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Microhardness and Microstructure of thin-film Metallic and Non-Metallic Coating on Fiber Reinforced Polymer Substrate

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Abstract

Fiber-reinforced polymer composites have a dominating position place in a variety of applications due to the increased specific strength and modulus. C-FRP composite is the most appealing choice for fabricating massive structural bodies like airplanes, automobiles, blades of wind power generation, and so on. SiC-FRP is used in a range of different applications from water pipes or drains coverings to electronic enclosures. Natural fiber derived from plants is gradually replacing synthetic fiber as a reinforcement for polymer composites. One of the key issues with these components is their metallic and electrical properties. Therefore, in this study, atmospheric plasma spray is used to fabricate thick Tungsten Carbide and Chromium Carbide onto C-FRP, SiC-FRP, and natural Bamboo-FRP substrate. Coated specimens were examined for Micro-hardness and Micro-structure. Results showed that the coating has sufficient adhesion strength with drastically improved properties.

Keywords: *Fiber Reinforced Polymer, plasma Coating, micro-hardness, micro-structure, metallization.*

1.0 Introduction

The goal of this article is to determine how the properties of Fiber Reinforced Polymer change when a thin metallic and non-metallic layer is deposited to the substrate.

Fiber-reinforced polymers (FRPs) are becoming more popular in the aerospace and automotive sectors because they offer a higher strength-to-weight ratio than standard aluminum alloys (e.g., the 2000 and 7000 series) [1]. Their application, on the other hand, is limited due to low electrical conductivity, erosion resistance, and operating temperature [2,3]. As a result, when employed as airfoil structures or as building components for airplanes or wind turbines, FRPs are susceptible to damage during lightning strikes [4]. Furthermore, integrating different materials such as FRPs with metals using traditional joining techniques remains difficult. As an alternative to typical joining methods, metallized coatings may be effective for connecting zones (e.g., rivet and screw connections) of FRP/metal materials [5]. To maintain structural integrity and safety, composite materials must be metallized.

Thermal spraying might be an intriguing alternative to those costly metallic meshes, allowing for greater adjustability in employed materials, shape, and thickness for the required conductive layer.

Plasma and Arc spraying have been investigated as potential solutions [6,7], with a few successful attempts [8,9], however such high temperature techniques tend to damage the polymer matrix owing to molten droplets, rather than forming a covering. Thermal spraying has several advantages over conventional spray methods, including cost efficiency, mobility, and convenience of usage, as well as a lower heat input on surfaces and the production of oxide-free coatings. However, because of the substrate's vulnerability to erosion [10] and other specific features of these materials, such as temperature-dependent thermal [11] and mechanical properties [12], Thermal Producing sprayed coating on organic materials is difficult.

According to the limited research, thermal spray methods can be utilised to deposit metallic coatings on FRP substrates, however they can present certain obstacles. Tungsten Carbide (WCC) and Chromium Oxide (Cr_2O_3) coatings can also be used as a suitable bond coat or top coat for polymeric composites [13,14,15,16]. To protect FRP materials from erosion, fibre breakage, and thermal deterioration during the TS process, a coating of filler particles may be applied as a top surface layer or as a bond coat [17,18,16,20]. The two main obstacles to the widespread use of Thermal Spray procedures as a coating production method for FRP substrates are increased coating/FRP adhesion and reduced mechanical and thermal deterioration of the substrate throughout the spray process [21].

The contrast between the characteristics of the coating and the substrate-based polymer might produce interface stress, resulting in rupture and crack formation. Two primary issues must be resolved when a metal compound is deposited on a polymer substratum: (a) coating should be deposited so that the substrate will not be damaged with minimum heat and speed impact. (b) ensure reliable adhesion in service of the final coating.

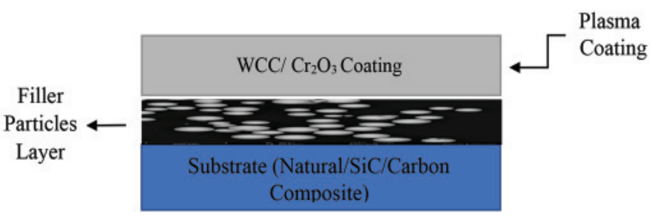

Figure 1: Coating ideas investigated in this study

The ultimate purpose of this project was to show how to change a composite's surface to allow for a metallic and non-metallic coating procedure on FRPs (Fig. 1). Bamboo, SiC, and Carbon Epoxy composites serve as the substrates. The microhardness and Microstructure characteristics of WCC and Cr2O3 coatings placed on FRPs were examined.

2.0 Experimental Procedure

2.1. Preparation of Composite Material

The composite materials are prepared by using the hand lay-up method. Epoxy and hardener mixture (10:1 weight ratio) is applied after every layer of fiber. Table 1 describes the weight ratio of fiber and epoxy matrix. The mold surface is cleaned with mold release wax. In Bamboo fiber-reinforced polymer after every layer of resin, Bamboo fibers were randomly distributed. In Unidirectional Glass Fiber Reinforced Polymer after every layer of resin, fibers were arranged at 90-90-90- degree orientations. Where in woven carbon fiber reinforced polymer after every layer of resin, fibers were placed randomly. After the mold gets filled with composites, it is squeezed and rolled to get uniform thickness and remove entrapped gases. Now a load of 15-20 kg is applied to the mold for a curing period of 24 hr. After completing the curing period, we get the composite which can be redesigned to the required dimensions. Table 2 shows the characteristics of the FRP composites.

2.2. Coating Procedure

WCC and Cr_2O_3 coating were applied on CFRP substrates using a thermal spray technique. Because the substrate is not directly exposed to flame, this production technique produces less substrate heating than flame spray procedures [31]. Sulzer F4MB from Sulzer Metco and Sulzer dual 10 powder feeder with a Sulzer A2000 control system using WCC and Cr_2O_3 in

Table 1: The weight ratio of fiber and epoxy matrix

	Fiber	Thickness (mm)	Fiber Weight (grams)	Epoxy LY556 Weight (gram)	Hardener HY951 Weight (gram)
1	Bamboo (fiber form)	3	74	111	11.1
2	Glass Fiber (unidirectional)	3	80	160	16
3	Woven Carbon Fiber	3	104.43	156.78	15.64

Table 2: Properties of FRP Composites

Parameter	Natural Fibers	E-Glass Fibers	Carbon Fibers
Diameter	3.5 µm	6 µm	7 µm
Fiber Tow Size	12000	12000	24000
Fiber Density	0.86 g/cm3	2.54 g/cm3	1.55 g/cm3
Strength	862 MPa	3445 MPa	3500 MPa
Modulus	9.8 GPa	87 GPa	240 GPa
Epoxy	LY556	LY556	LY556
Hardener	K6	K6	HY951
Curing Temperature	50°	80°	180°

wire form as raw material. The purity of the WCC is 99.9 percent, the density is 13.87 g/cm^3, the porosity is 10.8 percent, with a size range of -325 mesh + 15 microns and wire diameter is 1.62 mm. The purity of Cr_2O_3 is 98%, density is 4.52%, porosity is 4.7% with a size range of -170mesh + 15 microns. Molten WCC and Cr_2O_3 droplets arise at the melting terminals of the consumable wires and are carried to the substrate by a fast-moving gas [22]. Table 3 summarizes the spraying parameters. The specified parameters for substrate degradation and adhesion are optimized by taking the torch to substrate distance and sandblasting pressure into consideration. Sulzer F4MB and Sulzer dual 10 powder feeders with a Sulzer A2000 control system power supply from Sulzer Metco were used for the metallic coating. Six passes were used to achieve the appropriate thickness (60-70 m) of the continuous coating.

Thermal spraying was chosen for surface enhancement since it is a low-cost and efficient technology. Plasma spraying allows a variety of chemicals to be sprayed on a polymer substrate, allowing the characteristics of the substrate to be changed.

Table 3: Plasma spray interlayer process parameters [22]

Primary Gas flow rate (1/min Ar)	47.2/75/80
Secondary gas flow rate (1/min H2)	1.89
Arc Current (A)	400/450/500
Arc Voltage (V)	56-75
Spray Distance (mm)	100-110
Transverse Speed (mm/s)	202 (manual)
The carrier gas and flow rate (1/min)	Ar and 37
Power and size (µm)	Cu and 45
Layers	2 and 4
Plasma Gun Motion (XY Direction)	10 mm/sec
Power	35 kW

Table 3 lists the criteria of the procedure. To minimize FRP surface damage from high temperatures, a long spray distance and a suitable substrate cooling technique was utilized. Even the most thermally resistant composite materials have a maximum operating temperature of 372.15°C for long-term operation and 580.8°C for short-term use. The sprayed particles with a high temperature might degrade or even destroy the FRP's mechanical characteristics. As a result, copper powder is employed as a filler layer for curing in FRP of this perspective. The test conditions were derived from ASTM G76-13, and the details are listed in Table 4.

Table 4: ASTM G76-13 test conditions used

Nozzle	Ceramic Conical tube (2.4mm ID*50 mm L)
Erodent	Angular Al_2O_3 (nominal particle size 250 µm)
Compressed Air Pressure	0.13 MPa
Impingement angle	90°
Test Time	20 s
Test Temperature	25°C

3.0 Results and Discussions

The FRP substrates were mechanically prepared before plasma spray coating; else, zero to minimum coating formation on the composite materials happened. The smoothness and integrity of the substrate surface have

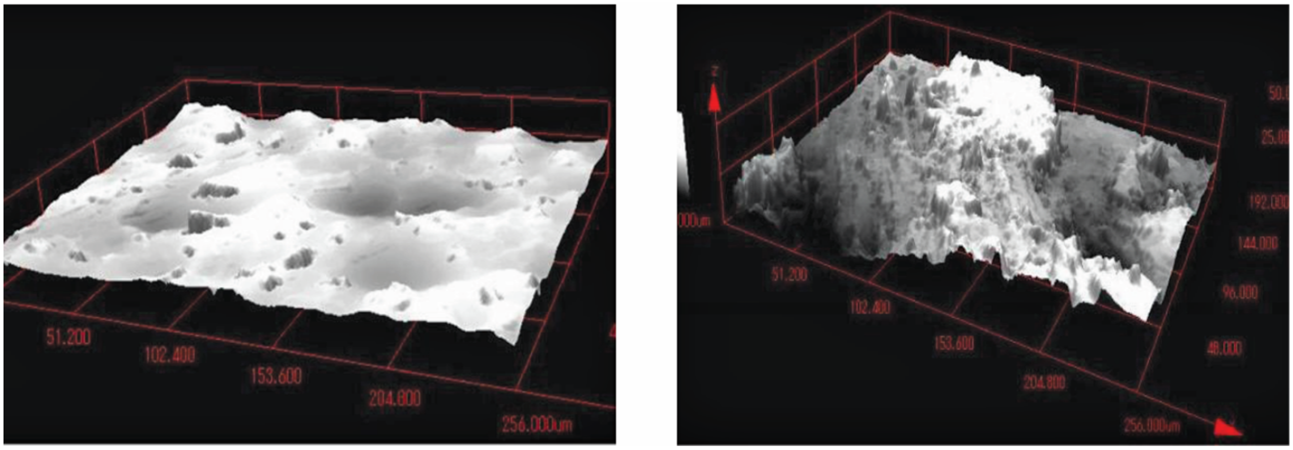

Figure 3: Laser optical Microscopy of the surface profile of (a) Untreated C-FRP and (b) Mechanically treated C-FRP

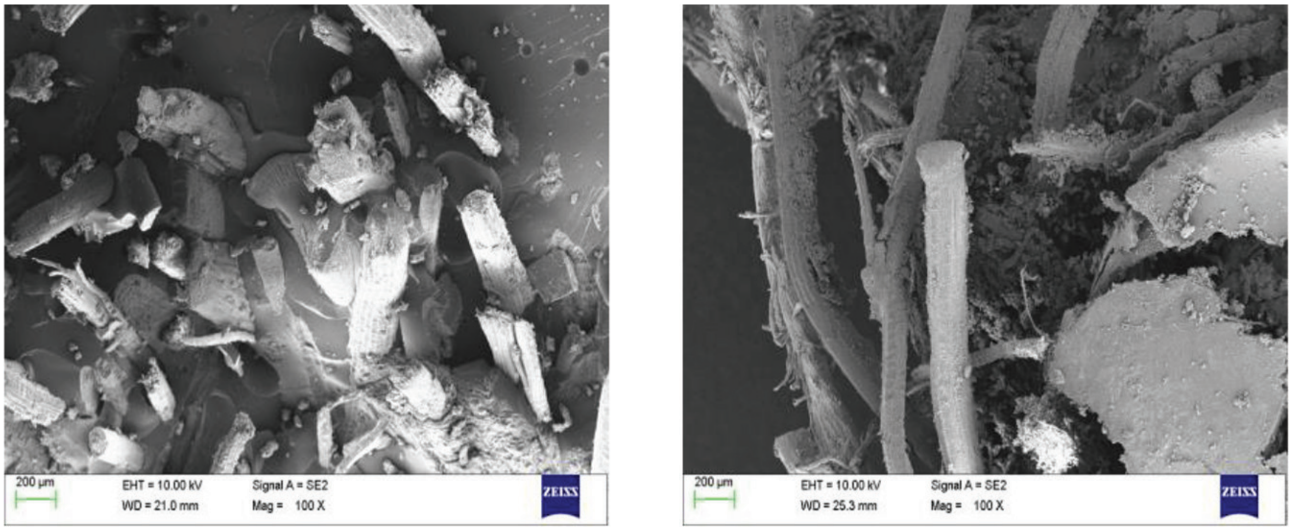

Figure 4: SEM micrographs of Bamboo FRP after conductive coating

an impact on the coating properties. With adequate surface preparation, the binding strength between the deposited components and the receiving substrate has been demonstrated to be sufficient. Grit blasting is one of the most used ways of pre-treatment. The cured composite sample was cleaned with acetone and grit blasted at a 90° angle with alumina powder mesh size 24 at a pressure of 50 psi. The treated surface was subjected to compressed air to remove any remaining alumina particles.

Fig 3 depicts a laser optical micrograph of the FRP substrate's surface profile before and after mechanical treatment, with roughness values of 6.6 and 9.3 µm, respectively. The picture clearly shows that mechanical treatment causes surface fracture and, as a result, increased surface roughness.

3.1 Scanning Electron Microscopy

To get SEM imaging, prepared specimens were treated to sputter coating to achieve a conductive surface and also to avoid electron beam splattering when obtaining surface details. The SEM micrographs of the fibers of the Bamboo FRP are visible, indicating that the FRP composition was effective using the approach adopted.

SEM micrographs of Ceramic Coatings have also been coated with a conductive material. The topography of the coating is observed to be regular throughout without any build up in a particular area.

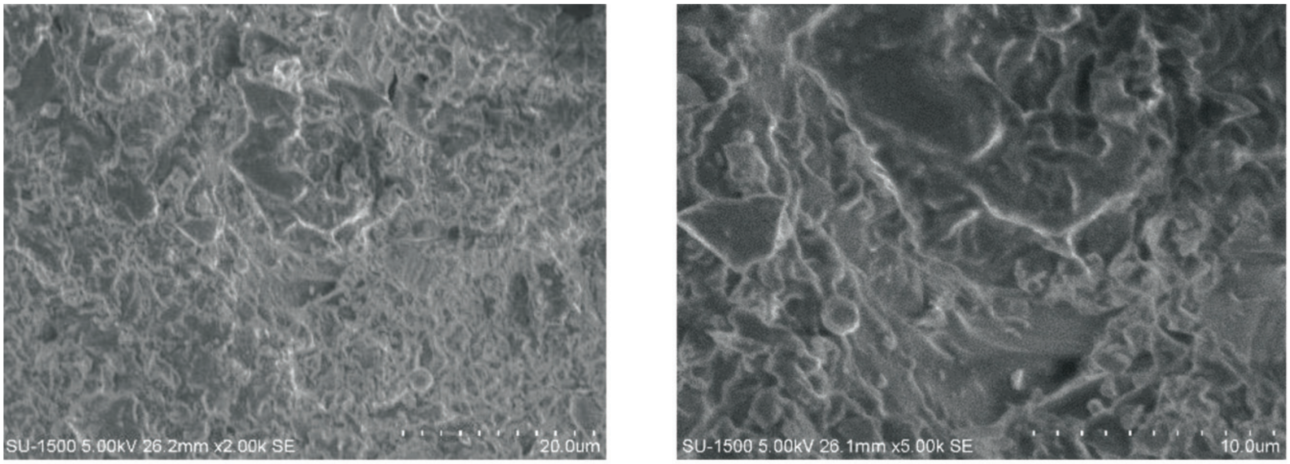

Figure 5: SEM images of Bamboo FRP coated with Cr_2O_3 (Ceramic Coating)

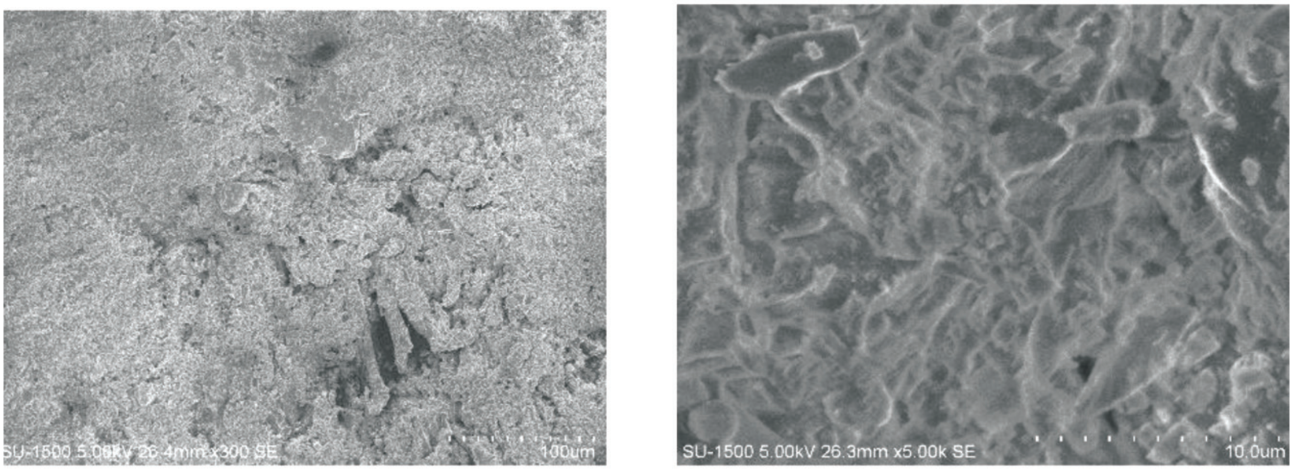

Figure 6: SEM images of SiC-FRP coated with Cr_2O_3 (Ceramic Coating)

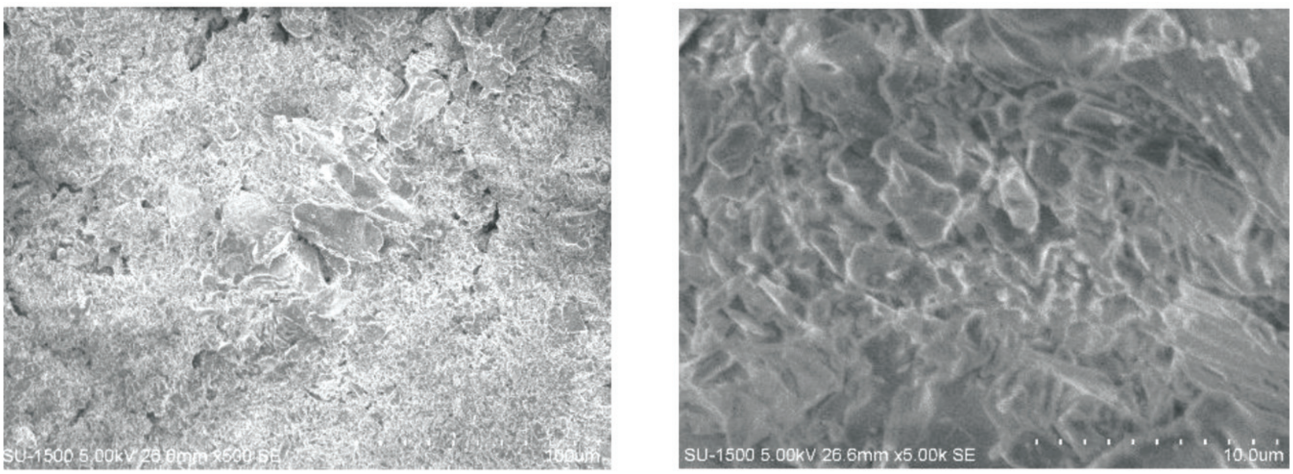

Figure 7: SEM images of C-FRP coated with Cr_2O_3 (Ceramic Coating)

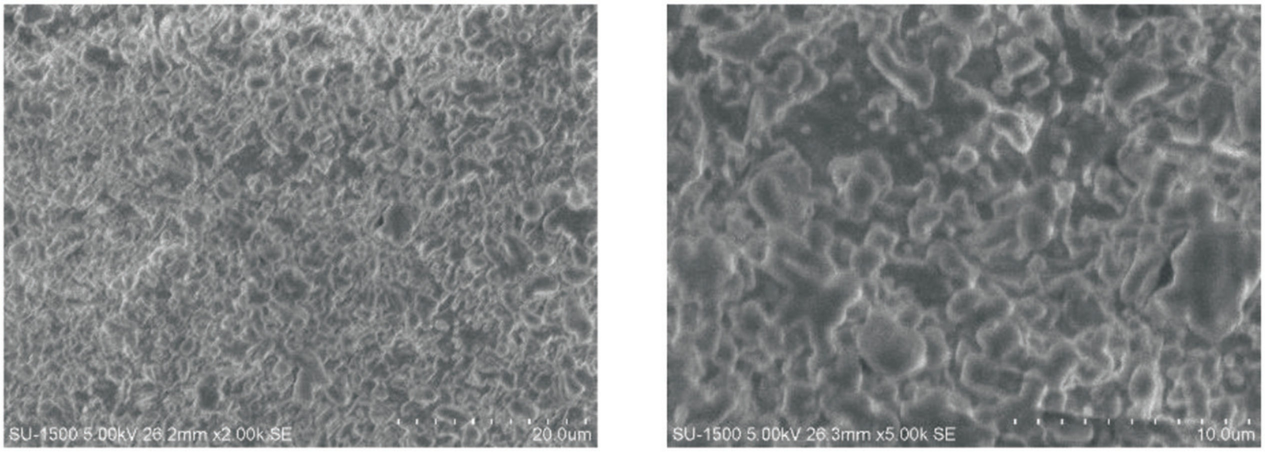

Figure 8: SEM images of Bamboo FRP coated with WCC

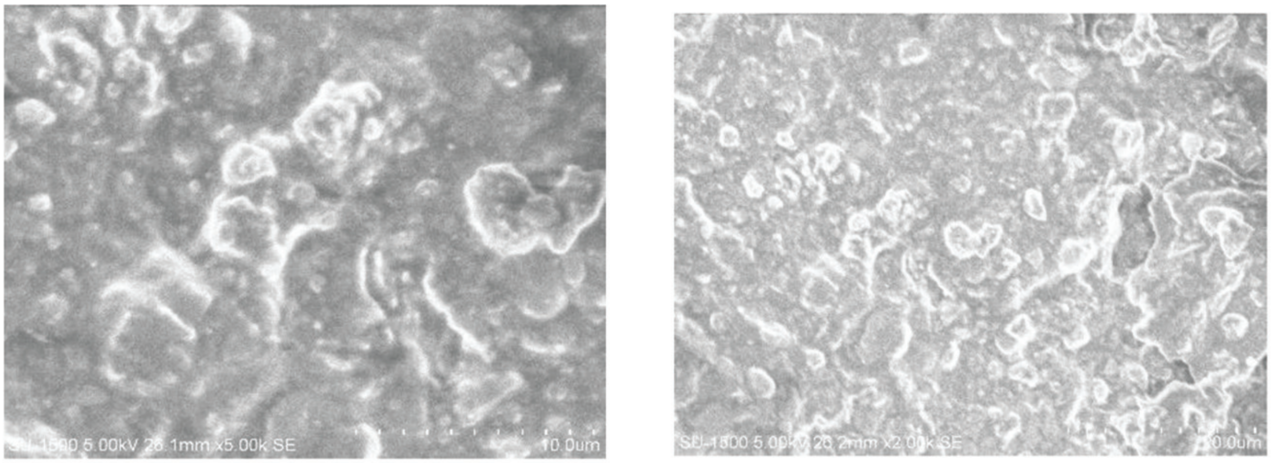

Figure 9: SEM images of SiC-FRP coated with WCC

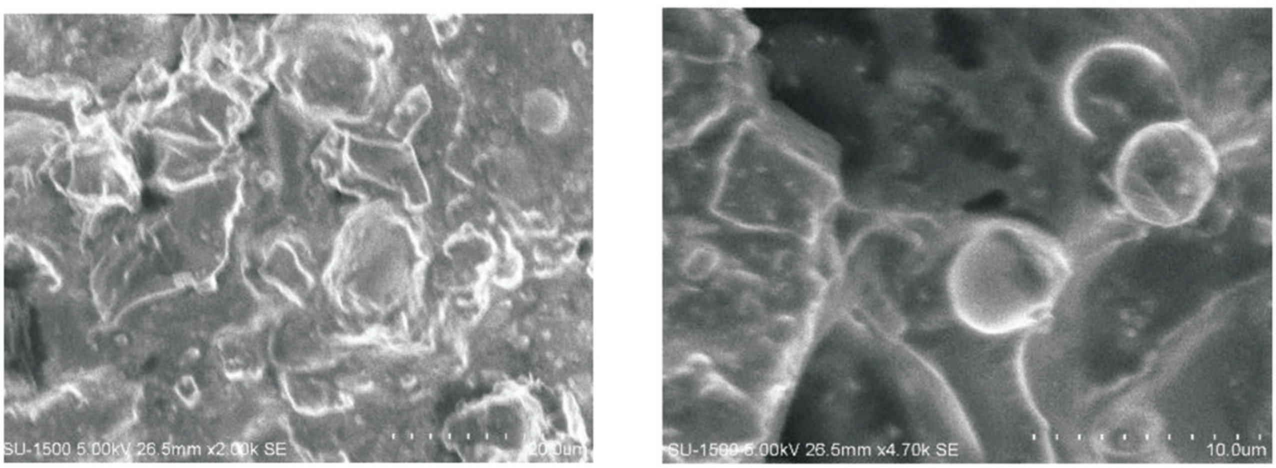

Figure 10: SEM images of C-FRP coated with WCC

As a result, surface roughness has a significant impact on coating build-up on mechanically treated samples.

The Hexagonal form of the Tungsten Carbide is observed in the SEM micrographs of WCC coatings. Good retention of tungsten carbide particles was seen in the microstructures of all the FRP composites. Tungsten Carbide is well known for its temperature property and has a withstanding capacity of 950^{o} which serves the requirement for aeronautical application.

3.2. Microhardness

The hardness of the substrates was determined using the Vickers hardness test technique. It entails indenting the test material using a diamond indenter in the shape of a pyramid with a square base and a 136^{o} angle between the opposing sides. For 15 seconds, a 100 kgf weight was applied. After removal, the two diagonals of the indentation left in the material surface are measured.

The specimens were polished and processed in the same way as metallographic specimens. The machine is calibrated, and the indenter is used to provide a precise indentation load. Deformed indentation diagonals are measured. The concluding hardness values in HV (hardness using Vickers test) are calculated by the hardness instrument and then converted to MPa. Per sample, five indentations were computed.

The results are a clear indication that thin-metallic coating on Fiber Reinforced Polymer increases its hardness levels by 3 to 5 times its original values making it a perfect candidate to replace the composite material in aerospace and automobile parts.

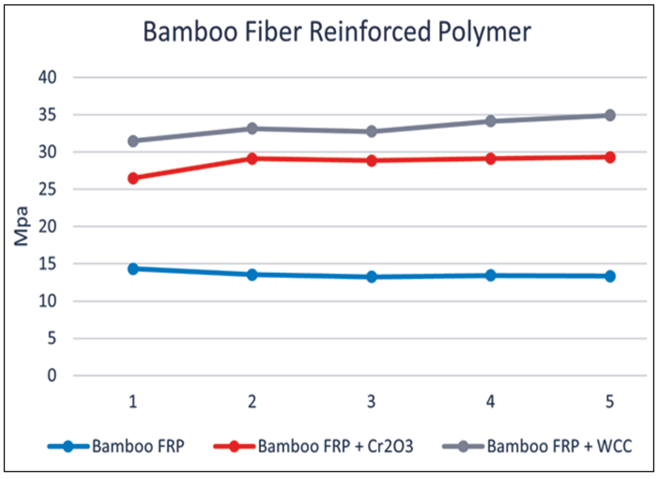

Figure 11: Microhardness of Bamboo FRP with and without coating

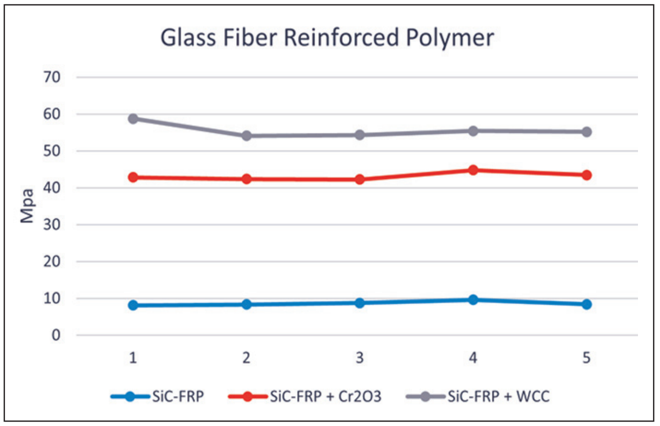

Figure 12: Microhardness of SiC-FRP with and without coating

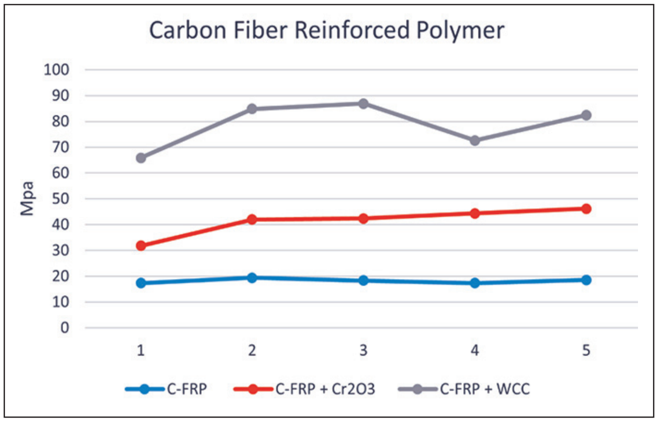

Figure 13: Microhardness of C-FRP with and without coating

4.0 Conclusions

The goal of this research was to create a new coating for Fiber Reinforced Polymer to increase surface characteristics, hardness, electric conductivity, porosity, and erosion resistance. Bamboo Fiber composite material and SiC-FRP and C- FRP were used as base material.

- Fiber-reinforced materials can be coated successfully with thermal spray coating, without degrading the material.
- Tungsten Carbide and Chromium Oxide were discovered as suitable metallic and ceramic coatings for composite materials due to their great temperature resistance.
- The extra layer of coating has improved the hardness of the material by at least 3 to 5 times the un-coated substrate.

- Thermal Spray coating is a feasible method for protecting the surfaces of polymer/plastic composites.

Future studies can involve ascertaining bonding mechanisms that will contribute to further improving the adhesion of the coating's strength and conductivity. Also, in areas of power size distribution, which can result in a more uniform layer. Techniques for measuring the electromagnetic effect and deicing impact of coatings might be developed.

A residual stress study can help determine the impact of increasing the number of coating layers and top coating thickness without causing the coating to peel off. The effects of varied layer thicknesses and post-heat treatment procedures can also be investigated.

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