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Experimental Study on Graphene Coating Thermosetting Epoxy Polymer for the Manufacture of Electronic Circuit Boards

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Abstract. *Graphene is a microstructure of graphite that has enormous properties and is also one of the carbon allotropes. There are several metals with low strength. The properties of these metals can be increased by coating the graphene. The primary goal of the work is to create composite graphene that exhibits the optimised properties and characteristics that meet the requirements of the industries. The properties of graphene when coated with other metals are studied and their applications in different industrial fields are analysed through several tests and experiments. Research-based on graphene coatings and composites is studied and the properties are adapted.*

Keywords: *Graphene, powder metallurgy, chemical properties, mechanical properties*

1. Introduction

Graphene is one of the four-carbon allotropic atoms with a single layer of atoms in a two-dimensional hexagonal lattice in which each atom forms a vertex. Graphene is a fundamental structural element of other allotropes, including graphite, carbon-carbon nanotubes and fullerenes [1]. It is said to be a large aromatic molecule that belongs to the family of polycyclic aromatic hydrocarbons. Graphene has a peculiar set of properties that makes it different from other carbon allotropes. From a thickness point of view, it's about 100 times stronger than steel. But its density is lower than that of steel. It has good electrical and thermal conductivity [2]. The corrosion-resistant properties of Mild Steel that can be improved by developing GO nanosheets filled with epoxy coatings. The most important parameter that influences the performance of the coating is the distribution of graphene oxide in polymer matrix GO to a polymer of 0 1 % with lower viscosity to give the required properties such as good adhesion properties, good dispersion quality and protection of corrosion under sodium chloride electrolyte [3]. Mechanical characteristics of the graphene-coated aluminium layer tested by numerical tensile method experiments with the help of molecular dynamic simulations. Based on the results obtained, it is found that the graphene-coated aluminium layer enhances the young's modulus and the strength of the material [4]. The loading rate of the coating shall be tested. Although the hybrid coat structure is mostly of the aluminium core, the Graphene core plays a vital role in increasing the ultimate tensile strength. The high loading rate makes the structure amorphous. The loading effect and temperature on amorphization are therefore investigated by performing various simulations [5].

The microstructure and antibacterial activity have been investigated. The graphene is found to be uniformly coated on the aluminium surface. Researchers have developed a graphene-coated aluminium composite to avoid all the drawbacks of organic coatings [6]. Composite coated graphene, which is synthesised using appropriate methods and applied to copper by electrophoretic deposition. By this method, a minimum thickness of 40nm at 10V and a deposition time of the 30s. The morphological characteristics of the copper surface are studied using electron microscopy scanning, which describes the distribution of graphene oxides of a few nanometers [7]. Acetone derived graphene coating that improves the corrosion efficiency of copper in the marine environment. Copper and copper alloys used

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as components of the seawater system due to good corrosion and biofouling resistance. It depends not only on the inherent cathodic nobleness of metal but also naturally on positive layers [8].

The research then began with theoretical descriptions of its composition. High-quality graphene is found to be easy to isolate, making further analysis possible. This work has led researchers to win the Nobel Prize in Physics for experiments on two-dimensional material graphene. The global graphene market was almost nine million two decades earlier, with most of the demand for graphene emerging from researchers and developers of semiconductors, electronics, battery power and composites [9].The objective of this work is to enhance the properties of a metal matrix composite using graphene and to know about the applications of graphene in different fields to apply the concept of graphene coating and to develop a useful product.

2. Materials and methods

Graphene is a carbon allotrope with a crystal structure with two-dimensional properties. It's carbon atoms are densely packed in a hexagonal structure. Each carbon atom has four bonds, one of which is a sigma bond with three neighbour bonds and one pi bond that is oriented out of the plane. The distance between the two atoms is 1.4 angstroms. Graphene's hexagon-shaped structure is considered to be two interleaved triangular lattices. This feature is used to determine the bond structure of a single graphite layer by applying a tight bond approximation [10].

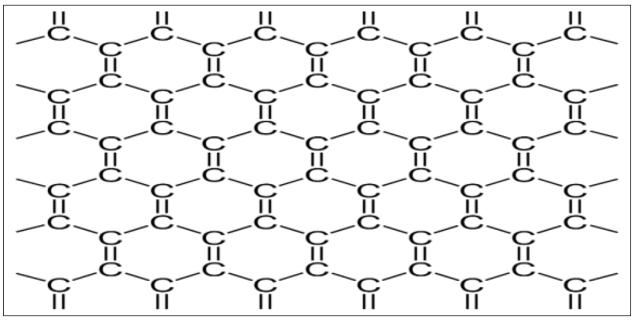

Figure 1. Structure of graphene

The stability is due to its close package of carbon atoms and the sp2orbital hybridization of the Px group, Py, which makes a sigma bond. The final Pz electron is a Pi bond. The hybridization of pi bonds together will form pi bonds and pi* bonds. Most of the graphene's electronic properties are due to these band atoms. Solid graphene sheets show the graphite layering diffraction. Unlayered graphene with only rings was found in onions [11]. Graphene can self-repair the holes. When bombed with pure carbon atoms, the atoms completely arrange them into a hexagon, filling the holes. The structure of the atom in graphene is isolated and studied by transmission electron microscopy (TEM) on graphene sheets placed between bars of the metal grid. The pattern of electron diffraction showed the structure of the honeycomb lattice [12]. Structure of graphene is shown in Figure 1.

2.1. Epoxy properties

The primary reason for epoxy's popularity is its superb mechanical strength. Epoxy also has excellent resistance to chemicals. After setting, there is no worry of a chemical reaction that will weaken the seal. That resistance makes it ideal for electronics and electrical systems and other industrial applications.

2.2. Graphene properties

The impressive intrinsic mechanical properties of graphene, its stiffness, strength and toughness, are one of the reasons that make graphene stand out both as an individual material and as a reinforcing agent in composites. it is one of the best electrical conductors on Earth. The unique atomic arrangement of the carbon atoms in graphene allows its electrons to easily travel at extremely high velocity without the significant chance of scattering, saving precious energy typically lost in other conductors [13].

2.3. Experimental work

2.3.1. Epoxy-graphene mixture preparation

The initial step in the preparation of the Graphen-Copper Functionality Gradient Material is the preparation of the epoxy resin and graphene mixture. The graphene that is powdered must be added to the epoxy resin in the glass. The amount of graphene required for the production of graphene-copper Functionality Gradient material is 5 g. Once the graphene is added to the epoxy resin in the glass, it must be well stirred for some time to make the epoxy resin and the graphene to be properly bonded to each other. The hardener used in this gradient functionality is Triethylenetetramine (TETA). The hardener is used in this mixture because the epoxy resin, which is in liquid form, must somehow solidify to be added to the layer. Triethylenetramine is a hardener to be used at a ratio of 1:10 which means that if 200 g of epoxy resin is used, 20 g of Triethylenetramine must be added. Epoxy mixture is shown in Figure 2.

Figure 2. Epoxy mixture

2.3.2. Epoxy-graphene mixture coating and placing the copper mesh

After the epoxy graphene mixture has been prepared, a rectangular flat plate is removed and a rubber mould is produced on all four sides of a rectangular flat plate. When the rubber mould is placed on the plate, and Over Head Projector (OHP) sheet is placed on the plate. The OHP sheet is coated with wax. It has to be dried for some time. The mixture of epoxy resin and graphene is then coated on the OHP sheet with a wax coating. The copper mesh and the copper particles are then placed on the epoxy-graphene coating. The epoxy coating must be half-dried so that the copper mesh is completely bound to the epoxy-graphene coating. Copper mesh, along with copper particles, will occupy almost 20% of the entire first layer. Once the copper mesh has been attached to the epoxy coating, the entire setup must be dried for almost 45-50 min. If it is not well dried or if another layer is placed over it the binding strength between two layers would be reduced. The first layer thus consists of epoxy resin, graphene and copper mesh (copper particles). The first layer which would be at the bottom would have high electrical conductivity as well as high thermal conductivity. This layer would have high strength and high properties in this layer. Copper mesh with epoxy graphene is shown in Figure 3.

Figure 3. Copper mesh with epoxy graphene

2.3.3. Second layer Preparation

Once the first layer of FGM is finished with copper mesh, epoxy and graphene. Another OHP sheet is placed over the first layer of the setup. Then the OHP sheet is again coated with a wax coating. Then the wax coating is made to dry for some time. Once dried, the epoxygraphene mixture is coated above the dried wax coating. The epoxy graphene coating is made to dry again for almost 1 h to obtain better results. Then the rectangular flat plate is again placed at the top of the second layer. The weight of 500g is kept above the total setup. Then the whole setup with the weight would be dry for one full day. The longer the setup will dry, the stronger and more FGM properties it would have. Then the weight would be removed. This second layer would be electrically insulated and thermally conductive.

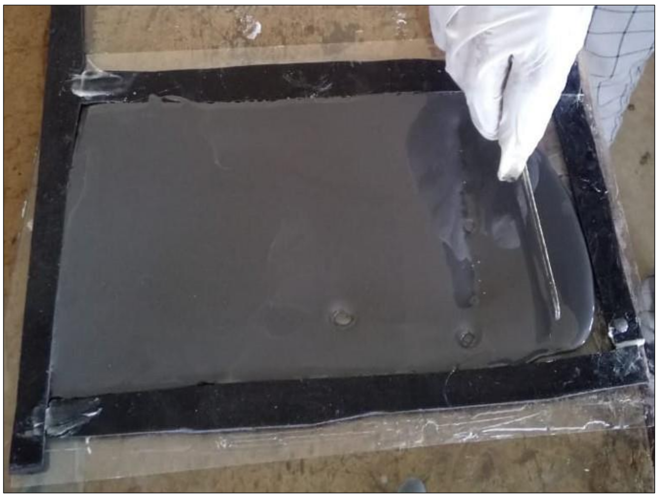

Figure 4. Coating of the second layer

The FGM is completed with its fabrication; tests are to be carried out to check the properties of these gradient functionality materials. Functionality gradient materials are those made up of different materials so that desirable properties can be obtained. After the production of functionally gradient materials, all-important properties must be tested and their results can be plotted. Coating of the second layer isshown in Figure 4**.**

3. Results and discussions

3.1. Thermal conductivity test

The thermal conductivity of a material is a measure of its capacity to conduct heat. The thermal conductivity characteristics of the graphene-coated epoxy gradient functionality material were analysed using Lee's Disc method. Steam has been used as a heating medium. The diameter of the chamber and the diameter of the specimen were maintained to prevent the entry of atmospheric air. Three circular specimens with a diameter of 112 mm and a thickness of 3 mm were tested for average thermal conductivity. The steady-state temperature was observed on both the chamber and the bottom metal disc using a thermometer. The cooling rate was calculated after the metal disc was removed from the test specimen. A graph has been plotted between time and temperature. The thermal conductivity value has been calculated. Figure 5 shows Lee's disc device used to detect thermal conductivity with appropriate dimensions [14].

Figure 5. Lee's Disc method

3.2. Electrical Conductivity test (Dielectric Analysis)

Electric conductivity is a fundamental property of a material that quantifies how strongly it resists or conducts electrical current [15]. Dielectric properties such as dielectric constant and dielectric loss of graphene-coated epoxy functionality gradient material were analysed using an LCR metre (HIOKI 3532-50, Japan) as standard ASTM D150. The operating frequency used for this study ranged from 50 Hz to 5 MHz. The voltage and current of the measurement signal varied from 10 mV to 5 V and from 10μA to 100 mA, respectively. All measurements were made with a basic accuracy of ±0.08 percent. The operating temperature ranged from RT to 2000C. Circular specimens with a diameter of 13 mm as per ASTM D 150 were used to test the dielectric constant (ε') and the loss (ε''). Samples were stored between two circular head electrodes as a parallel plate capacitor method. The input voltage was kept constant and the frequency changed step by step to 5MHz. Resistance and current were noted for each increase in the frequency of corresponding capacitance in parallel. The LCR meter measures current, voltage and phase angle and calculates the corresponding LCR values. LCR meter is shown in Figure 6.

Figure 6. LCR meter

3.3. Interlaminar shear Strength test

The interlaminar shear strength of the graphene-coated epoxy functionality gradient material was tested by three-point bend tests following ASTM D 2344. According to the known standard, the width is three times the thickness. Likewise, the length is 10 times the thickness. Universal Testing Machine (UTM) as shown in Figure 7.

Figure 7. Universal Testing Machine (UTM)

3.4. Graphene-epoxy functionality gradient material (FGM)

Table 1 shows the interlaminar shear strength of the graphene-epoxy gradient functionality material. Graphen-epoxy functionality gradient material gives maximum interlaminar shear strength. As-received and graphene-epoxy composite values are 23 MPa and 27 MPa respectively. Improvement of 17.4% on InterLaminarShearStrength (ILSS) is the result of improved adhesion and delamination resistance of Graphene in the epoxy matrix. Improved adhesion between fibre and resin is the result of a reaction between the NH2 functional group on the surface-modified graphene and the epoxy resin group. The addition of both as-received and surface-modified ferric oxide particles to epoxy resin reduced the delamination resistance of graphene under shear loading. Particles that are placed on the Graphene contact surface in the epoxy resin may affect the direct bonding of graphene and resin. As a result, the ILSS of Graphene-epoxy gradient functionality of the added hybrid epoxy composite material is reduced [16]. ILSS graph of the sample is shown in Figure 8.

Table 1. Interlaminar shear strength

Material Designation	**1 % weight of graphene FGM**	**2% weight of graphene FGM**
	ILSS(MPa)	**ILSS (MPa)**
RG	20.02	18.9
RG_1	20.1	20.6
RG_{11}	21.4	17.8
RG_{12}	21.01	18.7
RG_2	18.2	18.09
RG_{21}	20.6	19.1
RG_{22}	20	19.06

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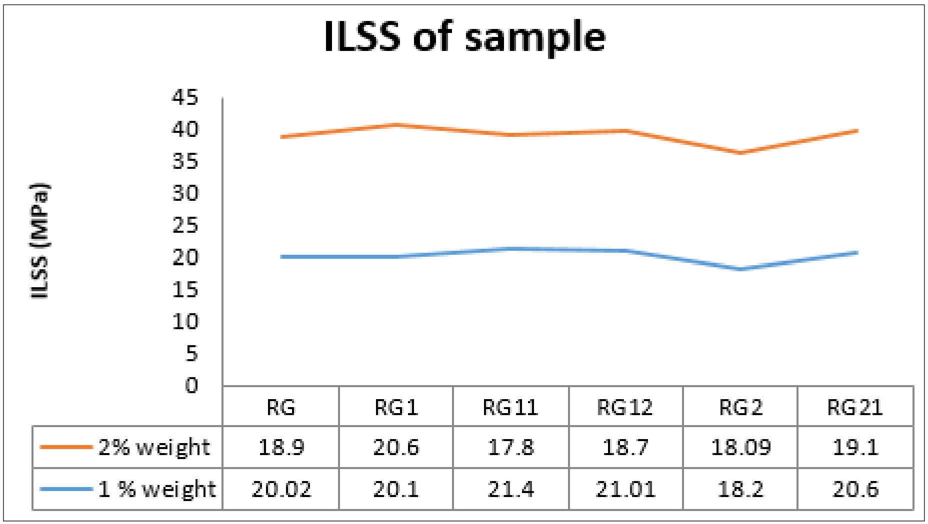

Figure 8. ILSS graph of sample

3.5. Pure epoxy vs graphene epoxy functionality gradient material (FGM)

Figure 9 shows the thermal conductivity of graphene-epoxy resin as-received and surface-modified gradient material. The addition of graphene to epoxy resin in either as-received or surface-modified thermal conductivity improved by 20.1 and 22.4 %. This is due to the ability of graphene to conduct more heat energy through the adjacent molecule, leading to improved thermal conductivity [17].

Figure 9. Testing specimen for thermal conductivity

3.6. Pure epoxy vs graphene epoxy functionality gradient material (FGM)

Figure 10 shows the graph of dielectric loss Vs frequency of graphene-epoxy resin function gradient material. Pure epoxy resin results in a maximum dielectric loss of 0.3 at a lower frequency. This is due to the presence of alkyne compounds on the primary epoxy chain, which responds to the external frequency and induces electronic polarisation, thereby increasing the mobility of charges at a lower frequency. However, the dielectric loss decreased at high frequencies as a result of poor relaxation time for the composites to be polarised. Although in graphene epoxy functionality gradient material, there is a huge increase in frequency dielectric loss. This is because more dipole molecules of graphene become progressively polarised and conductive, which are transformed into heat due to poor dielectric relaxation [18].

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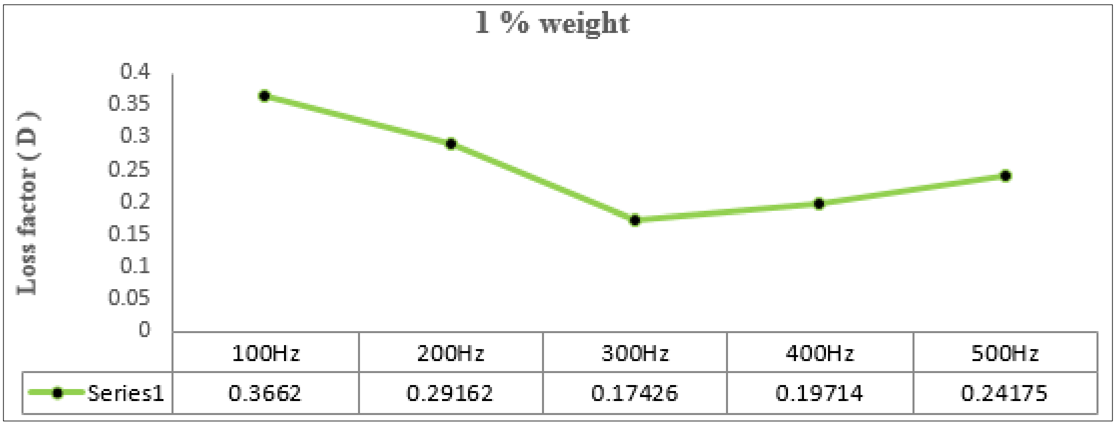

Figure 10. Loss factor graph of 1% weight

4.Conclusions

The role of adding graphene of different quantities together with thermosetting of epoxy polymers has been studied. The effectiveness of graphene on the epoxy matrix for their thermal, dielectric and shear strength has been studied. Thus, epoxy-graphene functionality gradient material is manufactured using dual casting and the graphene-epoxy functionality gradient material is tested for three main parameters. They are thermal conductivity, electrical conductivity and interlaminar shear strength, which are carried out as necessary for the application of the motherboard in the central processing unit. The main purpose of making this epoxy composite using graphene is to reduce the heat produced in the motherboard of the central processing unit. There are a lot of epoxy composites made with a lot of carbon fullerenes like carbon nanotubes. The results of the mechanical behaviour and thermal stability studies show that graphene improves properties such as thermal conductivity, electrical conductivity and laminar shear strength.

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