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Abstract. In general, the composites are electric insulators but there are so many applications where the properties of composites are required along with partial conductivity. In aeronautical applications to avoid turbulence, it is required to provide electromagnetic shielding effect along with an increase in electrical conductivity. While improving electrical conductivity to serve the purpose for which the FRP (Fiber-reinforced polymer) is fabricated, balancing other properties such as mechanical and thermal properties is an essential task. In this paper, a brief review of the previous work is carried out to understand the effect of various metallic fillers on the characteristics of FRP composite. After reviewing the scope of using metallic filler in FRP composites, it is figured out that the electrical conductivity of FRP can be improved by adopting metal particulates as fillers in the process of FRP fabrication. These procedures play an additional role in the FRP structure and the electrical conductivity rises significantly in some of the cases.

Keywords: FRP, Electrical conductivity, Electromagnetic shielding, Filler.

1. Introduction

Over the past few years, FRPs have emerged as the principal material for various industries such as aeronautics, electronics, structure, communication, etc. This has led to the exploration of various properties of FRP in context with its mechanical, thermal and electrical performances. The area of mechanical and thermal properties has been well explored and there are numerous applications in this era based on the results and discussion of various experiments performed in the field. Though the domain of their electrical properties is being studied it has not reached its full potential and much more is yet to be done. Various applications are using the inherent electrical insulation of most of the FRPs but less work has been done to improve the conductivity to be able to use them more vividly. Industries like aeronautics and automobiles require their structures to be strong as well as a good electrical conductor to deal with situations like a lightning strike, electromagnetic interference, etc. and this has led to the need of improvement in electrical conductivity of the FRPs along with a minor change in their strength. The excessive weight addition by metals to fulfill this requirement plays an important role in the dependence on FRPs. Properties for various reinforcement materials are mentioned in the table below.

Table 1. Comparison of Properties of Various Materials [1].

Material	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Density (kg/m^{3})	Modulus of Elasticity to Density Ratio (Mm^2/s^2)
Carbon	2200-5600	240-830	1800-2200	130-380
Aramid	2400-3600	130-160	1400-1500	90-110
Glass	3400-4800	70-90	2200-2500	31-33
Epoxy	60	2.5	1100-1400	1.8-2.3
CFRP (Carbon fibre reinforced polymer)	1500-3700	160-540	1400-1700	110-320
Steel	280-1900	190-210	7900	24-27

As inferred from the above table, the tensile strengths of carbon and glass fibers are almost similar i.e. in the range of 2200-5600 MPa and 3400-4800 MPa respectively. However, aramid and other fibers show a lower strength compared to these. Modulus of elasticity shows a larger deviation for different reinforcement materials. Modulus of elasticity to density ratio (or specific modulus) is an essential factor of material selection for stiffness-driven structures such as wings of an airplane. For structural weight to be minimum along with high stiffness, the high specific modulus is required.

In a study performed by Ha et.al [2], used aluminum mesh in FRP composite to be used in B787 aircraft has conductivity 73000 S/m (Siemens/meter) whereas for maiden FRP composites could reach up to 15000 S/m. When silver nanoparticles were used as filler material it achieved up to 26000 and 28000 S/m at 5% colloid for spray time of 3 and 5 seconds respectively while 56000 and 63000 S/m at 10% colloid for spray time of 3 and 5 seconds respectively which reached about 86% of the aluminum filled composites along with reduced weight. These results are shown in fig.1.

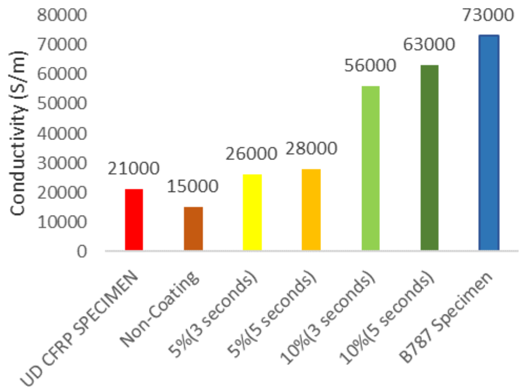

Fig.1. The comparison of conductivity from B787 aircraft spaceman and the hybrid CFRP by conductive nano-particle colloid coating [2].

Electrical conductivities of commonly used metals are within the range of 106 S/m which is still much greater than that of FRPs [3].

2. Basic Process of FRP Fabrication

The initialization of the process begins with the selection of appropriate matrix material, reinforcement, additives and choosing the technique as per the application. The matrix material is liquefied and molded-in required shape with reinforcement being done either by hand, spray or with any other technique. The impregnated resin is then left to dry or is oven-dried. The extraction of a semi-finished product is done and then the final finishing is done by various machining methods. Every FRP goes through this process with some little changes in the environment or addition of one or more processes which depends on the future use of that fabricated FRP [4].

3. Fillers in FRP

Fillers are the substances that are used in composites to improve their inherent properties along with the lesser effect on the cost which may affect some other properties. They also are used to reduce shrinkage, control viscosity, and improve part stiffness. Commonly used fillers include kaolin, calcium carbonate, silica, feldspar, talc, and glass microspheres. Fillers are not as common in high-performance composites because they may adversely affect the fiber-resin load transfer and decrease the toughness of the resin at high filler content. Some of the previously used metallic fillers are copper, zinc, silver, tin, etc. [4].

4. Effect of fillers on characteristics of FRP

An investigation conducted by Ha et al. [2] to improve the electrical conductivity of composites was done with the assistance of conductive fillers for the better performance of FRP in the aircraft lightning protection. Silver nanoparticles were used as fillers for this purpose. A colloid of silver nanoparticles was sprayed on the carbon fibers, which were then to be impregnated in the epoxy resins. The experiment was conducted for various amounts of the colloid and the spray time was also varied to examine the effect of the period for which colloid is sprayed. The electrical resistance was first measured with the contact type resistance meter which used the principle of AC 4-terminal method. The resistance was then converted into resistivity and then resistivity was finally converted to electrical conductivity. SEM (Scanning electron microscopy) and EDS (Energy-dispersive X-ray spectroscopy) verification of the silver nanoparticles was also done. The results showed that electrical conductivity was increased as much as to four times the ordinary CFRP [2].

Another experiment was carried out on CFRP by Zhu et al. [5] for their application as the anode material in the ICCP (Impressed current cathode protection) for the protection of the steel-reinforced concrete structure. This was done to find out the performance and service life of CFRP under various configurations when used as an anode in the ICCP system. The current densities applied are maintained to be constant for the idealization of conditions. The results of the experiment showed that there was no significant degradation in the electrical and mechanical properties of CFRP when subjected to anodic polarization with various current densities. The recordings were

helpful to judge the property change of CFRP and the performance was determined based on the study of the practical reinforced concrete structure layout [5].
FRPs are also used for reinforcement in concrete structures for their strengthening purpose. This is done for obtaining various features in the concrete structures such as seismic retrofitting, additional live or dead load. This reinforcement is done by various methods such as steel jacketing, externally bonded steel plates, external retrofitting, concrete jacketing and post-tensioning. The technique is selected based on interference material or vice versa. According to JSCE, 1999 [6]; the steps followed are the identification of requirements, an inspection of an existing structure and its evaluation of performance, design of retrofitting structure, selection of material and technique, evaluation of the retrofitted structure and implementation of the technique [1].
Srinivas et al. [7] performed a study on the electrical conductivity of RT (Room temperature) cured epoxy resin (LY556+HY951) containing three different particulate fillers. The particles taken for the study were classified as soft material graphite, a hard material SiC (Silicon Carbide), and a hybrid of both of them. The weight fractions of the fillers in the specimen were also varied from 10-40% in the steps of 10% for all to study the impact of the weight of the filler on the electrical conductivity. It was observed that the change in electrical conductivity of the epoxy resin was directly proportional to the weight fraction of the filler. Another observation was that the resins with 40% filler fraction showed a significant change in electrical conductivity especially the one with 40% hybrid fillers (20% Graphite, 20% SiC, and 60% epoxy resin) has electrical conductivity about 2.5 times the original epoxy. The experiment results were verified with the Maxwell-Wagnor and Wideman-Franz law which relates the thermal and electrical conductivity. The experimental results showed a good correlation with analytical equations [7].

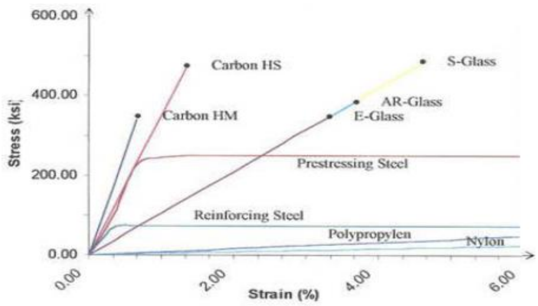

Fig.2. Schematic diagram of stress vs strain with respect to behaviour of reinforcing fibres in comparing with steel [8].

According to Tarafder and Swain [8], the stress vs strain curve for the carbon fibre is much more linear than any other fibre including various types of steel as shown in fig.2. This results in the higher strength of CFRP and thus gives it priority over others in the group for more use in the strengthening purpose. Tarafder and Swain also suggested different types of reinforcement fibres according to the purpose they are required for by a case study on the durability of FRP.
Another study performed by Caradonna *et al*. [9] to study thermal and electrical conductivity of composites with carbon-based fillers has been done which makes the use of graphene-like nano-platelets, and graphite fillers. The epoxy resin and the fillers

were first cast into a mold and then cured to obtain the experimental specimens. Multiwall carbon nanotubes were also used as fillers along with nano-platelets and graphite. Electrical and thermal conductivity was investigated for various filler composition and weight fractions. The study was accompanied by the percolation theory and it was inferred that the percolation paths enhance the electrical conductivity but were not so helpful for the increment of the thermal conductivity. Also, the results of single filler composites were compared to the hybrid fillers composites which were occupied with the combination of any two fillers out of the three. Results showed that fillers having different aspect ratios were observed to have a synergetic effect in relation to electrical conductivity showing noticeable improvement in it but showed a smaller effect if compared in case of thermal conductivity [9].

Wang et al. [10] performed an experiment to study the mechanical properties of FRP reinforcement bars when used as internal reinforcement in concrete structures. The experiment was conducted at different temperatures up to the failure of FRP bars. FRP bars of different geometry were procured from an external source and then specimens were prepared. It is observed in the experiment that stress-strain relationship of FRP bars remained linear to the range of 300-400°C. After this temperature, there was a sharp drop in the elastic modulus up to the point of failure at 500°C [10].

A study conducted by Tsangaris and Kazilas of National Technical University of Athens [11] used the metallic fillers that resulted in the increment of electrical conductivity with their concentration. These materials were complex and considered to be a chaotic mixture of conductive particles which are randomly distributed in an insulating matrix. The conductivity of the materials in DC electrical field is studied with the assistance of percolation theory where there is a rapid increase in the electrical conductivity of the material at a particular concentration of conductive phase, referred as the critical phase. In this experiment, the various specimen with multiple conductive fillers were used. The fillers used were powders of copper, aluminium, or zinc. The temperature range at which study conducted was also varying from 20° to 140°C. The results obtained from this experiment were also analyzed using percolation theory and semi-empirical algorithm were used for the determination of some new parameters [11].

5. Conclusion

The literature reviewed by the authors in the present paper shows that by using various fillers the conductivity of FRP composites can be increased without degrading its mechanical and thermal properties. Metallic and non-metallic both type of Filler materials can be used to improve the conductivity of FRP composite. The metallic fillers increase the conductivity 4 times while Non-metallic fillers increase conductivity 2.5 times. Effect of metallic fillers such as silver nanoparticles and powdered zinc, copper and aluminum have already been studied for different concentrations and at different temperature conditions. It was also concluded from the literature that the viscosity of the resin rapidly increases due to the addition of metallic filler to increase conductivity. We can infer that the electrical conductivity of FRP composites may further increase by introducing some other metallic fillers at the various concentration in different forms. Some other aspects such as variation in electrical conductivity with temperature should also be studied. The systematic alteration of electrical conductivity of FRP composites can widen the scope for the usage of FRP in applications of aeronautics where fly by wire systems are used, automobiles, communication to prevent the noise due to electromagnetic interference, etc.

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