AN EVALUATION SYNTHESIS OF NICKEL COATED CARBON FIBER RODS WITH REINFORCED ALUMINUM MATRIX ON COMPOSITE MATERIALS

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Abstract

Due to its better strength and modulus characteristics, a continuous fibre made of carbon fibre (CF) in the shape of a rod was employed as reinforcement. Using stir casting liquid metallurgy, a carbon fibre rod reinforced aluminium 6061 alloy metal matrix composite material was created. Metal matrix composite materials made of aluminium are lightweight. Metal matrix composites bonded with carbon fibre were the subject of very little study (MMC). To increase wettability, electroless nickel deposition was applied to carbon fibre rods (2mm and 3mm in diameter). SEM (scanning electron microscopy) and EDAX (energy dispersive X-ray spectroscopy) studies were used to confirm the efficacy of electroless nickel coating on carbon fibre rods. Nickel electroplating was used to increase the thickness of the nickel coating even further. Nickel-coated carbon fibre rods were placed in a circle within a cast iron mould. At 600–700 C, molten 6061 aluminium alloy that had been completely degassed was poured into a cast iron mould. The improvement of mechanical and tribological qualities is always a requirement for technical development in the automotive industry. For density testing, bulk and microhardness tests, friction and wear tests, specimens of synthetic composites (11.11% vol. CF and 25% vol. CF reinforcement) were generated. In compared to aluminium 6061 alloy, synthetic composite has lower density, greater bulk and microhardness, a lower coefficient of friction, and a lower rate of wear.

Keywords: Mechanical, Tribological, Casting, Nickel coating, Carbon Fibre (CF) rod

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1. Introduction

Because of their high modulus, high strength, resistance to chemical reactions, enhanced wear resistance, and hardness, carbon fibres are effective as reinforcing components in a variety of matrix materials(Baker, 1975). The unique properties of conventional metal alloys restrict their use in automotive and aerospace applications. Conventional structural materials are less strong and heavier than carbon fibre reinforced composite technologies. Aluminum alloys are used in a range of automotive applications because of their light weight and high strength qualities. They cannot be employed in a variety of applications due to their poor hardness and weak wear resistance. Reinforcement and matrix are the two main parts of composite materials. The matrix and reinforcing materials employed, as well as the manufacturing technique, all affect the characteristics of composite materials. Composite materials combine the finest qualities of two heterogeneous materials. The advantages of Metal Matrix Composites (MMC) are their high specific strength, high stiffness, and increased wear resistance. It was discovered that aluminium alloy worked well as a matrix material for composites for making various vehicle parts. Due to its light weight, high strength, and exceptional wear qualities, carbon fibre reinforced aluminium metal matrix composite material is popular for use in automobiles (Chand, 2000).

Carbon fibre may be employed as a reinforcing material in ceramic, metal, and polymer matrices because of its excellent qualities. Carbon fibre reinforced polymer composites are widely used in a variety of applications; but, due to manufacturing challenges, carbon fibre (CF) reinforced metal matrix composites have not yet attained that status. Squeeze casting, stir casting, and infiltration with squeeze casting are the most popular processes for producing carbon fibre reinforced metal matrix composites in the liquid metallurgical pathway. For the production of metal matrix composite material, the stir casting liquid metallurgical approach proved convenient and affordable (Park, 2015).

Poor wettability is one of the biggest problems that arise during the synthesis of carbon fibre reinforced aluminium matrix composites. The aluminium alloy was employed in the molten phase at 600–700 °C for this stir casting method. Metallic (nickel or copper) coating on carbon fibres is used to enhance interfacial properties and prevent carbon fibres from being destroyed during processing. The wetting of carbon fibres with molten aluminium is made possible by nickel coating. The chemical connection between the metal matrix and carbon fibre is strengthened by the metal coating (Manu et al., 2019). Magnesium works very well as a surfactant, which enhances wettability. An ideal amount of magnesium is necessary for the synthesis of composite materials (Manu et al., 2019).

In place of MMC production, short fibres or whisker fibres of carbon are employed. Several types of carbon fibres were combined during the stir casting process in molten metal, which compromises their properties. The current study focuses on the stir casting liquid metallurgical method for the production of an aluminium 6061 alloy and nickel-coated carbon fibre rod composite material. As the CF rods solve the aggregation issue, it is not necessary to control every parameter during stir casting. Prior until this, the only methods for depositing metal on the surface of CF rods were electroless nickel or copper coating. In this study project, electroless nickel plating was done initially, then nickel was electroplated on the surface of CF rods. For electroless nickel plating CF rods, a readily accessible EN solution was utilised, saving coating time. This dual plating results in nickel coating thickness enhancement leads to little damage to CF rods and improvement in mechanical and tribological characteristics. For coated and uncoated CF rod, SEM and EDAX analyses were used to confirm the dual nickel plating. The current work involves new dual nickel plating and inventive usage of CF rods as reinforcement in Al 6061 MMC. Fabricated composites' mechanical and tribological properties were investigated. As comparison to traditional aluminium 6061 alloy, synthetic composite has a lower density, greater bulk and microhardness, a lower coefficient of friction, and a lower rate of wear. Due to their exceptional wear resistance and low density, the synthesised composites are a potential material for vehicle brake drum and disc applications.

2. Experimental Methodology

2.1. Selection of Materials

The alloy 6061 aluminium was regarded as a matrix material. The ingot shape was made of matrix material. Table 1 provides the chemical make-up of the cast aluminium alloy 6061. Bangalore-based Fen Fee Metallurgicals provided the aluminium 6061 alloy. As a reinforcing material, PAN-based carbon fibre rods (2 mm and 3 mm in diameter) were used. RC Dhamaka, a company in Bangalore, donated the carbon fibre rods.

Table 1: Aluminum 6061 Alloy Chemical Composition

Elements	Si	Mg	Fe	Mn	Cu	Zn	Cr	Pb	Ti	Al
Weight %	0.54	0.85	0.39	0.14	0.2\51	0.008	0.171	0.032	0.019	Balance

2.2. Electroless Coating of Carbon Fibre Rod

Electroless nickel covering was performed to work on the wettability of carbon fiber poles in Aluminum 6061 combination. Electroless nickel on carbon fiber incorporates cleaning, carving, sharpening, enactment and electroless covering. Cleaning, carving, sharpening and enactment, these means were associated with pre-covering. Each move toward pre-covering was trailed by balance. Deionized water was utilized for balance after each step. The underlying residue and finish layer was taken out by utilizing CH3)2CO (ultrasonic cleaning). Drawing was finished on the cleaned filaments utilizing ammonium fluoride and sodium chloride. Scratching was finished for pore development to increment surface region and lay out hydrophilic spots that can assimilate the etchant rapidly. Scratching follows sharpening utilizing stannous chloride and actuation utilizing palladium chloride arrangement. During sharpening and enactment, there was the arrangement of surface miniature cavities for the autocatalytic electroless metal plating cycle to be begun. Insights about each step (ultrasonic cleaning, drawing, refinement, actuation and balance) were referenced in Table 2. For electroless nickel covering business EN832 arrangement given by Marshal Labs, Pune was utilized. Pre-covered carbon fiber bars were covered utilizing EN 832 arrangement at 83±2˚C as displayed in Figure 1. This arrangement incorporates nickel particles, stabilizer, decreasing specialist, and buffering specialist. Impact of pH esteem on nickel covering was contemplated and complete electroless nickel covering was done at pH=5. Nickel electroplating was utilized to improve the thickness of the nickel covering on carbon fiber pole (Sandhanshiv & Patel, 2020, 2022).

Table 2: Electroless covering of nickel on carbon fiber bar

Sr. No.	Operation	Chemical used	Composition	Duration (min)
1	Cleaning	Acetone	-	30
2	Cleaning	Deionized Water	-	5
3	Etching	NH4F/NaCl	150g/l/150g/l	10
4	Neutralization	Deionized Water	-	5
5	Sensitization	SnCl2/HCl	10g/l/40ml/l	240
6	Neutralization	Deionized Water	-	5
7	Activation	PdCl2/HCl	0.5g/l/10ml/l	15
8	Neutralization	Deionized Water	-	5
9	Nickel-free Electrode Coating	EN832 solution	EN832 Solution	35

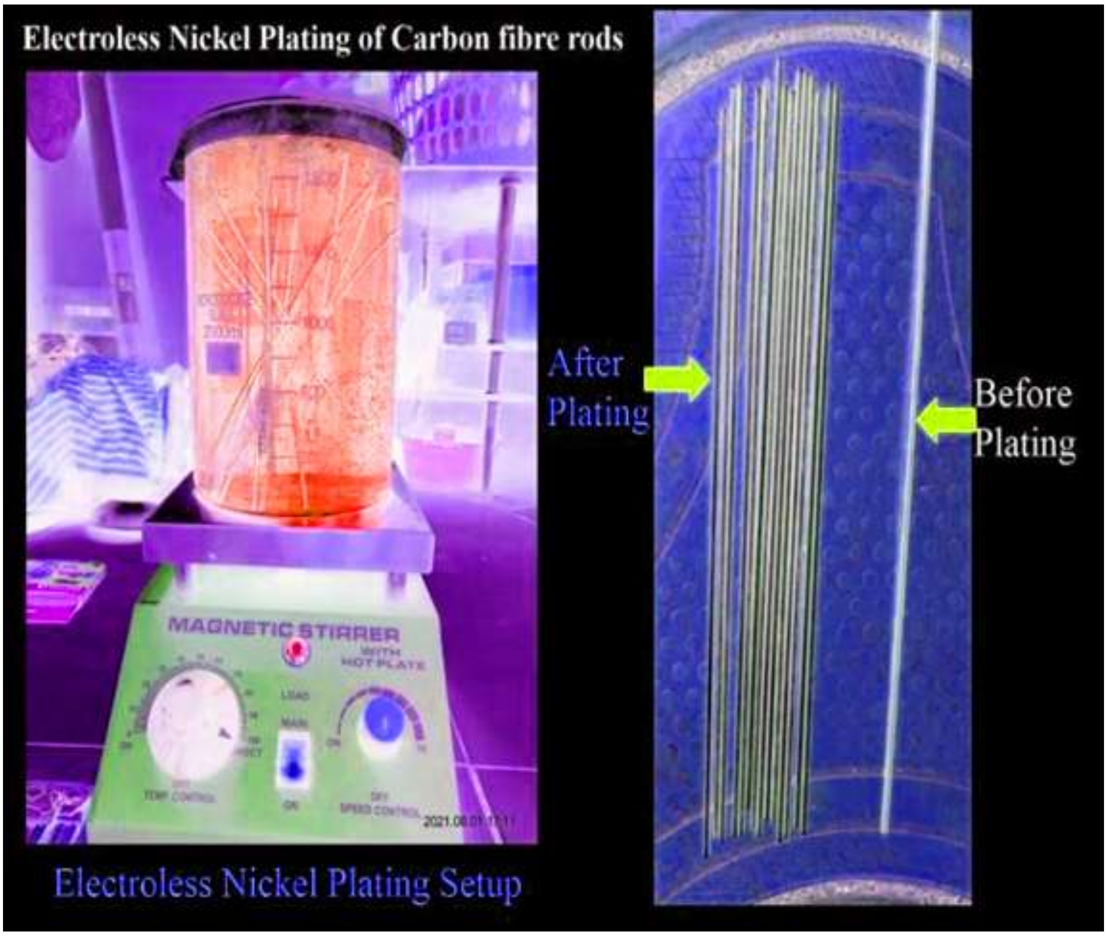


Figure 1: Electro less Nickel Plating setup

EDAX (Energy Dispersive X-Ray Spectroscopy) analysis and SEM were used to study the morphology of nickel coated and untreated carbon fibre rods (Scanning Electron Microscopy). The surface and a cross-section of the carbon fibre rod were subjected to SEM examination. EDAX analysis was done on the surface of coated and untreated carbon fibre rod. Coated and uncoated CF rod samples were subjected to SEM-EDAX analysis utilising the JSM-6390 (SEM) at the Sophisticated Test and Instrumentation Centre in Cochin, Kerala.

2.3. Composite material synthesis

Aluminum 6061 alloy was employed as the matrix material in the manufacture of metal matrix composite materials. Split type Die for casting was designed and constructed. For casting aluminium alloys, cast iron was employed as the material for the die. Circular rod form (bar) was chosen for casting after taking into account the specimen size needed for various characterizations. Finalized were the circular rod's dimensions.

In a coal-based furnace, aluminium metal matrix composite material (AMMCM) was created. Weighted (5 kg) aluminium alloy ingots were heated to a preheated temperature (400–450 °C) in a furnace. The furnace next to it was heated up. The temperature was maintained at 700800 ˚C for aluminium alloy melting. Magnesium was added to the Aluminum 6061 alloy to increase wettability, and the molten alloy was swirled at 700-800°C at 200-250 rpm (Sharma et al., 2014; Singh & Balasubramanian, 2009). To prepare the bars, the cast iron die was preheated at a temperature of 200–250 C. The cast iron die was kept ready to pour molten aluminium alloy using g-clamps and green sand. A degassing tablet was used to degas the molten aluminium alloy. Aluminum alloy rods were separated after the completely degassed molten alloy was injected into the casting die (Ramesh et al., 2013).

In a volume proportion, carbon fibre rods were used to strengthen the aluminium matrix material. Before the molten aluminium alloy was poured, nickel-coated carbon fibre rods were put in the casting die. A circular plate with holes that were the same diameter as the carbon fibre rods was maintained below the casting die in order to keep the rods upright. Five carbon fibre rods were positioned so that one was in the centre and the other four were set in a circle all around it. The diameter of the cast AMMCM bar was 35 mm. A degassed molten aluminium alloy was poured into a hot casting die, which included coated carbon fibre rods. AMMCM cast rods were collected after solidification (Sandhanshiv & Patel, 2022).

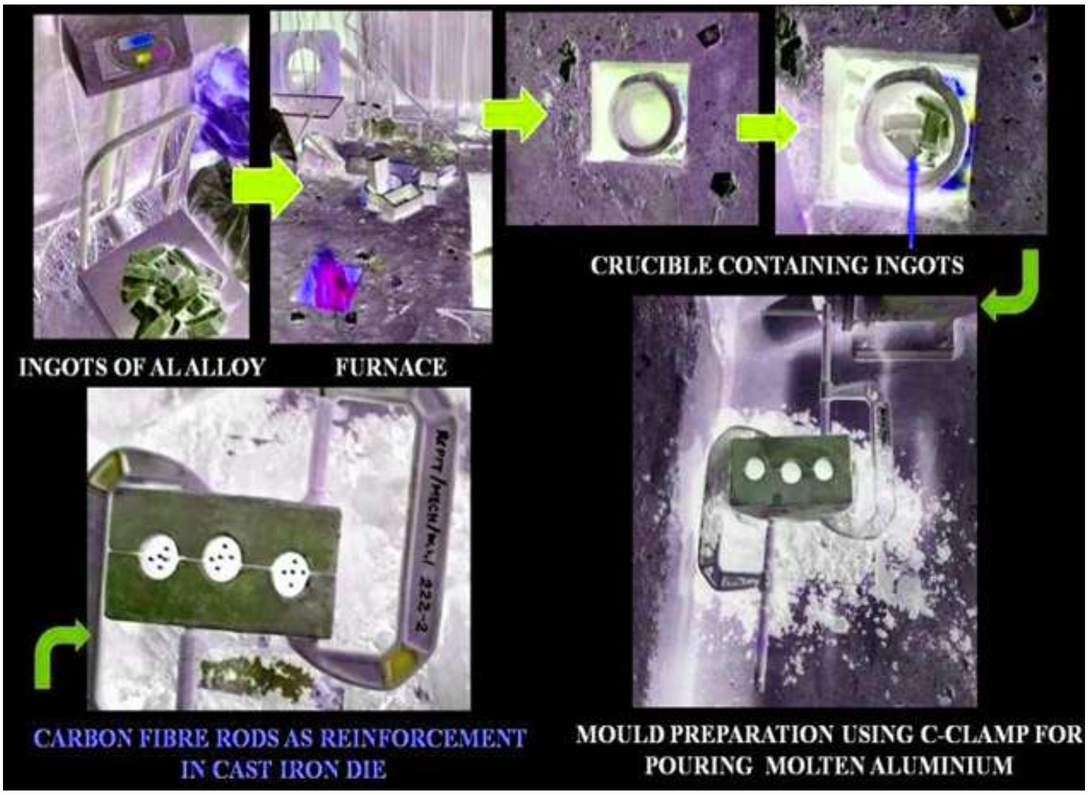


Figure 2: Aluminum Metal Matrix Composite Material Synthesis

2.4. Characterization of Composite Material

Laser machining was used to create the sample that was needed for characterisation. The density of carbon fibre rod reinforced aluminium metal matrix composites was calculated using the Archimedes principle. Cast rods were used to create specimens for tribological and mechanical evaluation.

Bulk hardness test according to ASTM E10 standard was utilised for Brinell hardness (BHN). Vickers hardness (VHN) implies microhardness test was carried out in accordance with ASTM E92-17 standard. In the Aurangabad Mattest Laboratory, a hardness test was conducted (NABL Accredited). Testing for hardness was done on a cylinder-shaped disc. The cylindrical disc is 10 mm thick and 30 mm in diameter. The bulk hardness test was conducted using a 2.55 mm diameter hardened steel ball indenter. 15 seconds of a load of 187.5kgf were applied. For the final BHN value, an average of six separate readings was taken into account. The microhardness test was conducted using a diamond indenter. The test for microhardness was conducted both close to and far from the CF rod. The final VHN value was calculated as the average of the six individual readings. Cast aluminium 6061 alloy and its composites underwent a bulk hardness and microhardness test.

ASTM G99-95 standard was utilised to create specimens of the wear test. A pin-on-disc tribometer (Make: Ducom Instrument Pvt. Ltd. Bangalore) was subjected to a tribological test at a research facility called PREC, Loni, Pune University. The cylindrical pin was manufactured for both cast AMMCM and cast aluminium alloy for tribological analysis. As a wear (tribological) pin, a cylindrical pin with a 6 mm diameter and a 25 mm length was employed. The end surfaces of the test specimens were flattened and polished. A counter disc made of cast iron with a surface polish of 1 m and a hardness of 60 HRC was employed. The examination had a 30-minute time limit. The wear rate had been calculated using the force applied and the sliding velocity. The analysis of several study publications revealed that as the load and sliding velocity rise, so does the wear rate (Singh & Balasubramanian, 2009). 20 N Load and 0.51 m/s sliding velocity were chosen for the tribological test after a thorough review of research articles. The steady-state region was used to quantify wear loss. Data on frictional and normal load were taken into account while evaluating the coefficient of friction. The wear rates were assessed using height loss data in terms of volumetric wear loss per unit sliding distance. For cast aluminium 6061 alloy and its composites, friction and wear tests were conducted.

The Result and Discussion will discuss the comparison of findings (Tribological and Mechanical characterisation) for cast aluminium 6061 alloy and its composites.

3. Finding and Analysis

3.1. Nickel Coated and Uncoated Carbon Fiber Rod Characterization

To strengthen the chemical link between carbon fibre (CF) rod reinforcement and aluminium 6061 alloy matrix, effective nickel coating on CF rod was essential. The increased bonding between the matrix and the reinforcing material greatly improved the hardness and wear characteristics of the synthesised composite. The CF rod was coated with electroless nickel. CF rod surface coating morphology was investigated using SEM-EDAX analysis. SEM examination was carried out at the surface and cross-section of coated and uncoated CF rods to observe nickel coating at high magnification. EDAX analysis was used to determine the elemental composition at the coated and uncoated surfaces of the CF rod (Tang et al., 2009).

3.1.1. Uncoated Carbon Fibre Rod SEM-EDAX Analysis

Carbon fibre rods with and without a nickel coating were manufactured as specimens. The surface of nickel-coated and untreated carbon fibre rods was examined using SEM examination. SEM study of the nickel-coated and untreated surfaces of CF rods is shown in Figure 1. At a magnification of 50 microns, the surface was studied. It was noted that the nickel coating was applied equally throughout the surface of the carbon fibre rod.

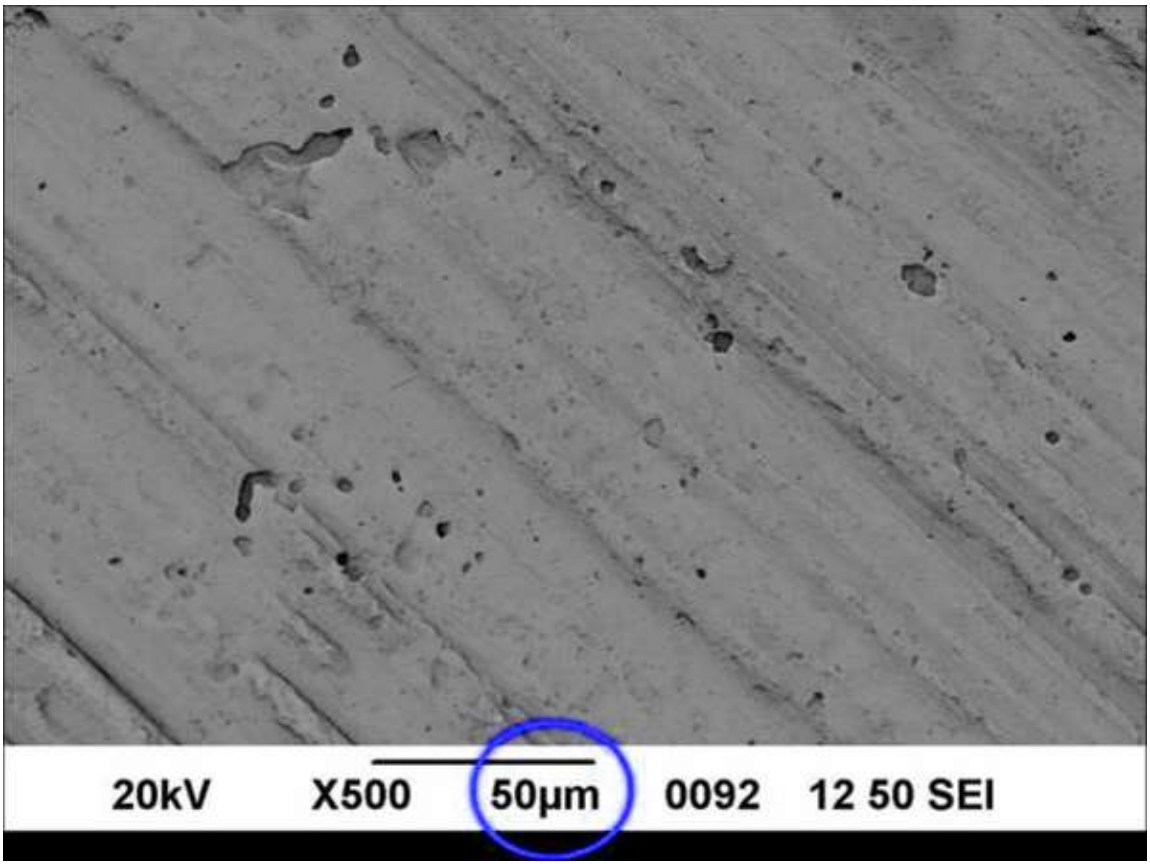


Figure 3: shows the surface of an uncoated CF rod

The cross-section of the carbon fibre rod was also subjected to SEM investigation. Figure 2 displays a SEM study of the cross-sections of nickel-coated and untreated CF rods. At a magnification of 500 microns, it was possible to see that the carbon fibre rod's cross section was entirely covered with nickel. It was determined by thorough SEM inspection of the carbon fibre rod's surface and cross-section that the nickel coating was evenly dispersed.

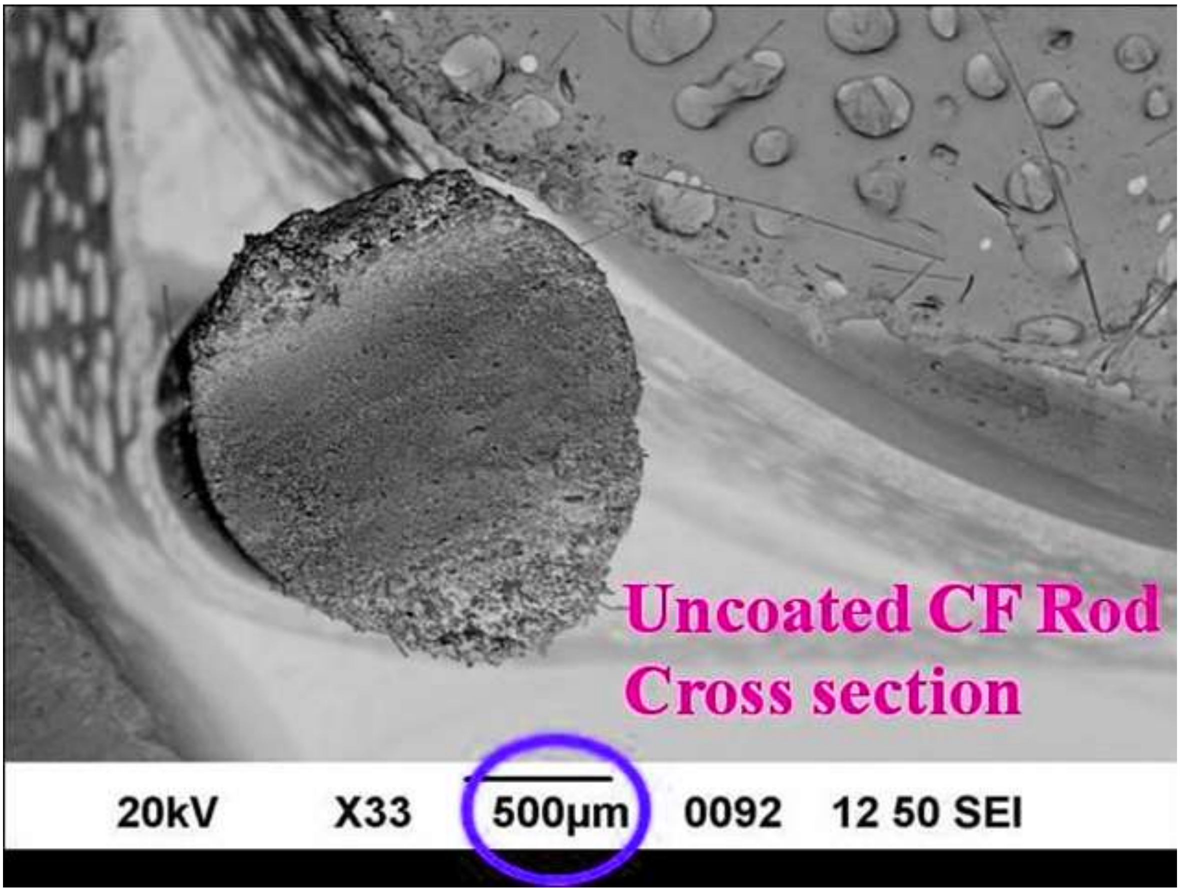


Figure 4: SEM of Nickel Covered and uncoated CF bar crosssection

Figure 3 shows the EDAX range of the uncoated CF bar surface. It was observed that carbon was available at the outer layer of the CF bar. Significant EDAX examination was completed for nickel covered CF bar surface. Figure 4 shows the EDAX range of Nickel Covered CF pole surface. It was plainly seen that nickel was covered over the CF pole surface. Nickel compound was tracked down over carbon (CF pole surface) during the Essential sythesis study. No void was available on the CF bar surface which brings about uniform nickel covering. After electroless nickel covering, nickel electroplating was finished to expand the thickness of the covering. This viable nickel covering brings about a decent connection between CF pole support and aluminum 6061 composite network material.

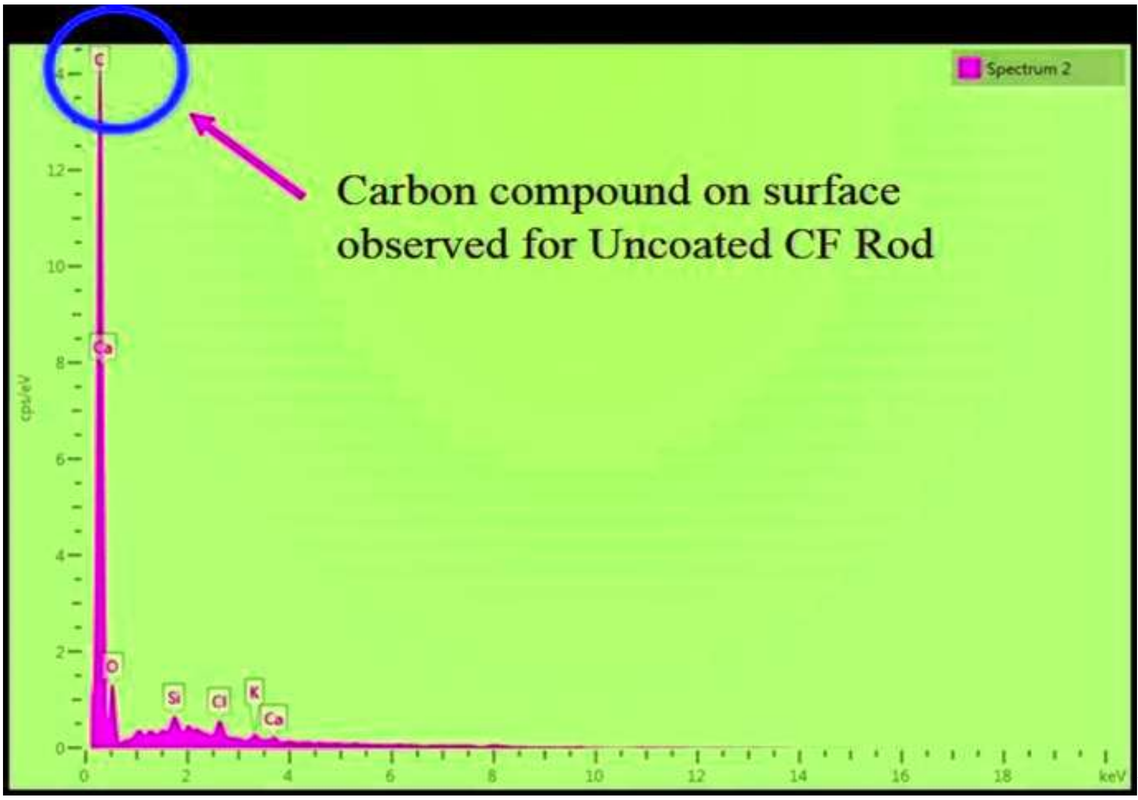


Figure 5: EDAX range of uncoated CF pole surface

Table 3: Compositional Examination of uncoated CF pole surface

Sr. No.	**Element**	**Weight (%)**	**Atomic (%)**
1	C	83.98	87.93
2	O	14.76	11.6
3	Si	0.35	0.15
4	Cl	0.51	0.18
5	K	0.21	0.07
6	Ca	0.19	0.06

3.1.2. SEM-EDAX Examination of Nickel Covered Carbon Fiber Bar

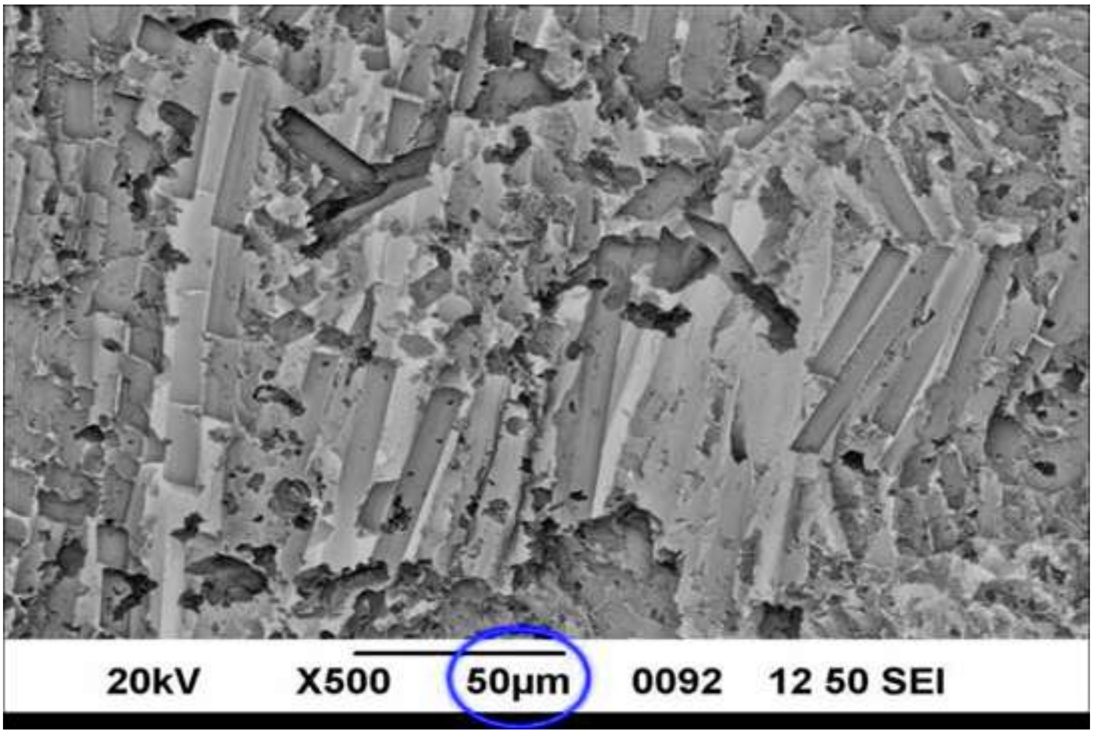


Figure 6: SEM of Nickel Covered CF pole surface

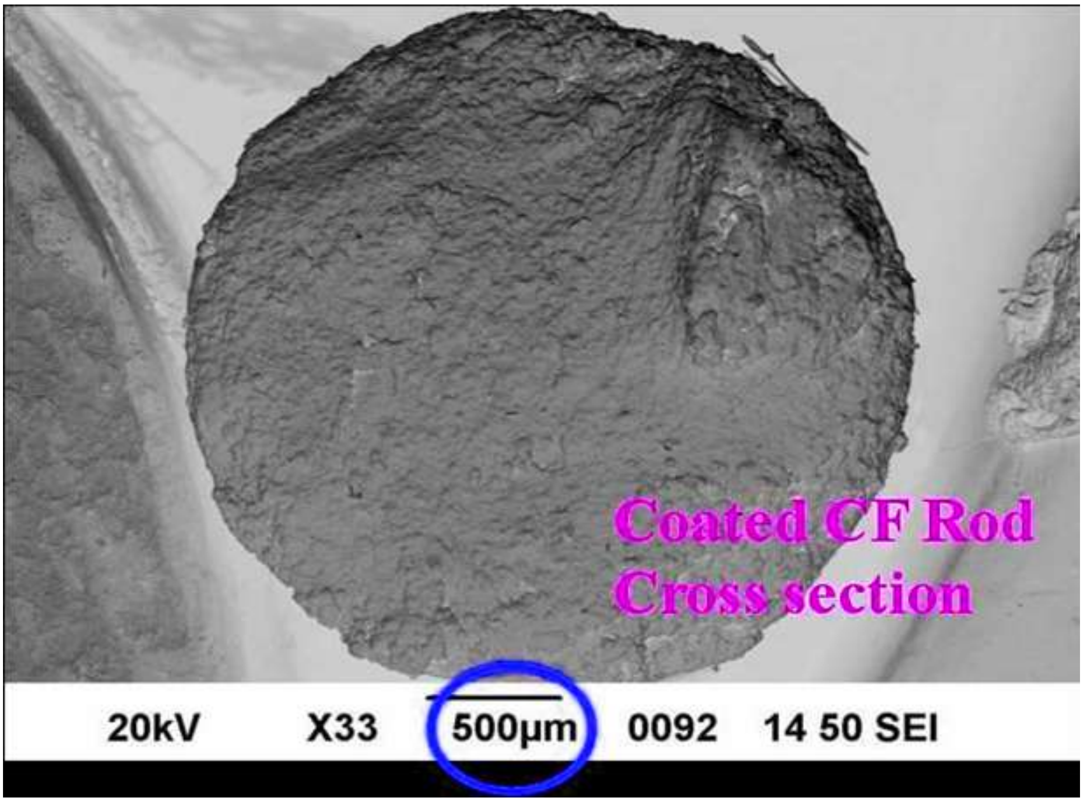
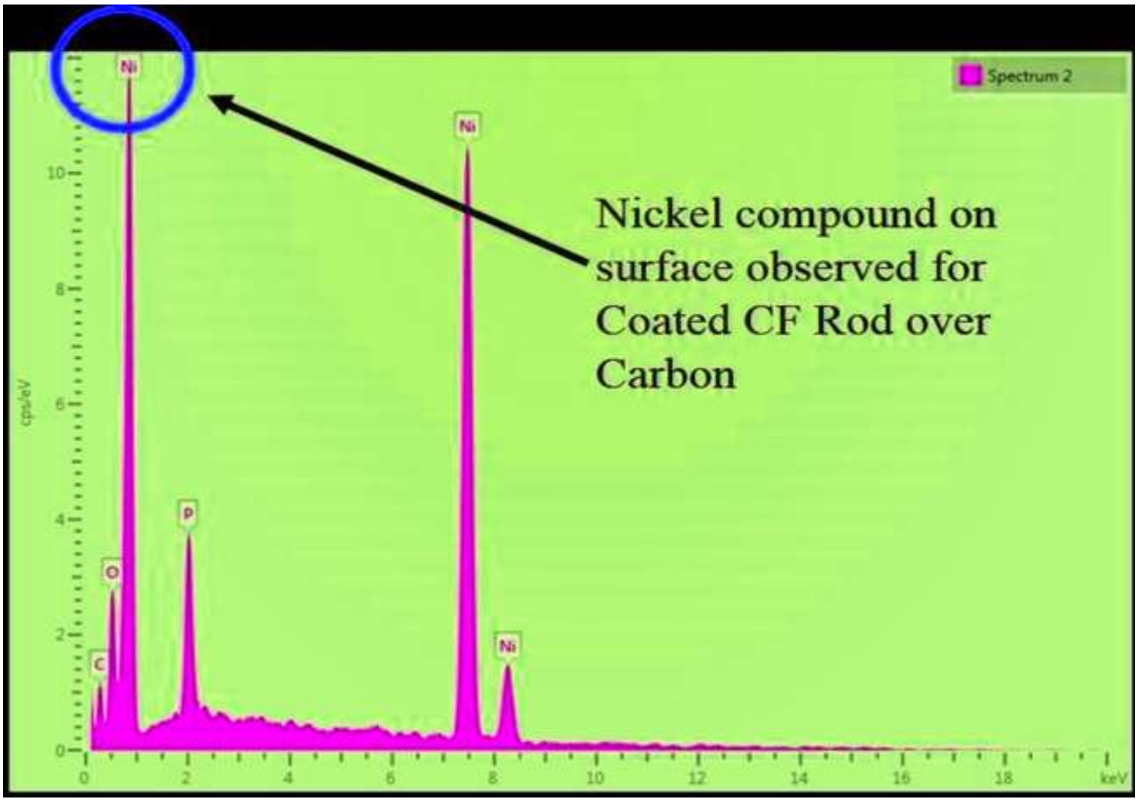


Figure 7: SEM of Nickel Covered and uncoated CF bar crosssection



Nickel compound on surface observed for Coated CF Rod over Carbon

Figure 8: EDAX range of Nickel Covered CF bar surface

Table 4: Compositional Investigation of Nickel Covered CF bar surface

Sr. No.	Element	Weight (%)	Atomic (%)
1	C	15.92	40.95
2	O	8.8	16.98
3	P	5.24	5.23
4	Ni	70.04	36.84

3.2. Composite material density

Carbon fibre (CF) reinforced composite materials and aluminium 6061 alloy densities were determined using the Archimedes principle. The density of Aluminium 6061 alloy and CF reinforced composite materials were exhibited in Figure 5. There is a decrease in density when the % volume portion of carbon fibre rod reinforcing in aluminium alloy rises. Due to carbon fibre rods' lower density as compared to aluminium alloy matrix material, the density has decreased. It has been noted that the density of composite materials reinforced with Al6061+11.11% Vol. CF and Al6061+25% Vol. CF is, respectively, 8.45% and 13.28% less dense than aluminium 6061 alloy (Naji et al., 2008).

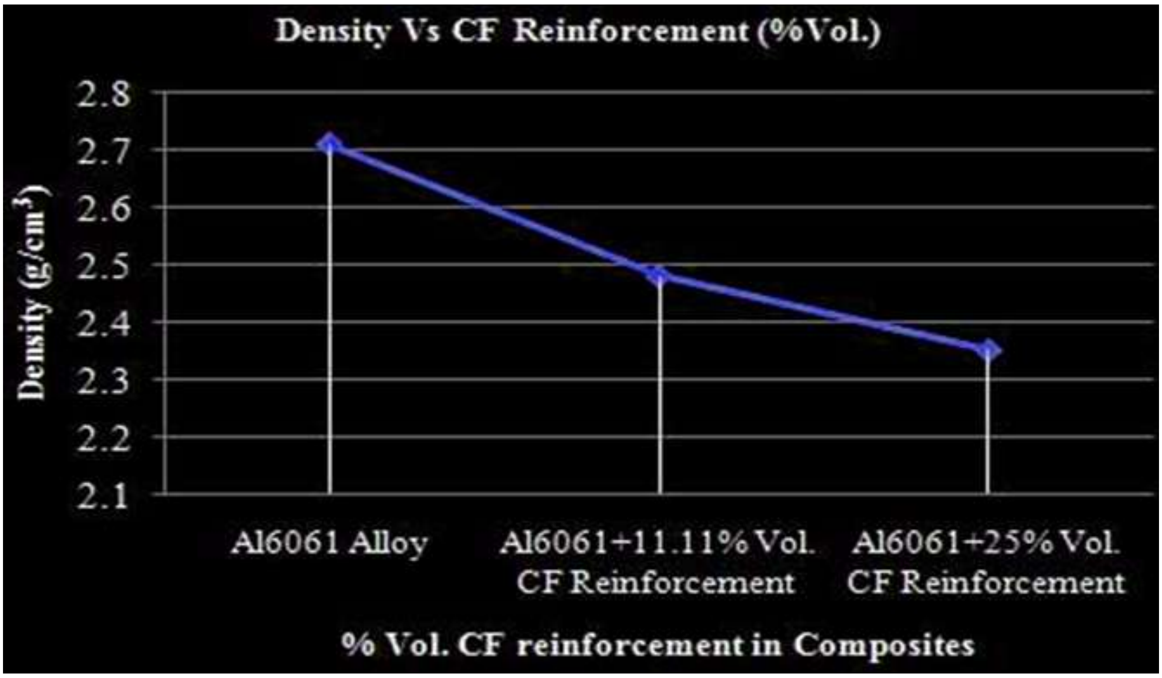


Figure 9: shows the density of composites using CF reinforcement and aluminium 6061 alloy

3.3 Mechanical Characterization

Figure 6 depicts the bonding of a metal matrix composite material's Al 6061 alloy and CF rod. Due to the nickel coating, excellent bonding between CF rod and Al 6061 alloy was seen at the micron level (SEM). No CF rods are being pulled away from the cast composite bar in the actual photograph. Carbon fibre does not deteriorate because the nickel coating on the fibres prevents chemical reactions between the rods of carbon fibre and the aluminium alloy matrix (Jung et al., 2017).

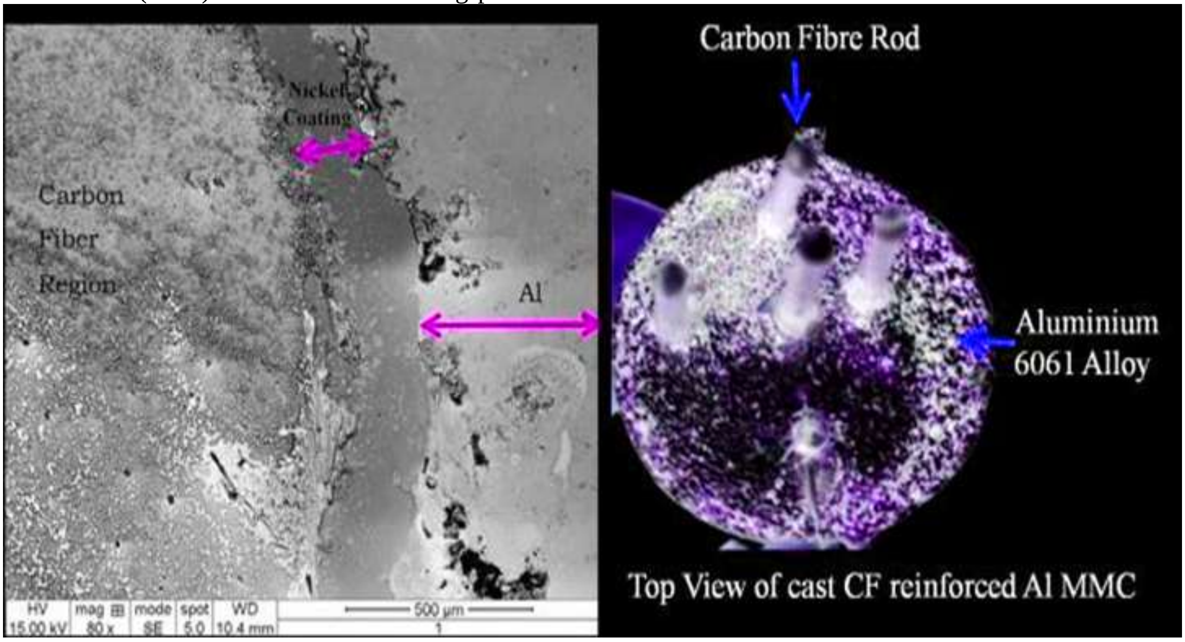


Figure 6: an actual picture and a SEM of the bonding of a composite's Al 6061 and CF rod

Surface hardness is one of the most crucial factors that affects how quickly composite materials wear out. Brinell hardness (BHN) indicates bulk hardness was determined for Aluminium 6061 alloy and CF reinforced composite materials as illustrated in Figure 7. The strong connection between the reinforcement and matrix material enhances the bulk and microhardness of the composite material.

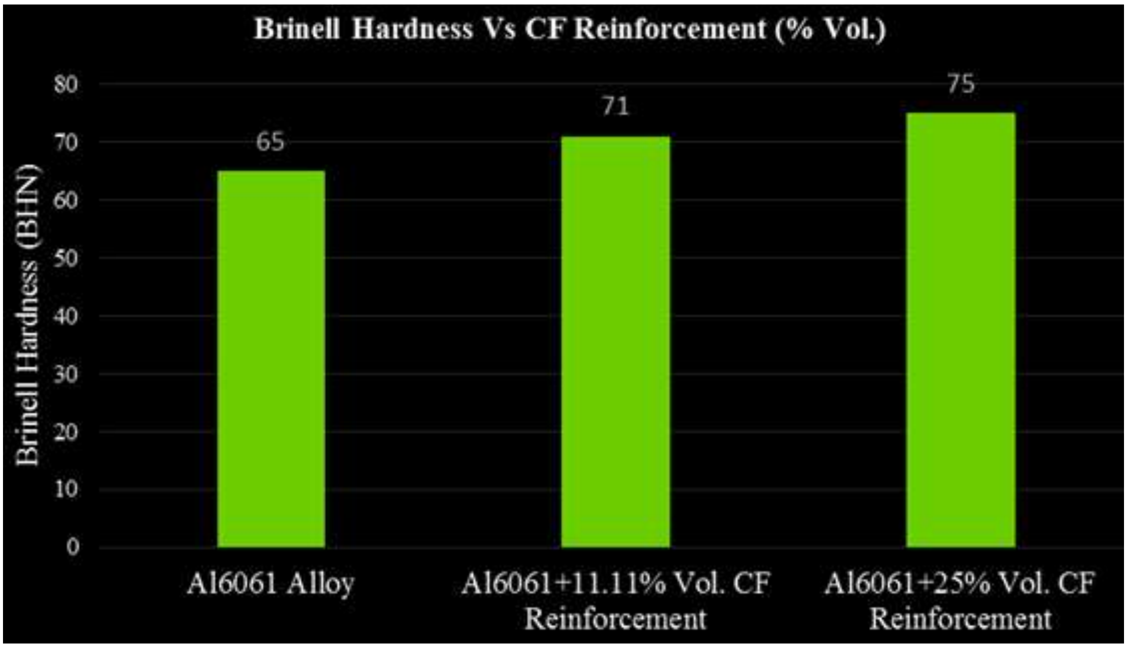


Figure 7: The Brinell hardness (BHN) of composites using CF reinforcement and aluminium 6061 alloy

Bulk hardness rises when carbon fibre rod reinforcement as a proportion of the volume of the aluminium alloy increases (BHN). Bulk hardness (BHN) measurements reveal that the Al6061+11.11% Vol. CF reinforced and Al6061+25% Vol. CF reinforced composite materials have, respectively, 9.23% and 15.38% greater BHN than aluminium 6061 alloy.

Vickers hardness (VHN), which is a measure of microhardness, was determined for materials made of CF-reinforced composite and aluminium 6061 alloy, as illustrated in Figure 8. Microhardness measurements were made close to and not near the CF rod. Microhardness rises together with the % volume fraction of CF reinforcement in the matrix material. During the production of the composite material, nickel is also dispersed close to the CF rod, which further increases microhardness. In comparison to aluminium 6061 alloy, the microhardness (VHN) of the Al6061+11.11% Vol. CF reinforced and Al6061+25% Vol. CF reinforced composite materials increased.

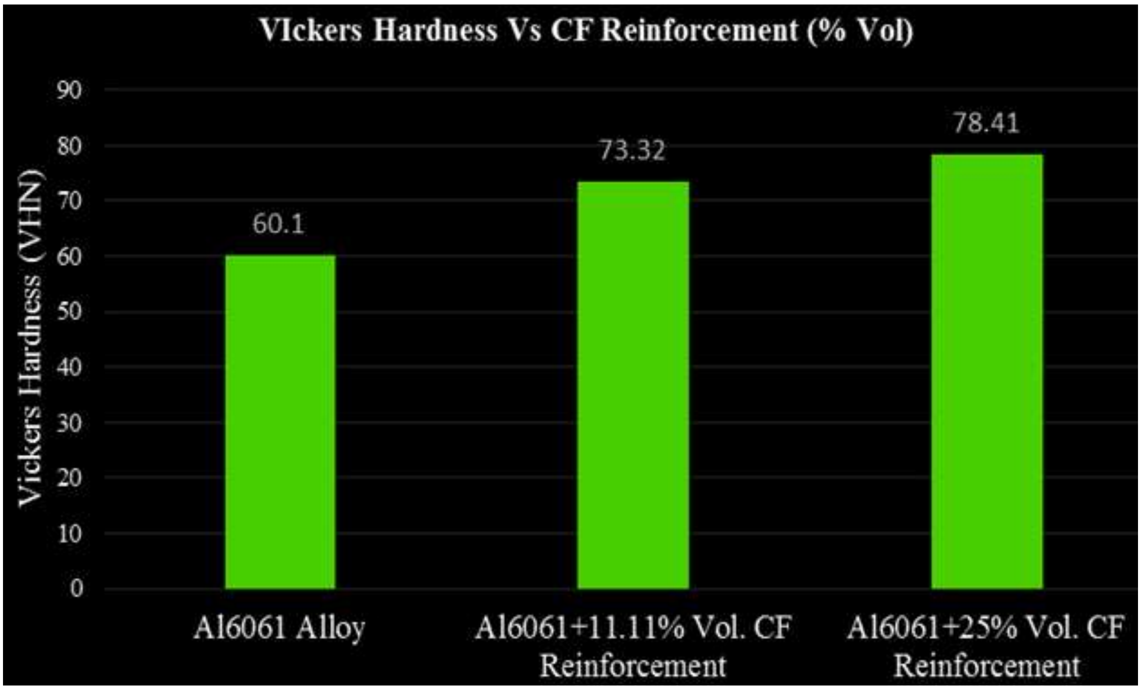


Figure 8: Vickers hardness (VHN) of composites with CF reinforcement and aluminium 6061 alloy

3.4 Tribological Characterization

When the percentage volume fraction of CF reinforcement rises, bulk and microhardness increase which results in higher wear resistance of composite material. The excellent bonding between the nickel-coated CF rod and the aluminium 6061 alloy, the superb lubricity between the carbon fibres inside the CF rod, and the absence of carbon fibre pullout during wear tests all contributed to the improvement in wear resistance.

Figure 9 shows the coefficient of friction for the composite materials made of the aluminium 6061 alloy, al 6061+11.11% vol. CF reinforced, and al 6061+25% vol. CF reinforced. Tribological evaluation led to the conclusion that synthesised composite materials have a lower coefficient of friction than aluminium 6061 alloys. The coefficient of friction of composite materials reinforced with Al6061+11.11% vol. CF and Al6061+25% vol. CF was discovered to be 4.59% and 11.6% lower than those reinforced with aluminium 6061 alloy, respectively.

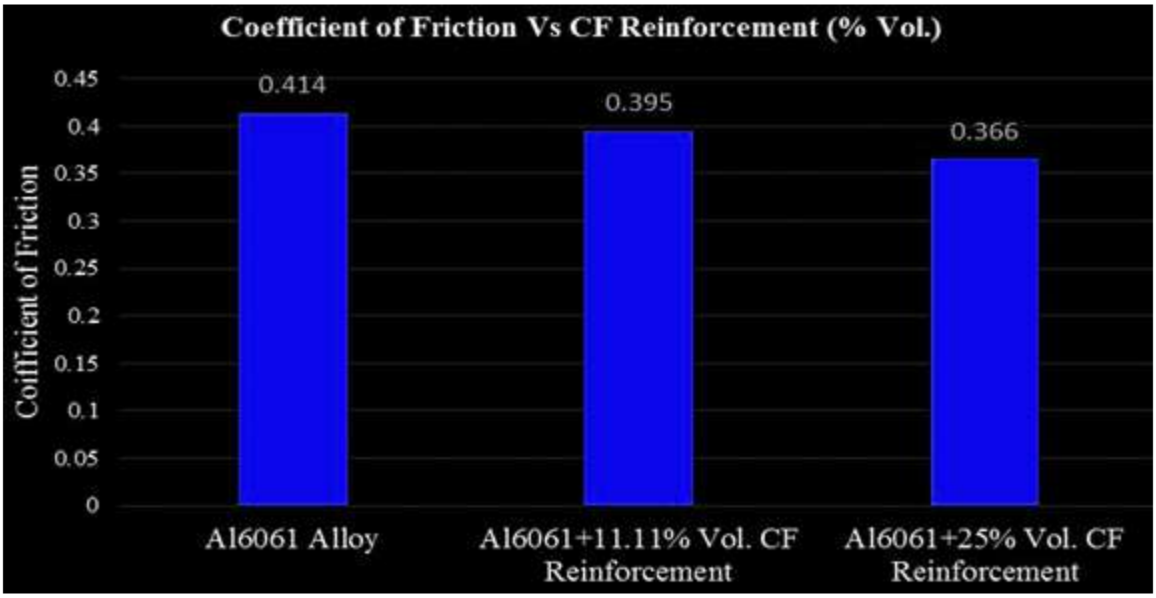


Figure 9: Composites with carbon fibre reinforcement and aluminium 6061 alloy's coefficient of friction

The wear rate had been calculated using both the sliding velocity and the applied stress. The analysis of several study publications revealed that the wear rate increases as the applied force and sliding velocity increased. Following a thorough investigation, it was determined that the DUCOM pin on disc tribometer was used to monitor wear rate at applied loads of 20 N and 0.51 m/s. Figure 10 depicts the wear rate for the composite materials made of the aluminium 6061 alloy, Al6061+11.11% Vol. CF reinforced, and Al6061+25% Vol. CF reinforced.

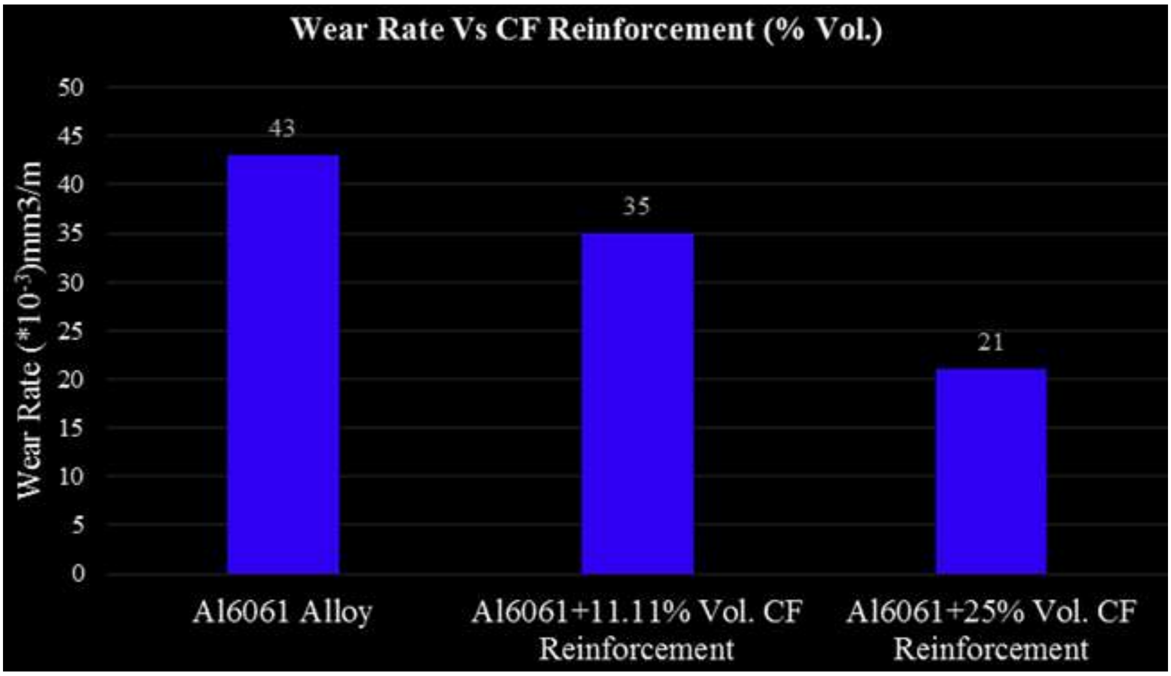


Figure 10: Composites with carbon fibre reinforcement and aluminium 6061 alloy's wear rates

It was discovered that increasing the volume of CF reinforcement by a percentage in the matrix material—up to 25%—results in a decrease in wear rate. Graphite, which serves as a solid lubricant and lowers wear rate, was found between sliding surfaces during the wear test. Additionally, it was discovered that the wear rates of composite materials reinforced with Al6061+11.11% Vol. CF and Al6061+25% Vol. CF are, respectively, 18.6% and 51.16% less than those of aluminium 6061 alloy.

4. Conclusion

Key findings from the work include the following:

1. For the synthesis of carbon fibre rod reinforced aluminium 6061 alloy metal matrix composite material, the stir casting liquid metallurgical process was cost-efficient and successful.
2. Using SEM-EDAX analysis, electroless coating process results in a uniform and efficient nickel deposition on the surface of carbon fibre rods. Because of the carbon fibre rod's efficient nickel coating, the chemical link between the reinforcement and matrix material has improved.
3. A synthetic composite material's remarkable 13.28% density decrease when compared to cast aluminium 6061 alloys.
4. Due to an increase in CF reinforcement, synthetic composites have a significantly higher bulk and microhardness than cast aluminium 6061 alloy.
5. Due to better bonding between the reinforcement and matrix material, the synthesised composite material has a lower coefficient of friction (11.6%) and a lower wear rate (51.16%) than cast aluminium 6061 alloy.
6. Due to its improved tribological and mechanical qualities, novel material has potential use in the automotive sector for braking disc, brake drum, etc.

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