope, which indicates an increase in the water absorption content for the graphene-composite material of 0.5wt%. At initial immersion of the 0.25wt% graphene-composite material, it was observed that the specimens showed an instantaneous water absorption but then decreased as time progressed in the first 24 hours. This absorption rate then increases slowly with time but more sharply at the 144th hour of soaking. At the 168th hour of soaking, there seems to be a quasi-absorption rate for the 0.25wt% and 0.5wt% graphene composite. These findings demonstrated that the graphene-carbon composite materials with a higher value of graphene have a lower rate of water absorption making the 1wt% composite sample have a lower water-

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absorption rate. This can be due to the high hydrophobic nature of graphene and the fibers in the matrix of graphene have the nature of making it difficult for water to penetrate the composite material.

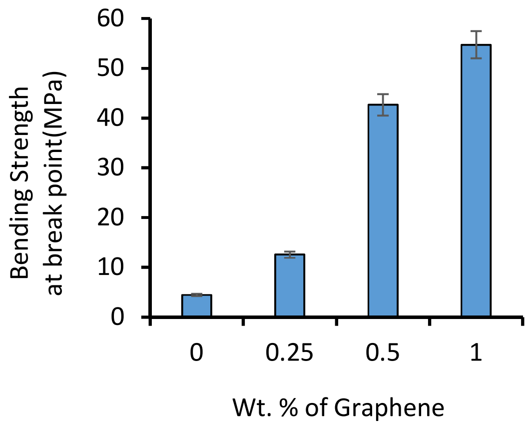


Figure 3: Bar chart showing the bending strength of each composite sample at fracture

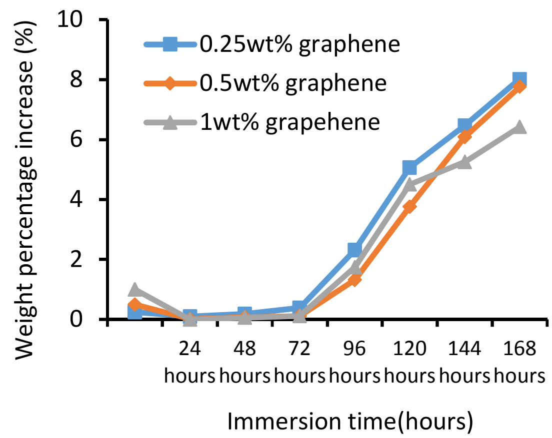
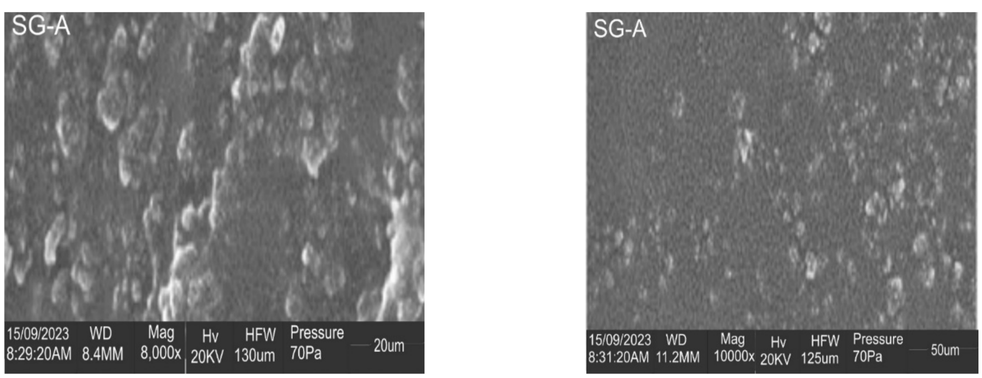


Figure 4: Water absorption of various composites with varying graphene percentage weight

3.4. SEM Results

Figure 5a and Figure 5b shows the SEM images 1wt% of graphene content samples at magnifications of 8000x and 10000x. It is evident that the graphene powder is evenly distributed across the samples. Although some voids are noticed in the 8000x magnification, it is due to irregular stirring. However, it could be stated that the specimen has a high uniform distribution of graphene-carbon hence it is more suitable than metals and conventional manufactured materials that are being used for pyramidal horn antennas (Castilho et al., 2019; Kovtun et al., 2019).



(a) 1wt% at 8000x magnification (b) 1wt% at 10000x magnification

Figure 5: Micrograph of 1wt% graphene and 1wt% carbon powder at 8000x magnification

4. CONCLUSION

A composite material that can be used particularly in the production of pyramidal satellite horn antenna was developed by using graphene and carbon powders. The developed composite samples demonstrated an improvement in mechanical and microstructural properties compared to conventional materials. The study showed that the more the graphene content in the composite material the better it becomes in terms of tensile and flexural strengths. Similarly, it was established that the more the graphene content, the more repellent to water the composite material becomes due to its hydrophobicity. Therefore, the presence of graphene in composition of the composite guarantees a more structurally reliable product, which is in agreement with literature. If this composite formulation, particularly, the 1wt% is adopted in the production of satellite horn antennas, the weight will be reduced drastically, the antenna will have enough strength to withstand natural and unnatural stresses and forces that may want to hamper its operation and durability. Likewise, the eventual antenna will operate better and be more durable compared to the ones produced from conventional materials like metals and plastic. However, this composite material has application in aerospace and electronics parts.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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