# Perspective on Effect of Metallic Fillers on Electrical Conductivity of FRP Composites

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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 (Fibre 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 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. There are various applications using the inherent electrical insulation of most of the FRPs but less work has been done to improve the conductivity in order to be able to use them in a more vivid way. Industries like aeronautics and automobiles require their structures to be strong as well as good electrical conductor in order 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 in order to fulfil this requirement plays an important role for dependence on FRPs. Properties for various reinforcement materials are mentioned in the table below.

**Table 1.** Comparison of Properties of Various Materials [6].

| **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 strength of carbon fibres lies in the range of 2200 to 5600 MPa which is superior among most of the other reinforcement known to the industry.

In a study performed by Ha et.al [5], used aluminium mesh in FRP composite to be used in B787 aircraft has conductivity 73000 S/m (Siemens/metre) whereas for maiden FRP composites could reach up to 15000 S/m. When silver nanoparticles were used as filler material it could achieve the range 23000-63000 S/m which was about 86% of the aluminium filled composites along with reduced weight.

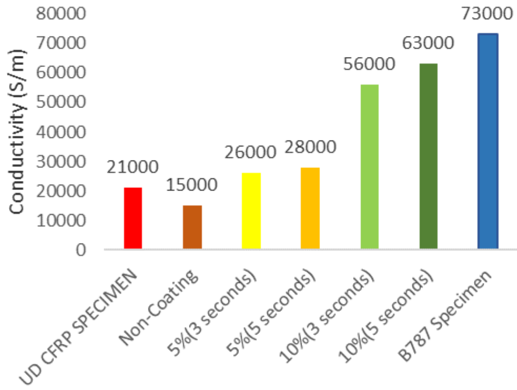


**Fig.1.** The comparison of conductivity from B787 aircraft spaceman and the hybrid CFRP by conductive nano-particle colloid coating [5].

Electrical conductivities of commonly used metals are within the range of $10^6$ S/m which is still much greater than that of FRPs [8].

## 2. Basic Process of FRP Fabrication

The initialization of the process begins with the selection 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. Extraction of semi-finished product is done and then the final finishing is done by various machining method. Every FRP goes through this process with some little changes in the environment or addition of one or more process which depends on the future use of that fabricated FRP [7].

## 3. Fillers in FRP

Fillers are the substances that are used in composites to improve its 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 fibre-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. [7].

## 4. Effect of fillers on characteristics of FRP

An investigation conducted by Ha et al. [5] 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 the fillers for this purpose. A colloid of silver nanoparticles was sprayed on the carbon fibres, which were then to be impregnated in the epoxy resins. The experiment was conducted for various amount of the colloid and the spray time was also varied to examine the effect of the time 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 [5].

Another experiment was carried out on CFRP by Zhu et al. [4] 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 condition. 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 [4].

FRPs are also used for the 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 on the basis of interference material or vice versa. According to JSCE, 1999 [9]; the steps followed are the identification of requirement, inspection of existing structure and its evaluation of performance, design of retrofitting structure, selection of material and technique, evaluation of retrofitted structure and implementation of the technique [6].

Srinivas et al. [1] 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 [1].

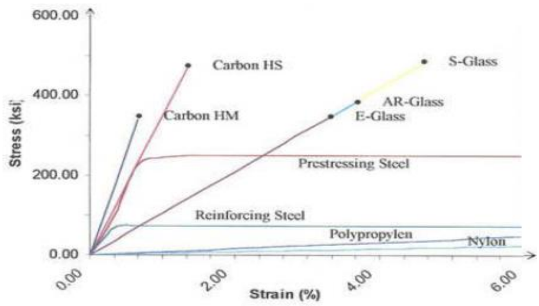


**Fig.2.** Schematic diagram of stress vs strain with respect to behaviour of reinforcing fibres in comparing with steel [10].

According to Tarafder and Swain [10], 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*. [2] 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 [2].

Wang et al. [11] 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 [11].

A study conducted by Tsangaris and Kazilas of National Technical University of Athens [3] 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 insulated 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 critical phase. In this experiment, various specimen with multiple conductive fillers were used. The fillers used were powders of copper, aluminium, or zinc. The range of 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 [3].

## 5. Conclusion

The above researches and their result shows that there is a wide 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, in the prevention of corrosion of structures by making FRP act as an anode in ICCP system. Though these play as an important factor in the industries there is still more scope left to be improved in the electrical applications of FRPs and with a constant increase in the usage of FRP, this is becoming essential for us to increment the conductivity which will open the gateways for many new applications. This has become a need because of the advantages that FRP brings into the structure like its lightweight, ease of implementation, good corrosion resistance etc. But the lower electrical conductivity of FRP becomes a barrier in its substitution for the metals and this calls for the investigation in the less concentrated domain of electrical conductivity and frequent researches need to be done to achieve our target to use FRPs instead of metals. The previous researches show that there is a big scope in FRPs to raise their electrical conductivity and further experiments need to be performed in the various configuration for the filling of conductive phases in FRP with the reference of the previous researches.

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## References

1. Srinivas, K., Bhagyashekar, M.S. and Darshan, B.G., 2018. Effect of Fillers on Electrical Conductivity of Epoxy Composites. JOURNAL OF POLYMER & COMPOSITES, 6(3), pp.25-30.
2. Caradonna, A., Badini, C., Padovano, E. and Pietroluongo, M., 2019. Electrical and Thermal Conductivity of Epoxy-Carbon Filler Composites Processed by Calendaring. Materials, 12(9), p.1522
3. Tsangaris, G.M. and Kazilas, M.C., 2002. Conductivity and percolation in epoxy resin/conductive filler composites. Materials science and technology, 18(2), pp.226-230.
4. Zhu, J.H., Zhu, M., Han, N., Liu, W. and Xing, F., 2014. Electrical and mechanical performance of carbon fibre-reinforced polymer used as the impressed current anode material. Materials, 7(8), pp.5438-5453.
5. Ha, M.S., Kwon, O.Y. and Choi, H.S., 2010. Improved electrical conductivity of CFRP by conductive nano-particles coating for lightning strike protection. Composites Research, 23(1), pp.31-36.
6. Günaslan, S.E., Karaşin, A. and Öncü, M.E., 2014. Properties of FRP materials for strengthening. International Journal of Innovative Science, Engineering & Technology, 1(9), pp.656-660.
7. Agarwal, B., Broutman, L. and Chandrashekhara, K. (2015). Analysis and Performance of Fibre Composite. 3rd ed. New Delhi: Wiley, p.562.
8. Jean Tiberghien, G. (2019). TIBTECH innovations: Metal properties comparison: electric conductivity, thermal conductivity, density, melting temperature. [online] Tibtech.com. Available at: https://www.tibtech.com/conductivite.php?lang=en_US [Accessed 25 Sep. 2019].
9. Japan Society of Civil Engineers (JSCE)., 2000. Guidelines for retrofit of concrete structures—Draft. Concr. Library Int., 36, pp.61-112.
10. Tarafder, N., Swain, R., (2016). Durability and case study of fibre reinforced polymer (Frp) IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 6(3), pp.53-62.
11. Wang, Y.C., Wong, P.M.H. and Kodur, V.K.R., 2003, October. Mechanical properties of fibre reinforced polymer reinforcing bars at elevated temperatures. In SFPE/ASCE Specialty Conference: Designing Structures for Fire, Baltimore, Maryland, September (pp. 183-192).