PREPARATION AND CHARACTERIZATION OF CARBON FIBER EPOXY COMPOSITE COATED BY GRAPHENE

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Abstract. Developing a conductive composite using graphene is very important in manufacturing aircraft structures toward enhancing their electrical properties for future aviation applications. Consequently, this study used reduced graphene oxide (rGO) and functionalized graphene nanoplates (FGNP) to coat carbon fiber-reinforced epoxy composite (CFRE) for improving its properties to obtain an outstanding conductive composite. The painting method was used in this study to coat CFRE with rGO, while the inkjet printing method was used to coat CFRE with FGNP; after that, the conductive composites (CFRE/rGO and CFRE/FGNP) was fabricated using a hot press mold. Morphological characterization using atomic force microscopy was carried out to understand the behavior of the different multiscale laminates manufactured. The results showed that rGO and FGNP coating layers were uniformly and homogeneously distributed over the surface of CFRE, and there were no flaws or creation of voids between the coating layers and CFRE surface. In addition to that, the electrical conductivity of CFRE coated with rGO and FGNP was enhanced and increased significantly with a percentage of 8015%.

Keywords: Electrical Conductivity, Carbon Fiber, Composite, Graphene, lightning strike

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Introduction

Metals have been used in aircraft manufacturing for decades. However, metals are heavy, costly, need expensive maintenance, and are prone to corrosion. Therefore, aircraft manufacturers have recently turned to using composite materials in their aircraft industry due to their distinctive advantages. Composite materials are lightweight, where the application in the manufacturing of aircraft structures leads to improving the fuel efficiency and performance of the aircraft, in addition to reducing operating costs in the long run. Composites also provide structural strength comparable to metallic alloys (stronger than aluminum or steel); therefore, they are important to the aviation industry. Carbon fiber composites are used extensively in aircraft applications such as fuselages, leading edges, and wing surfaces. However, because carbon fiber-reinforced epoxy composite materials are poor conductors of electricity, they are prone to damage from lightning strikes. This has led to aircraft companies incorporating copper or aluminum meshes into composite materials, adding significant weight and cost. Therefore, it is necessary to find a new conductive composite material to solve these problems. These conductive composites contain an embedded layer of conductive fillers such as carbon-based materials like graphene and carbon nanotubes [1-4].

Nano-sized reinforcements like carbon nanotubes (CNTs) and graphene are considered key elements of the next-generation reinforced composites. With the incorporation of these nano-reinforcements into polymeric matrices, mechanical, electrical, and thermal properties can be enhanced without additional fillers. Therefore, using these conductive composites in the aircraft industry will solve these problems effectively; conductive composite materials have allowed engineers to overcome difficulties, and now, they are frequently used in the aircraft industry. Due to its extraordinary and wonderful properties, graphene revolutionized the industry; therefore, it is used in many applications such as aviation, automotive, electronics, etc. These exceptional properties, such as high strength and stiffness, high electrical conductivity, and high thermal conductivity, paved the way for graphene to be used with polymers to fabricate conductive composites [5-7].

Scientists have carried out many studies and research to improve the properties of carbon fiber reinforced epoxy composites by adding graphene, which led to developing conductive composite materials widely used in aviation applications. For instance, Chunxia et al. [8] prepared a graphene and carbon fiber nanopaper for multifunction composite materials in aviation, such as a lightning protection system. Kumar [7] used graphene as a replacement material in fiber-reinforced composites to protect against lightning strikes. Vishnyakov et al. [9] used a conductive nanostructured carbon modifier to improve the electric conductivity of carbon fiber-reinforced plastic laminates to withstand the high currents coming from lightning strikes. Kruckenberg et al. [10] invented electrically conductive composites reinforced by different nanofillers such as carbon nanotubes and graphene nanoplates, to protect aircraft from lightning strikes. Imran et al. [11] prepared a conductive composite of carbon/epoxy composites by graphene, and they found out that the electrical conductivity was enhanced. Bangwei et al. [3] used graphene to coat carbon fiber epoxy laminate to protect it from lightning strikes.

The aim of this research is to coat carbon fiber reinforced epoxy composites with reduced graphene oxide and functionalized graphene nanoplates to improve the composites' electrical and thermal conductivities, thereby allowing them to be used for more applications.

Materials and Methods

Carbon fabric reinforced epoxy (HexPly 8552 prepregs) was supplied by Composites Technology Research Malaysia Sdn. Bhd, Melaka, Malaysia (see Figure 1). HexPly 8552 prepregs is a high-performance tough epoxy matrix for use in primary aerospace structures. It exhibits good impact resistance and damage tolerance for a wide range of applications. It has been used as an amine-cured epoxy coating, and the carbon fabric is manufactured with T300 fiber [12,13].

Figure 1. Carbon fiber epoxy prepreg

Reduced Graphene Oxide (rGO) was used to coat the top surface of carbon fiber-reinforced epoxy composite (CFRE) to improve its electrical conductivity. rGO was prepared in the laboratory at the Faculty of Science at University Putra Malaysia. Firstly, graphite oxide was obtained by treating pristine graphite with strong oxidizers such as sulfuric acid. Then, graphite oxide was mixed with water; then, using sonication and stirring for 4 h, it was exfoliated into a few layers of graphene oxide (GO) sheets. After centrifugation for a certain period, the graphene oxide sheets were reduced to rGO by the chemical method using sodium hydroxide. Finally, rGO paste was prepared by mixing a certain percentage of rGO in the water, as shown in Figure 2(a).

Functionalized graphene nanoplates (FGNP) are also another form of graphene used to coat the top surface of CFRE to improve its electrical conductivity. FGNP was prepared in the laboratory at the Faculty of Science at University Putra Malaysia. Graphene nanoplatelets (GNPs) were functionalized by mixing 1 g of GNPs with 10 g of polymethyl methacrylate and heated at 150 ^{o}C for 24 h. Then, GNPs functionalized with polymethyl methacrylate were decanted by filtration. Finally, 10 mg/ml of functionalized GNPs was dispersed in a mixture of water and polymethyl methacrylate, methanol, and polyvinyl alcohol to obtain FGNP, as shown in Figure 2(b).

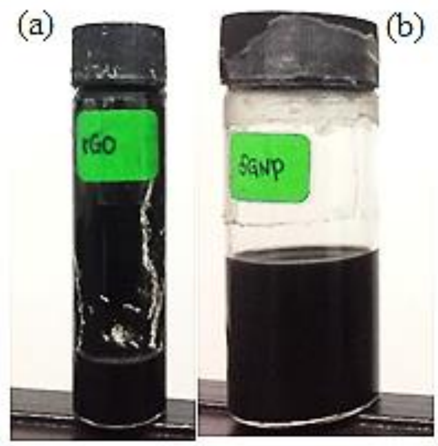

Figure 2. The types of graphene prepared, (a) FGNP and (b) rGO

***The Preparation of Specimens*.** CFRE is a carbon fiber reinforced epoxy composite without graphene, and this specimen was the control sample. CFRE was fabricated using the hot press molding method, as shown in Figure 3. 12 layers of HexPly 8552 prepregs were stacked one after another to form a CFRE laminate; then, it was cured using hot press molding at 180 °C for two hours.

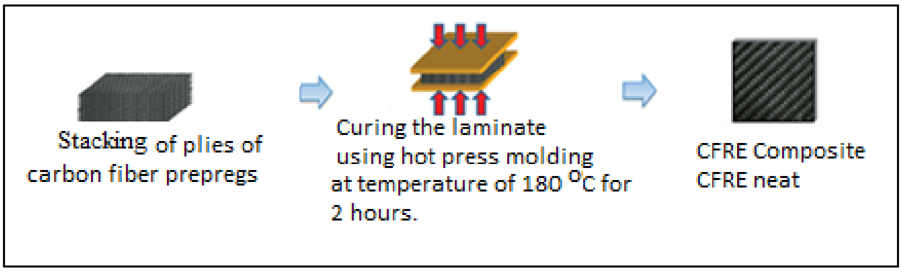

Figure 3. Procedures of preparation of CFRE neat specimen

CFRE/rGO specimens were prepared as described in Figure 4. Specimen CFRE/rGO has CFRE that coated with rGO (wt% of rGO is 90) paste after curing using a hot press machine at a temperature of 180 °C for 2 h.

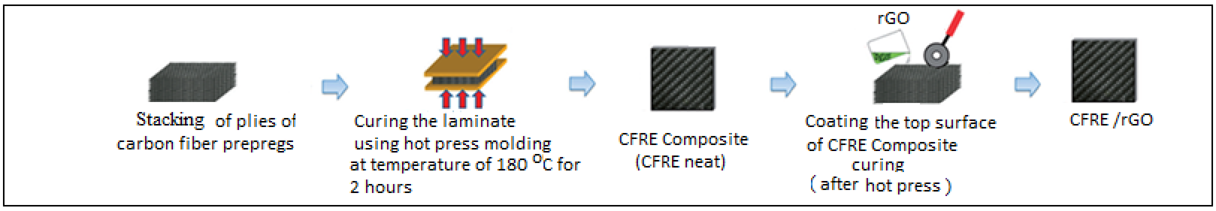

Figure 4. The procedures for preparation of CFRE/rGO specimens

In contrast, CFRE/FGNP specimens were prepared, as shown in Figure 5, by printing the top surface of CFRE by FGNP using an inkjet printer following the shape in Figure 6.

The graphene layer was printed on the surface of the CFRE composite using an inkjet printer that employed a cartridge with nano-nozzles. The graphene passed through these nozzles to be printed on the CFRE composite surface. This printer was completely controlled by a special software installed on the computer; then, the printer printed the desired shape on the surface of the composite.

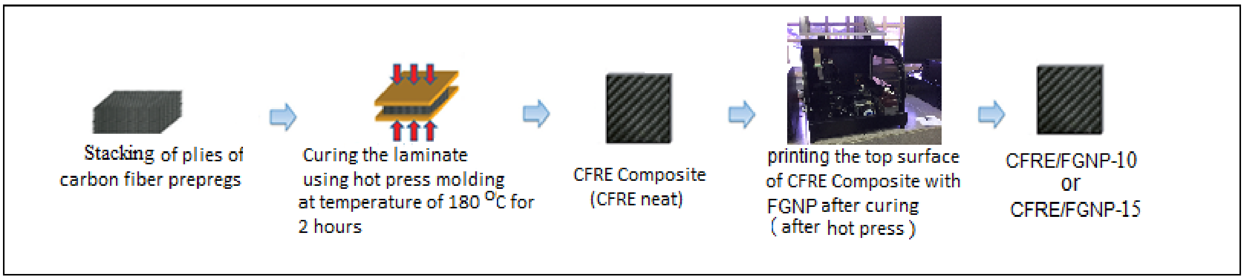

Figure 5. The procedures for preparation of CFRE/FGNP specimens

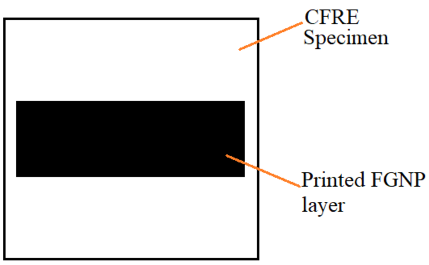

Figure 6. The shape of printed FGNP layer on the top surface of CFRE

Experimental Tests. Atomic force microscopy (AFM) is a three-dimensional topographic technique with a high atomic resolution. AFM is used as a surface imaging tool to scan surface materials, produce topographic images, and determine roughness, grain size, and features on the nanoscale. AFM allows us to investigate the structure and morphology of the surface. AFM device (Brand name: QUESANT-USA, Model name: 250, was used to find the thickness of rGO and FGNP coating layers for specimens CFRE /rGO and CFRE /FGNP. A four-point probe device was used in this research to measure the electrical conductivity of CFRE/rGO and CFRE /FGNP composites in addition to CFRE neat specimens. The specimens were cut into a (1 cm x 1 cm x 0.2 cm) to fit and be used in the device. A four-point probe device measured the voltage (V) and the current (I) through the specimen; then, the electrical conductivity was calculated.

Scanning Electron Microscopy (SEM) is used to obtain topographic information from sample surfaces and surface structures. The SEM is an electron microscope that images the sample surface by scanning it with a high-energy beam of electrons. In this research, the scanning electron microscope (brand: FEI, model: NOVA NANOSEM 230) was used to characterize the top and side surfaces of specimens (CFRE neat, CFRE/rGO, and CFRE /FGNP). Samples were sputter-coated with gold to prevent electrical charging during the examination and obtain clearer images.

Results and Discussion

Atomic Force Microscopy (AFM). AFM test was used to measure the thickness of rGO and FGNP coating layers, as shown in Table 1. According to the results, the thickness of rGO coating layer was 3.1 (µm), while the FGNP coating layer was 0.3 µm.

Table 1. Thickness value of rGO coating for all specimens

The specimen	Coating layer thickness (µm)
CFRE /rGO1	3.1
CFRE /FGNP	0.3

Based on Table 1, it can be noted that the rGO layer thickness in specimen CFRE/rGO was higher than the FGNP layer thickness in specimen FRE/FGNP, since the reduced graphene oxide contains much higher amounts of graphene than the FGNP. Due to a lack of graphene content during the printing process, it was necessary to repeat the printing process many times to obtain a proper thickness.

Morphological Characterization. Figures 8 and 9 show SEM images of the top surface of specimens: CFRE neat, CFRE/rGO, and CFREFGNP using SEM. The SEM image of the neat carbon fiber composite is shown in Figure 8. (a) reveals a plane, smooth and clean surface, and it was noticed that there were no FGNP or rGO layers at the top surface. The SEM image of the specimen CFRE/rGO shown in Figure 8(b) reveals a clear rGO coating layer, which was painted over CFRE top surface, while the SEM image in Figure 8(c) showed FGNP coating layer printed over CFRE top surface using a special inkjet printer. Figures 8(d) and (e) show SEM images of reduced graphene oxide sheets and graphene nanoplates sheets, respectively, at a magnification of 500 nm, showing that the sheets were transparent and homogeneous with fewer surface defects and agglomeration. Figures 9(a) and (b) present the SEM image of the side view for specimens CFRE/rGO and CFRE/FGNP, respectively. The images revealed that the thickness of coating layers was distributed over the CFRE surface in a homogeneous shape.

The changes in CFRE surface topography after coating it with rGO and FGNP sheets were verified by SEM. The results showed that CFRE neat has a relatively smooth and clean surface. After the coating process, some wrinkled rGO sheets were uniformly deposited on the CFRE surface, which can be observed in Figures 8(b) and (d). The result certified that the rGO sheets were successfully immobilized on the CFRE surface; the wrinkled rGO sheets having a small agglomeration on the CFRE surface might be attributed to the removal of the functional group during the chemical reduction of GO [14, 15]. The SEM images in Figures 8(c) and (e) demonstrated that FGNP sheets exhibited similar morphology to curvy and wrinkled sheets. It was noted in Figures 9(a) and (b) that the rGO coating layer in specimen CFRE/rGO was thicker than the FGNP-printed layer in specimen CFRE/FGNP, and this corresponded to the results was obtained in the AFM test. It was noted that rGO and FGNP coating layers were uniformly and homogeneously distributed over the surface of CFRE, and there were no flaws or creation of voids between the coating layers and CFRE surface [15 – 17]. The results confirmed the success of painting and inkjet printing methods for coating CFRE with rGO and FNP, which contributed to improving the properties of CFRE.

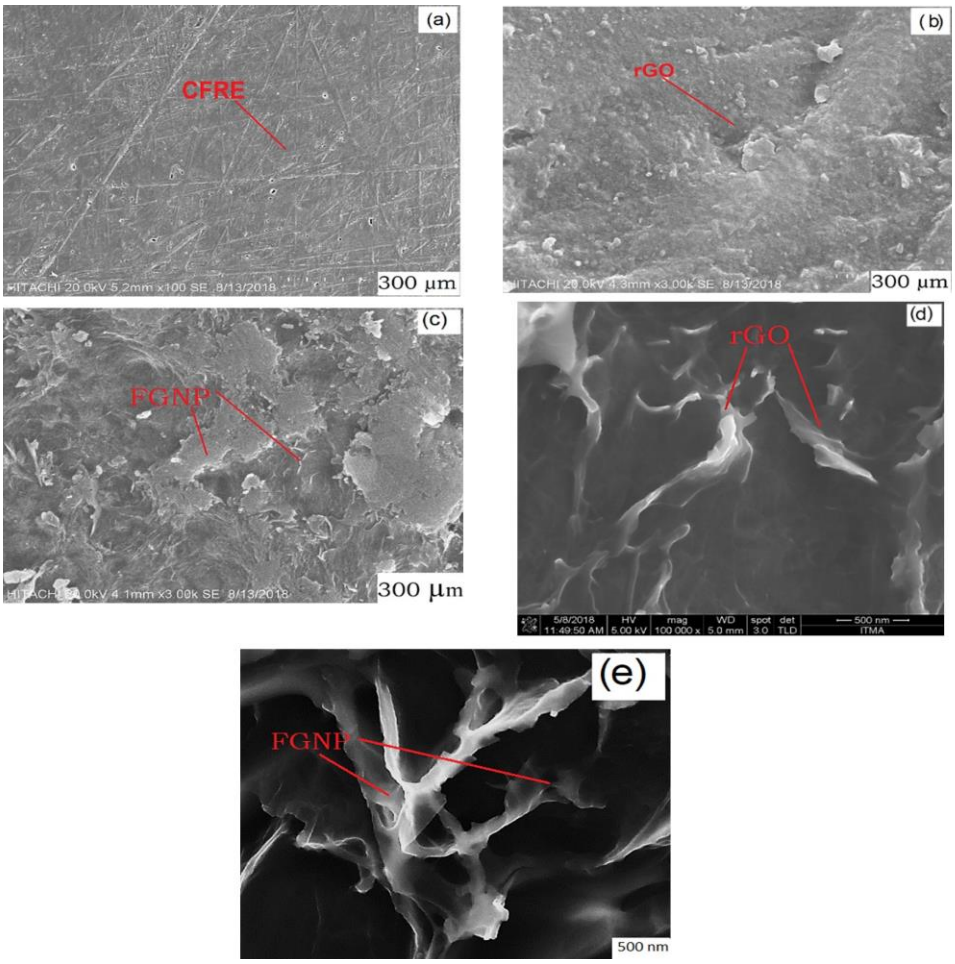

Figure 8. SEM images of top surface for the specimens (a) top view image of CFRE neat (b) top view image of CFRE/rGO2-A (c) top view image of CFRE/FGNP-15 (d) top view image of CFRE/rGO2-A at magnification of 500 nm and (e) top view image of CFRE/FGNP-15 at magnification of 500 nm

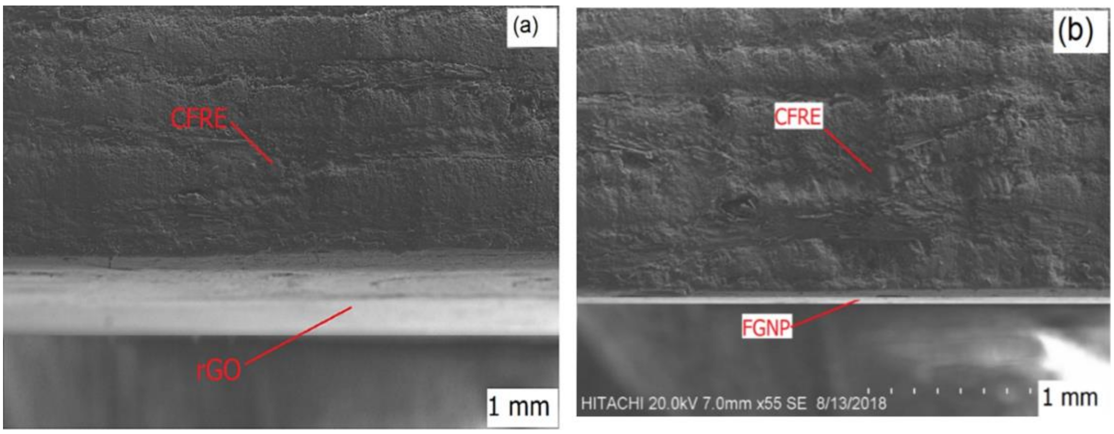

Figure 9. SEM images of side view of a) CFRE/rGO2-A and b) CFRE/FGNP-15

The Electrical Conductivity Test. It was observed that the electrical conductivity of all specimens decreased slightly with increasing temperature. However, this change is insignificant and considered constant. Figure 10 shows that the electrical conductivity increased by about 81 times with a percentage of 8015% after coating it with rGO, while for CFRE with FGNP coating, the electrical conductivity increased by about 23 times with a percentage of 2146 %. The results showed that CFRE/rGO specimen possessed the highest electrical conductivity of 1.12x105 (S/m), while CFRE neat has the lowest electrical conductivity of 1.38 x103 (S/m), as shown in Figure 4.10, and the electrical conductivity of CFRE /FGNP was 3.1 x104 (S/m). The electrical conductivity of CFRE was improved because rGO and FGNP coating layers created conducting paths through CFRE composite, decreasing electrical resistance, which led to an increase in electron flow through CFRE composite. Based on the analysis, it was determined that CFRE specimens could achieve higher levels of electrical conductivity b y increasing graphene content since higher graphene content formed more paths through the sample.

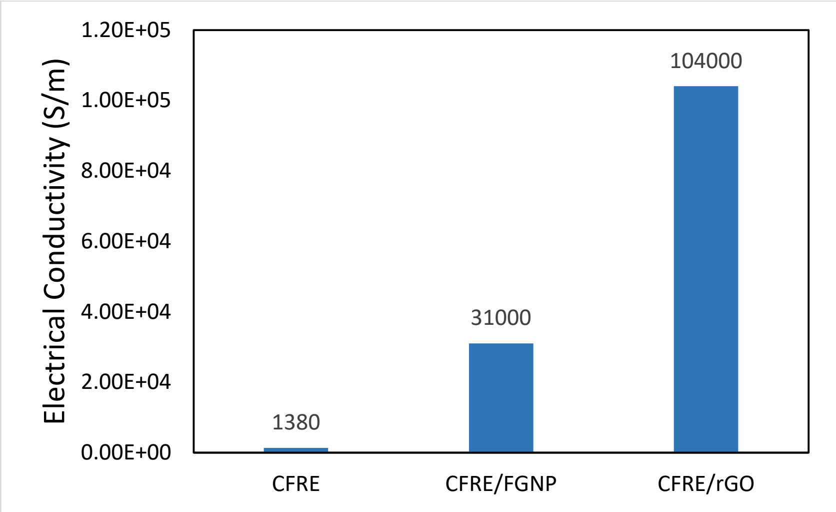

Figure 10. Electrical conductivity average values for all specimens.

The results of electrical conductivity in this study were compared with the results of previous studies, as presented in Figure 11. It is clear from the comparison that the results of this study were much higher because the properties of graphene used in this study were more close to the pristine graphene. The graphene coatings were more homogeneous and uniformly distributed over the surface of CFRE, forming more bridges between graphene sheets, leading to further increment in the electrical conductivity.

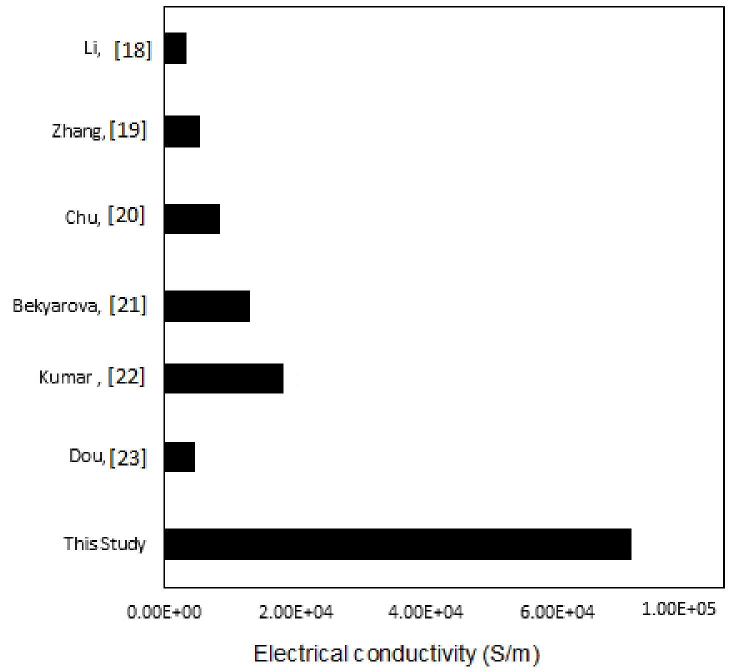

Figure 11. Comparison of results of this study with previous studies.

The correlation between AFM and electrical conductivity tests revealed that the electrical conductivity of CFRE could be increased to a higher level by increasing the thickness of the coating layer, as shown in Figure 12. As the FGNP coating thickness increases, more FGNP can be added to the surface of CFRE specimens, thus the possibility of forming more bridges between graphene sheets increases, resulting in a decrease in electrical resistance and an increase in electrical conductivity.

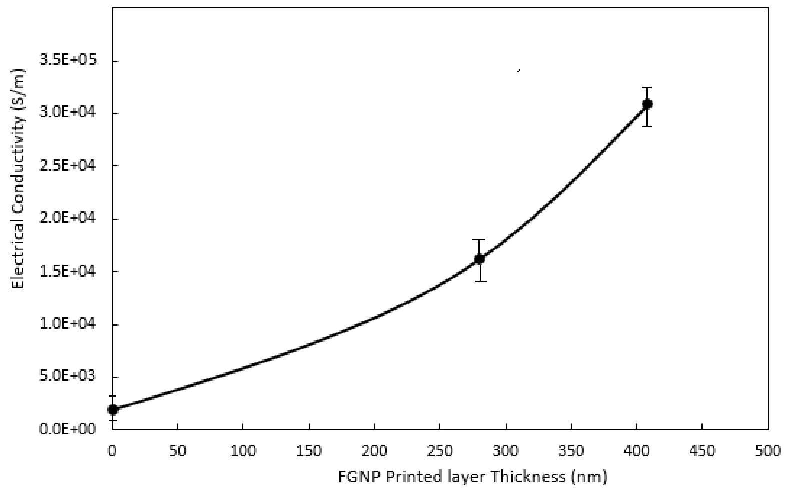

Figure 12. Electrical conductivity vs. coating thickness.

Conclusion

In this research, carbon fiber reinforced epoxy composite (CFRE) was coated with reduced graphene oxide (rGO) and functionalized graphene nanoplates (FGNP) to enhance its electrical conductivity and make it more suitable for aerospace applications. In this research, the painting method was used to coat CFRE with rGO, wherein the inkjet printing method was used to coat CFRE with FGNP. Morphological characterization using atomic force microscopy was carried out to understand the behavior of the different multiscale laminates manufactured. The results showed that rGO and FGNP coating layers were uniformly and homogeneously distributed over the surface of CFRE, and there were no flaws or creation of voids between the coating layers and CFRE surface. The results confirmed the success of painting and inkjet printing methods for coating CFRE with rGO and FGNP, which contributed to improving the properties of CFRE. After fabricating the composites (CFRE, CFRE/rGO, and CFRE/FGNP), the electrical conductivity for these composites was measured using a four-point probe device. The results showed that the electrical conductivity of CFRE was enhanced and increased significantly when it was coated with rGO and FGNP.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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