

Research Article

Carbon-Filled E-Glass Fibre-Reinforced Epoxy Composite: Erosive Wear Properties at an Angle of Impingement

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In the current study, multiwalled carbon nanotubes (MWCNTs) and carbon particles (micron size) were employed to create carbon particle dispersions. At different impact angles, the erosion of abrasive particles in an air jet is examined. Carbon particles dispersed across a metal matrix increased the fibre bonding but decreased the mechanical strength. In the sample, carbon nanotubes make up 5% of the total. The strength of carbon nanotubes in matrix materials overcomes the growth in carbon particle length significantly. When carbon particles are present, the matrix material weakens and becomes brittle. Due to the effect of attrition on exposed surfaces, materials that are subjected to particle impingement are more vulnerable to erosive processes. Carbon has significantly improved the matrix material's surface property. The research findings significantly affect 5% of the CNT composite. At 30°, 0.0033 g/min showed the least proportion of abrasive wear. Erosive wear decreases at the lowest impingement angle but increases as the impact angle increases. Since it causes brittleness, increasing the weight percentage of carbon particles is discouraged.

1. Introduction

Recent publications to fibre-reinforced polymer composites have gotten a lot of interest in the scientific community since they have great qualities including a high strength to weight ratio and can be used in structural applications. Carbon and glass artificial fibres are frequently reinforced with a variety of polymeric compounds. Because of its great mechanical strength and stiffness, the glass fibre is in high demand in ultrahigh automobile, the aerospace industry, navy, and also defense, which resulted in the development of multiple PMCs (polymer matrix composites) [1–3]. Moreover, a human-created fibre-reinforced composite material has good mechanical properties but processing of these man-made fibre composite takes high cost when compared to the natural fibre composite. Presently, many of the researchers

experimented with several FRCs (fiber-reinforced composites) to increase their wear and mechanical qualities. However, the wear features of PMCs were lacking to meet present industrial needs. As a result, a revolutionary notion of blending carbon fillers with manmade fibres in a common matrix has been developed, and hybrid composites have been coined [4]. The addition of micro carbon, Al₂O₃, SiO₂, carbon nanotubes (CNTs), and graphene as a reinforcement (as whiskers) to PMCs improves mechanical parameters including tensile, flexural, and interlaminar shear strength, as well as heat transfer characteristics [5].

A work from the authors of [6] discoursed the inclusion of carbon nanotubes in a polyethylene-based polymer matrix composite and has observed that the glass transition temperature and thermal expansion has enhanced significantly. Molecular dynamic simulations based on the Brenner

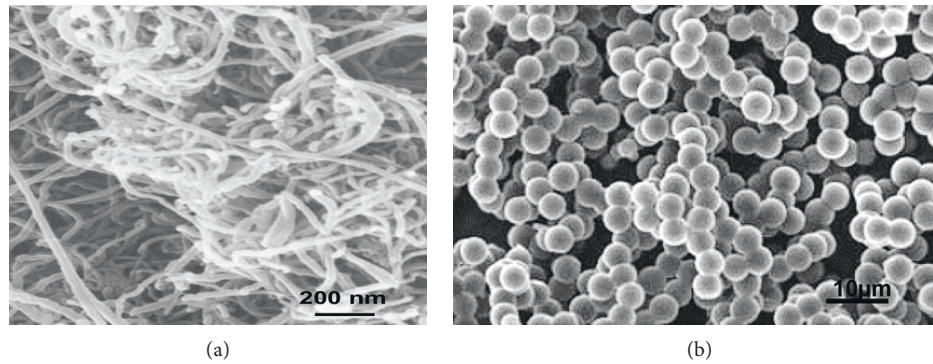


FIGURE 1: SEM images of materials incorporated (a) CNTs and (b) carbon particles.

TABLE 1: Carbon particle wt. % distributed in prepared materials.

Sl. no	Sample ID	Glass fibre layer	Name of the filler material	Weight % of the filler material
1	SP-1		—	—
2	SP-2		MWCNT	2.5
3	SP-3		MWCNT	5
4	SP-4	5	MWCNT	7.5
5	SP-5		Micro carbon	5
6	SP-6		Micro carbon	7.5
7	SP-7		Micro carbon	10

potential models were employed to study these properties. The author also attributed that the enhancement in the diffusion coefficient of the matrix atoms above T_g has enhanced the mobility of composite materials for the fabrication process. However, the simulation results do not implicate the exact experimental procedure to process these composites. Due to impracticability of attempts to disperse single-walled nanotubes (SWNTs) into an epoxy acrylate system is found to be unsuccessful [7]. In this context, a novel process, by using a solvent in conjunction with sonication to disperse SWNTs into epoxy, has been presented by the authors of [8, 9]. The work used the concept of interpenetrating polymer networks for the design of the composites.

The most commonly identified failures in the composites are delamination and fibre pullout. As a result, the CNTs may undergo either of these phenomena, and also additionally, they might undergo fracture within the CNT itself resulting in the failure of the composite material. Examining these failure characteristics of the CNTs in the composite matrix is one of the challenging problems for the characterization team [10]. Micro-Raman spectroscopy, on the other hand, sheds light on the failure process of CNT-based composite materials.

With the availability of hard powders such as tungsten carbide (WC) and tantalum niobium carbide (Ta/NbC), epoxy hybrid fibre glass composites are being explored for better abrasive wear characteristics. [11] The induced CNTs and micro carbons by several processing techniques not only generated excellent mechanical properties but also enhanced the tribological characteristics, as shown in the preceding literature. The purpose, according to the literature, is to incorporate micro carbon nanotubes in GFRPs using hand

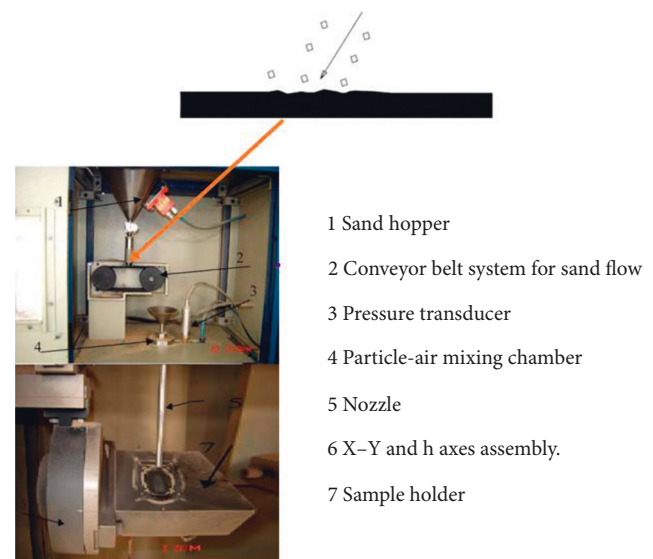


FIGURE 2: Erosive wear mechanism (top) and erosion test setup (bottom).

layup preparation, with a focus on composite performance at varied compositions [12].

From the literature survey, it is observed that the CNTs are widely accepted in various composites and found to be compatible to use with any kind of fibre and matrix composites. The comprehensive literature discussed in the above session have provided the insights to handle CNTs in an optimized way. The efficiency of a hybrid epoxy composite reinforced with both multiwalled carbon nanotubes (MWCNTs) and micro carbon particles is investigated in



FIGURE 3: Samples after erosion test.

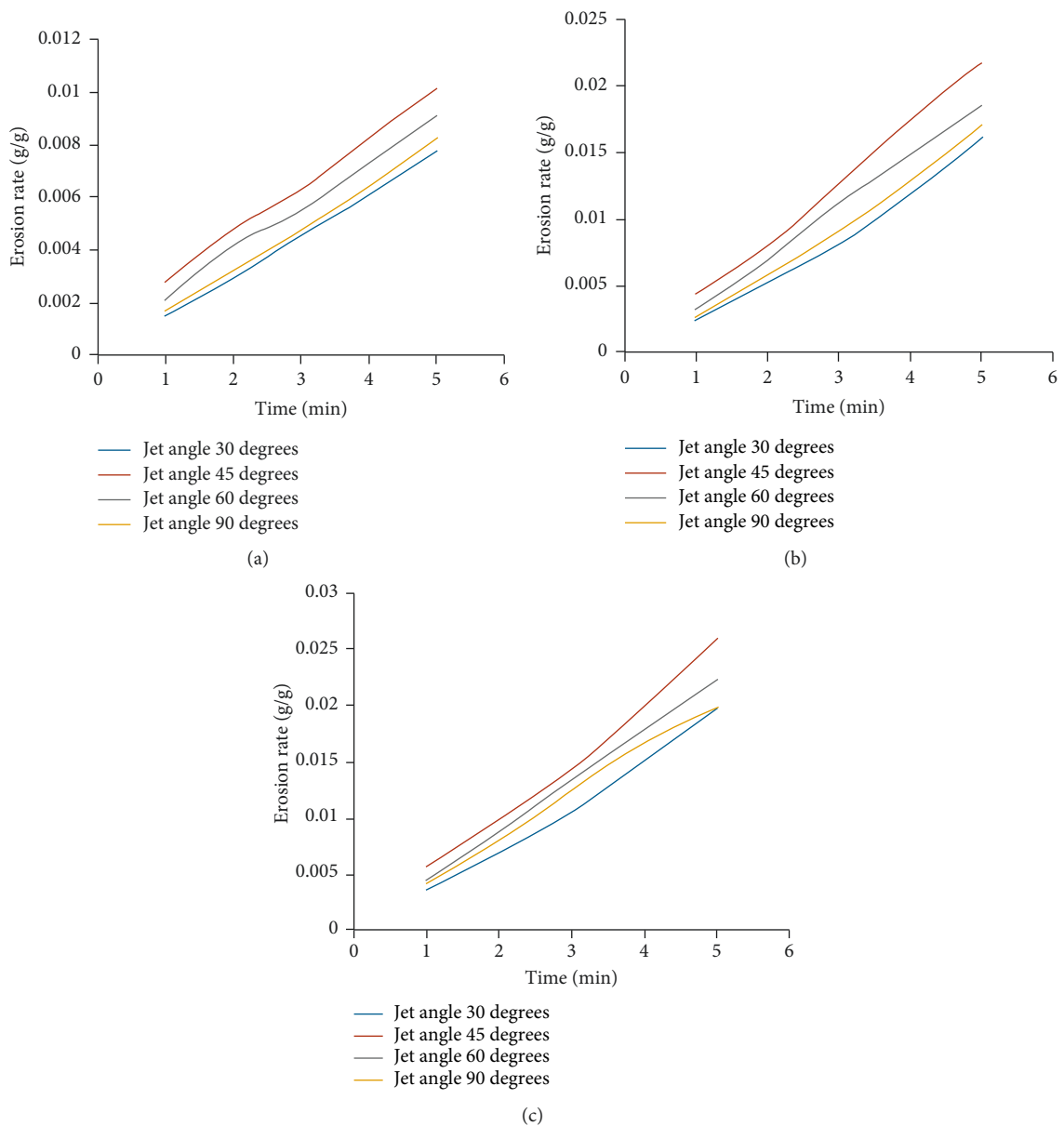


FIGURE 4: 5 layers glass fibre. (a) 1 bar pressure and 5% micro carbon powder filler. (b) 1.5 bar pressure and 5% micro carbon powder filler. (c) 2 bar pressure and 5% micro carbon powder filler.

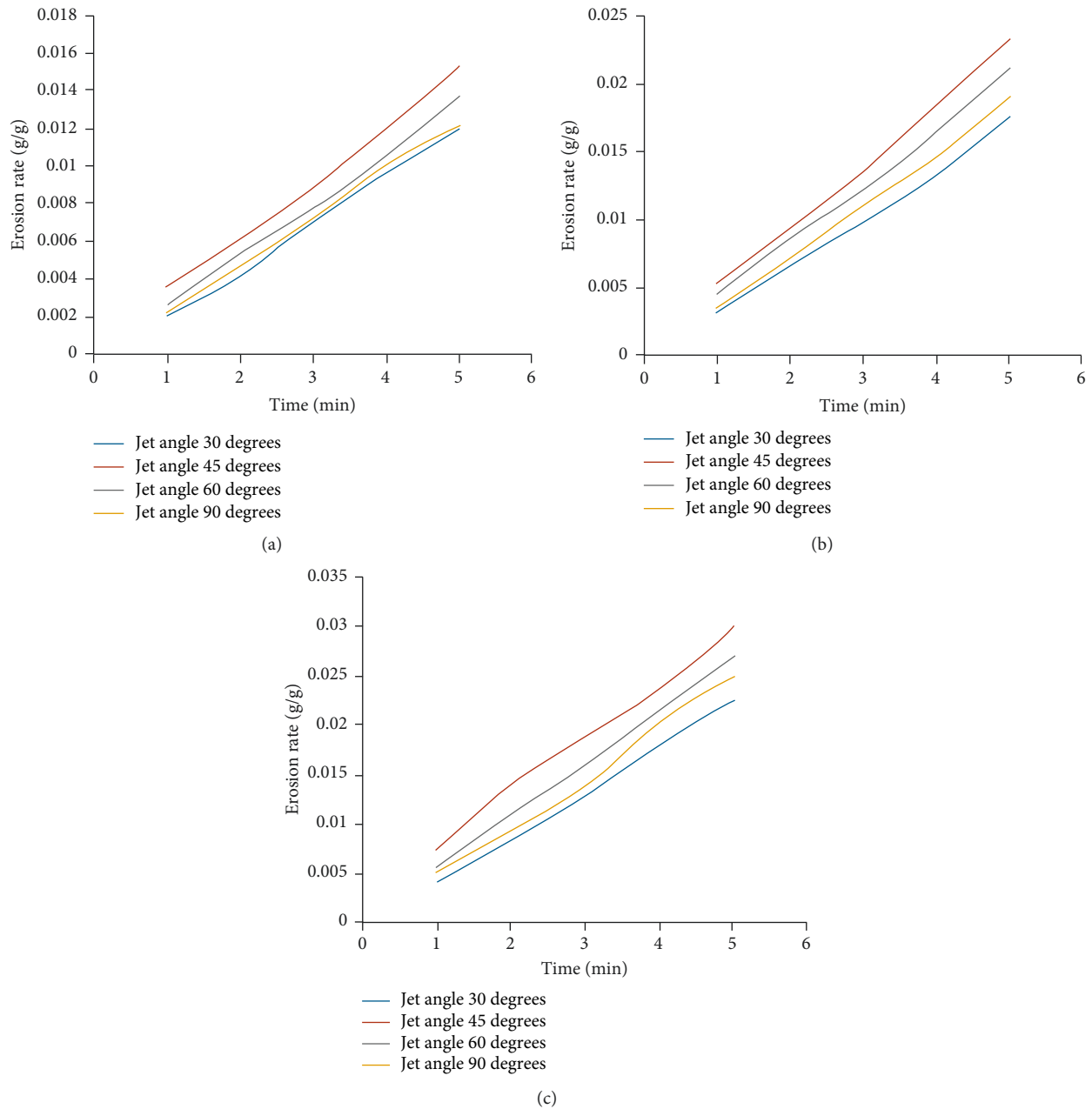


FIGURE 5: 5 layers glass fibre. (a) 1 bar pressure and 7.5% micro carbon powder filler. (b) 1.5 bar pressure and 7.5% micro carbon powder filler. (c) 2 bar pressure and 7.5% micro carbon powder filler.

this work. Using an abrasive jet machine, the tribological characteristics of the hybrid composite in terms of erosive wear are also assessed.

2. Materials and Methodology

This study utilizes glass fibre reinforcement to explore the impact of carbon in the matrix. The e-glass fibre is reinforced with epoxy resin. The composite material is pre-processed by carbon prior to composite fabrication. The composite is made up of carbon particles that are both nano and micro in size. The SEM image of the fibre glass and CNT employed with a carbon particle is shown in Figure 1.

Hand-layup is being used to produce the composite material, which has a fibre to matrix weight distribution of 40 : 60. The fibre matrix has a density of 2.56 g/cc and five laminations in total. The weight percent of nanotubes (CNT) and carbon particulates distributed in the prepared material is shown in Table 1 with sample labelling. Mechanical stirring is employed to disperse CNTs and carbon particles that are 10–20 microns in size in the epoxy. Using a wooden mould box, the preprocessed epoxy resin and fibre material are formed into a flat plate with dimensions of $150 \times 60 \times 5 \text{ mm}^3$. The curing period for a hand-crafted fibre and reinforcement materials using a hardener/catalyst is of twenty-four hours.

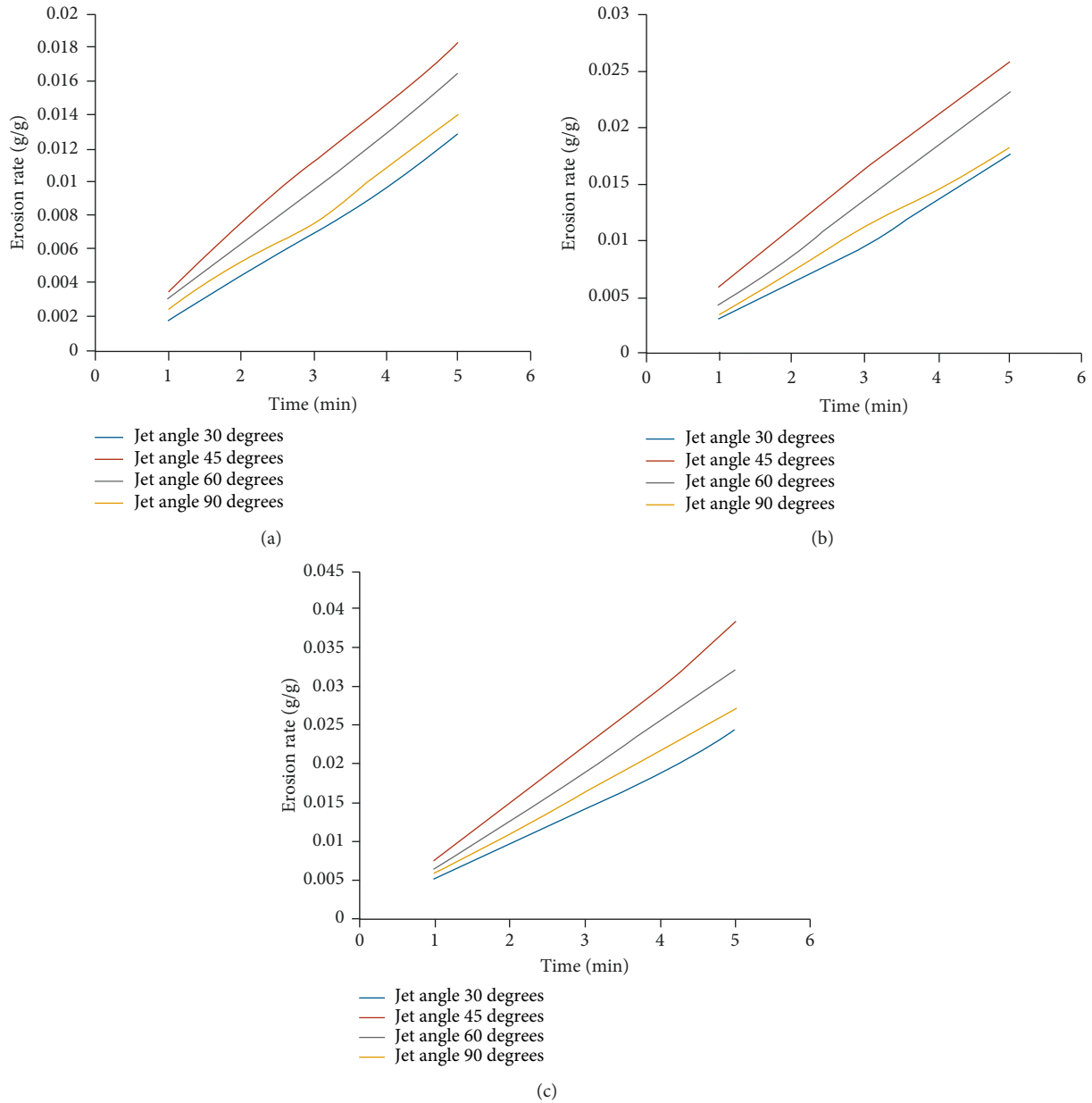


FIGURE 6: 5 layers glass fibre (a) 1 bar pressure and 10% micro carbon powder filler. (b) 1.5 bar pressure and 10% micro carbon powder filler. (c) 2 bar pressure and 10% micro carbon powder filler.

3. Air Jet Erosion Test

A erosion test performed using sand particulates on the material is used to investigate the erosion wear characteristics of a neat GFRP and GFRP with CNTs. Erosive wear is the process of metal removal caused by solid particles impinging on the surface. As it can be seen in Figure 2 where erosion is caused by gas jet impinging on the surface, if the impingement is small, the wear is closely analogous to abrasion. The essential erosion parameters will be investigated on the following aspects: impact angle and velocity, standoff distance, size of abrasive particles, test temperature, diameter of the nozzle, and duration. The schematic solid particle erosion test setup is as shown Figure 2. The ASTM

G76 standard is used for abrasive jet erosion investigation. The erosive wear rate is computed by equation (1).

$$E_r = \frac{W_m}{W_e}, \tag{1}$$

where “ W_m ” denotes the weight loss of the test sample (g), which may be calculated by comparing the weight values of the samples before and after each test and “ W_e ” denotes the mass of the erosion particles (g) that impacted the target sample for 10 minutes (i.e., the test duration). This method was repeated until the erosion rate reached a steady-state value. The abrasive wear samples from the planned study are also evaluated using an electron microscope.

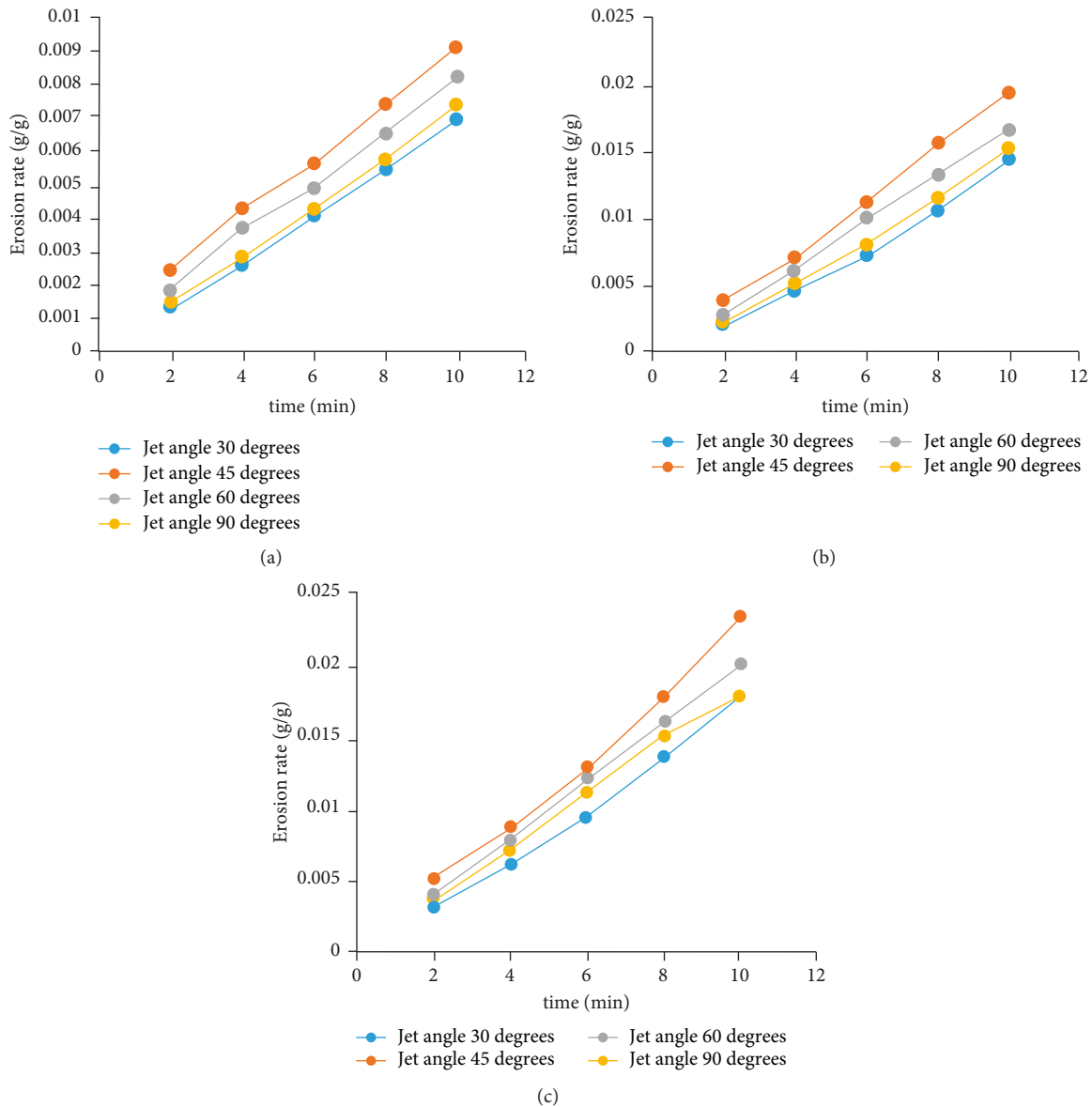


FIGURE 7: 5 layers glass fibre. (a) 1 bar pressure and 2.5% nanocarbon powder filler. (b) 1.5 bar pressure and 2.5% nanocarbon powder filler. (c) 2 bar pressure and 2.5% nanocarbon powder filler.

The following process parameters of used in this present work, that is, $50\ \mu\text{m}$ erodent size, 48 m/s, 70 m/s, 82 m/s velocity of erodent, 2 g/min flow rate of erodent, 10 mm SOD, and $30^\circ, 45^\circ, 60^\circ, 90^\circ$ angle of impingement [13]. Figure 2 shows abrasive jet erosive wear mechanism and erosion test setup.

4. Results and Discussion

4.1. Erosion Test Results for Micro Carbon Filler-Added GFRP. The important aspect of tribological studies is air jet erosion which is one of the most crucial and desired parameters by various industries especially in automobile and biomedical applications. The air jet erosion tested samples are shown in Figure 3. The results of the prepared samples air jet erosion test are presented below.

Case 1. For pressure 1 bar and 5% Micro-carbon Powder filler in 5 layers of Glass Epoxy.

Case 2. For pressure 1 bar and 10% micro carbon powder filler in 5 layers of glass epoxy.

Case 3. For pressure 1 bar and 15% micro carbon powder filler in 5 layers of glass epoxy.

From the graphs plotted in Figures 4–6, it is clearly measurable that for jet angle $30^\circ, 45^\circ, 60^\circ,$ and 90° , for a pressure of 1, 1.5, and 2 bars and to 5%, 7.5%, and 10% micro carbon powder filler in 5 layers of glass epoxy, the erosion rate is calculated. The test is performed consecutively measuring the erosion rate for an interval of 2 minutes for ten minutes. The results indicate that there is a substantial growth in erosion rate for all the jet angles in common but

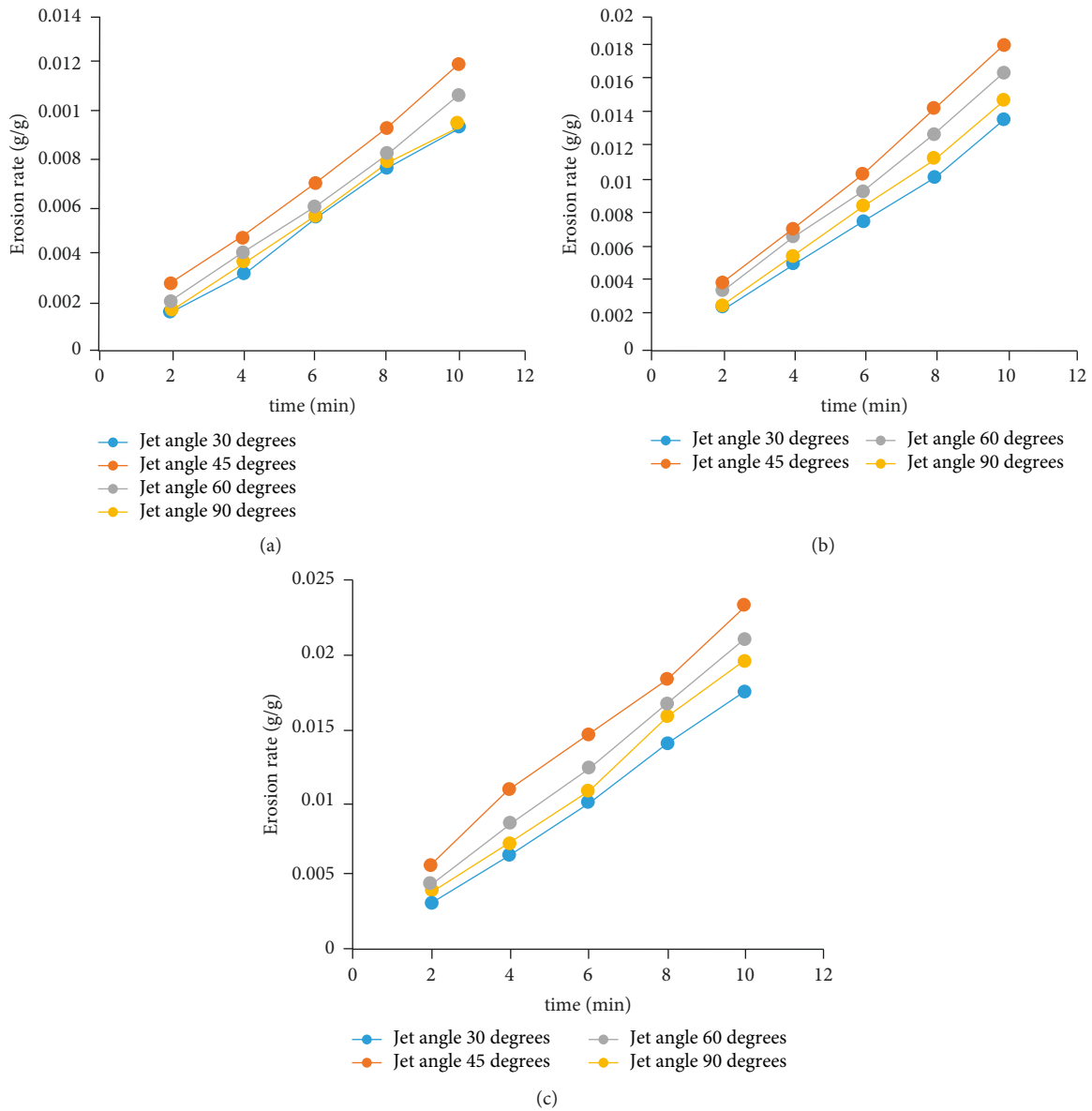


FIGURE 8: 5 layers glass fibre. (a) 1 bar pressure and 5% nanocarbon powder filler. (b) 1.5 bar pressure and 5% nanocarbon powder filler. (c) 2 bar pressure and 5% nanocarbon powder filler.

the magnitude of trend gave a diverse ideology that 30° with the lowest magnitude and 45° with the highest intensity of magnitude is observed, thereafter the intensity of magnitude decreased consistently until 90°.

4.2. Erosion Test Results for Nanocarbon Filler-Added GFRP.

Similarly, an erosion test is performed on the nanocarbon particle-based composite to verify the true facet of the property enhancement at different scales. However, we have observed a trend similar trend with microparticles, the same testing conditions but with 2.5, 5, and 7.5 wt% taken as constituents.

Case 4. For 1 bar pressure and 2.5% Nano-carbon Powder filler.

Case 5. For 1 bar pressure and 5% Nano-carbon Powder filler.

Case 6. For 1 bar pressure and 7.5% Nano-carbon Powder filler. It can be pursued Figures 7–9 that variation of erosion rate is significantly enhanced thus indicating the dispersion of nanoparticles also show similar behavior in comparison to the micro carbon fillers but decrement at 7.5%. However, we can observe there is little better enhancement observed with dispersed nanoparticles. This is attributed to the size of the particle as we move towards continuum, the scattering of particles reduced and no agglomeration can be sighed. As a result, we have better enhancement at the nanoscale when compared to the microscale. There is a substantial increment of the erosion rate at 30° to 45°; thereafter, it is observed to be reduced thus indicating the effect of the impact angle also plays a vital role.

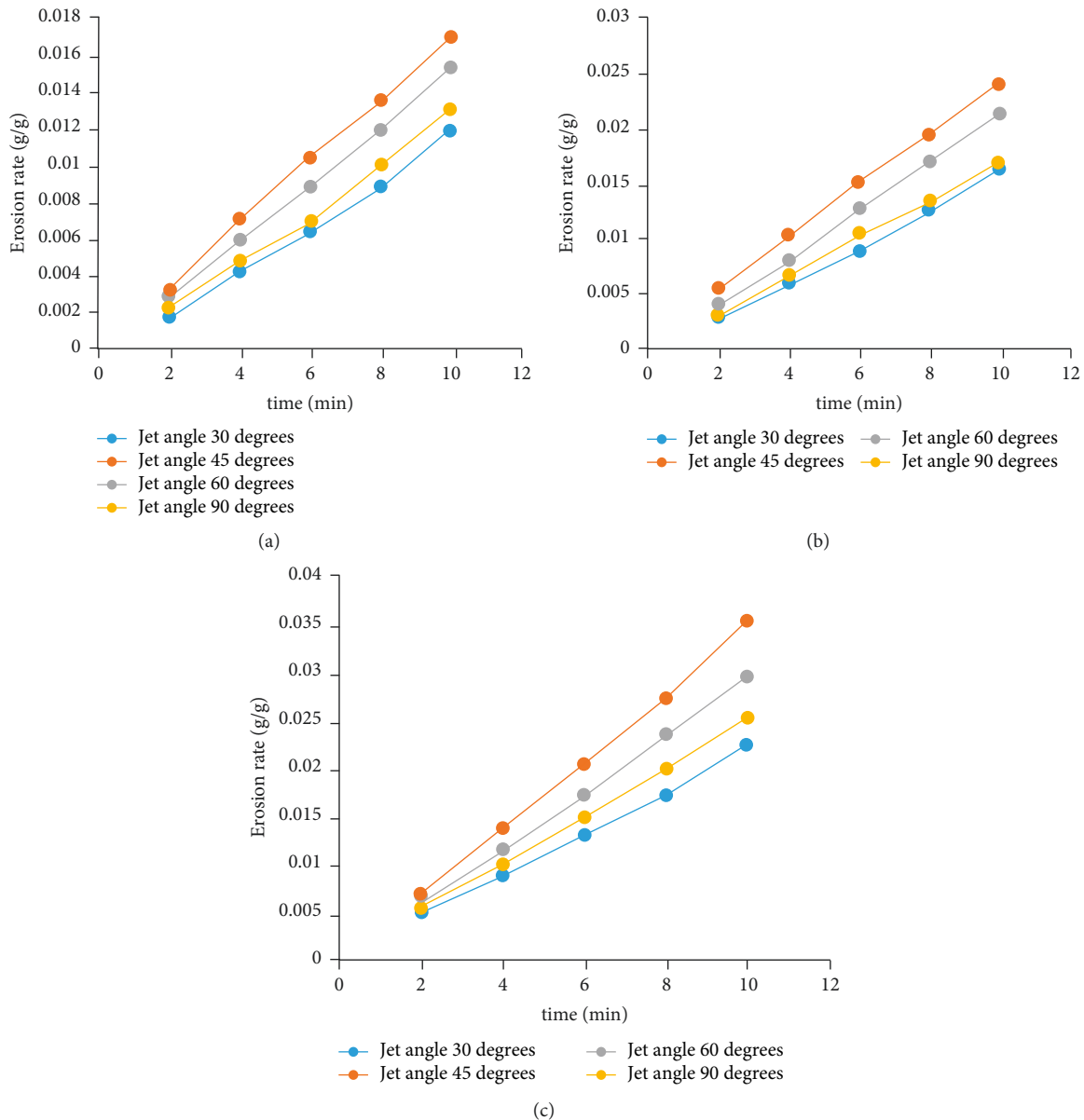


FIGURE 9: 5 layers glass fibre. (a) 1 bar pressure and 7.5% nanocarbon powder filler. (b) 1.5 bar pressure and 7.5% nanocarbon powder filler. (c) 2 bar pressure and 7.5% nanocarbon powder filler.

Herein, there is an intriguing observation in comparison to micro and nano that has reflected similarity between them in terms of trend and enhancement and declination of erosion rate. Though the trend shows similarity, the variation in the magnitude is attributed to the heterogeneity of the material micromechanics [14, 15]. The indentation involves compressive stress because micro carbons exhibit high micro bending; as a result, local removal of resin material from the composite can be observed. In transverse erosion, the tensile stresses from the impact adjacent particles cause high interfacial stresses hence fails easily in bending which gives visual confirmation on Figure 10. Multiple matrix microcracking independent of fibres and fillers, this phenomenon can be rarely observed in the composites. This is a processing defect. The respective EDS is given in (Figures 10–12).

Figures 10–12 depict the surface morphology of worn surfaces at 30°, 45°, 60°, and 90° jet angles. The surface roughness profiles illustrated in the above graphic demonstrate that the surface features created by silica particles vary with varied impact angles. In all of the cases, it can be observed in common that the trend indicates the relatively large craters for 45° and with lowest at 30°. This is generous to say that most of the literature cited in the scientific community exhibit for general materials without inclusion of CNTs exhibit larger depth craters at 60° when compared with jet angles of 30° and 90°. Variations in surface morphologies are linked to changes in the degree of plastic deformation that occurs during erosion [16].

From Figure 13, it can be inferred that the erosion rates increased with impingement velocity show semiductile

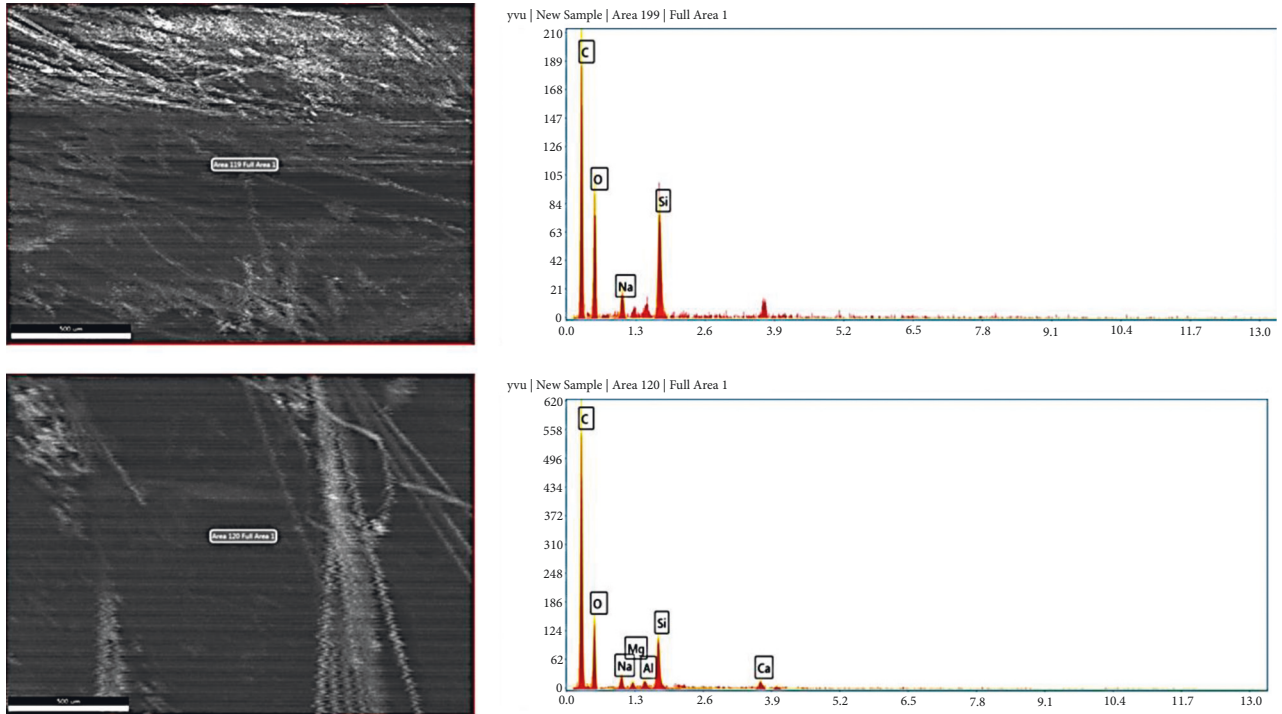


FIGURE 10: EDS of solid jet abrasion test micro carbon powder-filled GFRP.

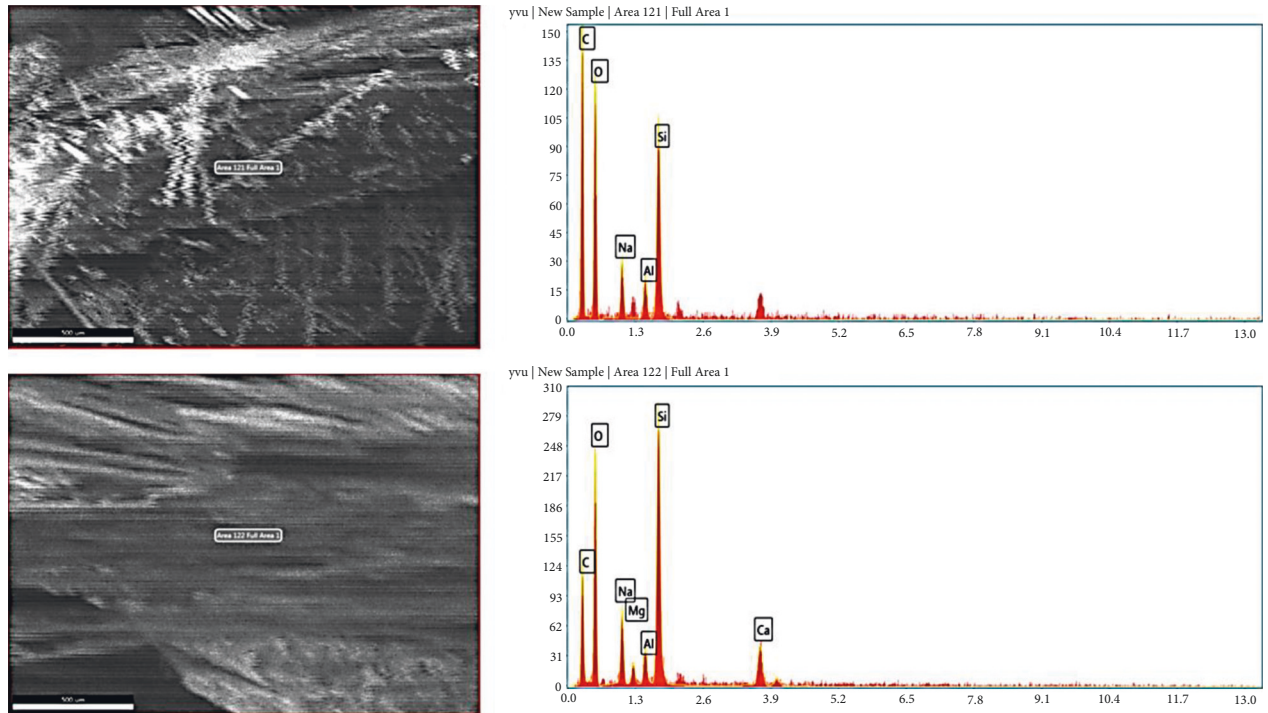


FIGURE 11: EDS of solid jet abrasion test nanocarbon powder-filled GFRP.

erosion behavior and as a result maximum erosion rate was observed at 30° to 45°. The failure mechanism clearly indicates few micro-cuts and immediate cracking occurred until 45° after which it is implicative that localized deformation is observed in Figure 13(b) due to the increase in the impingement angle. But at peak velocities

this is attributed to spackle of a brittle failure as the velocity was large enough [17–19]. This implicates loss of material though possessing better erosion resistance properties, however indicating that a little enhancement from the current property can be achieved a lower velocity. The continuous erosion by silica sand particles

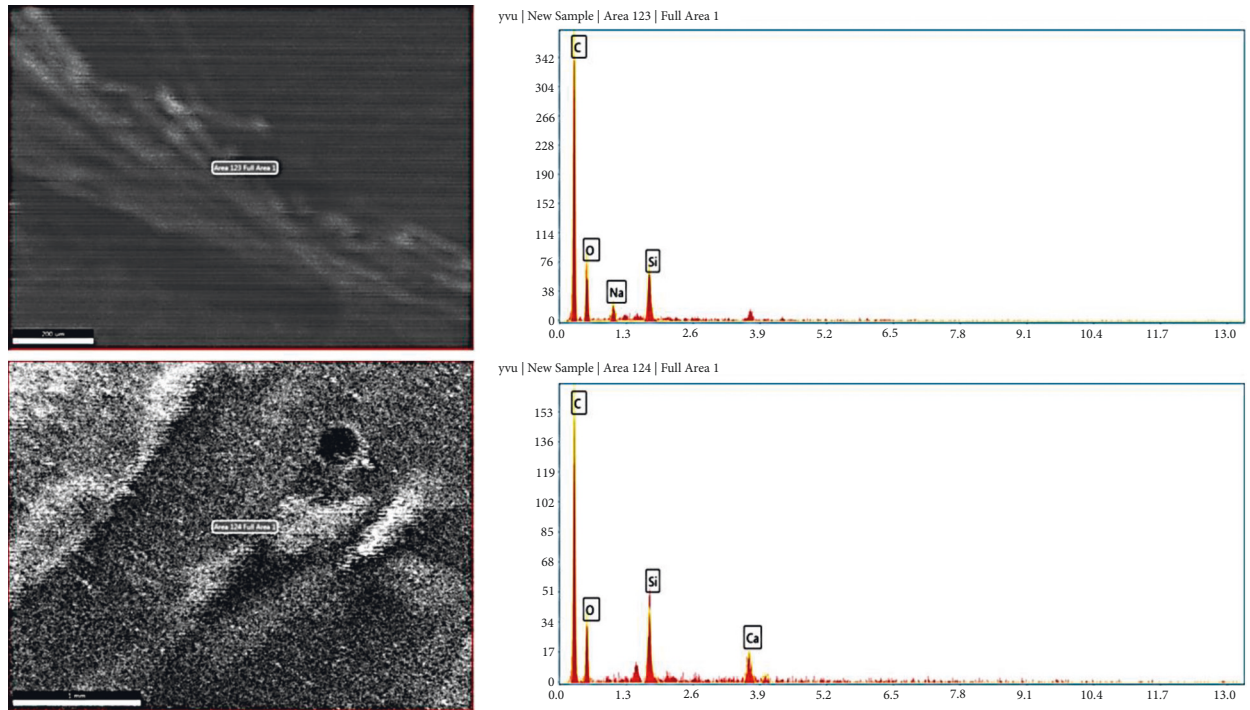


FIGURE 12: EDS of solid jet abrasion test for neat GFRP.

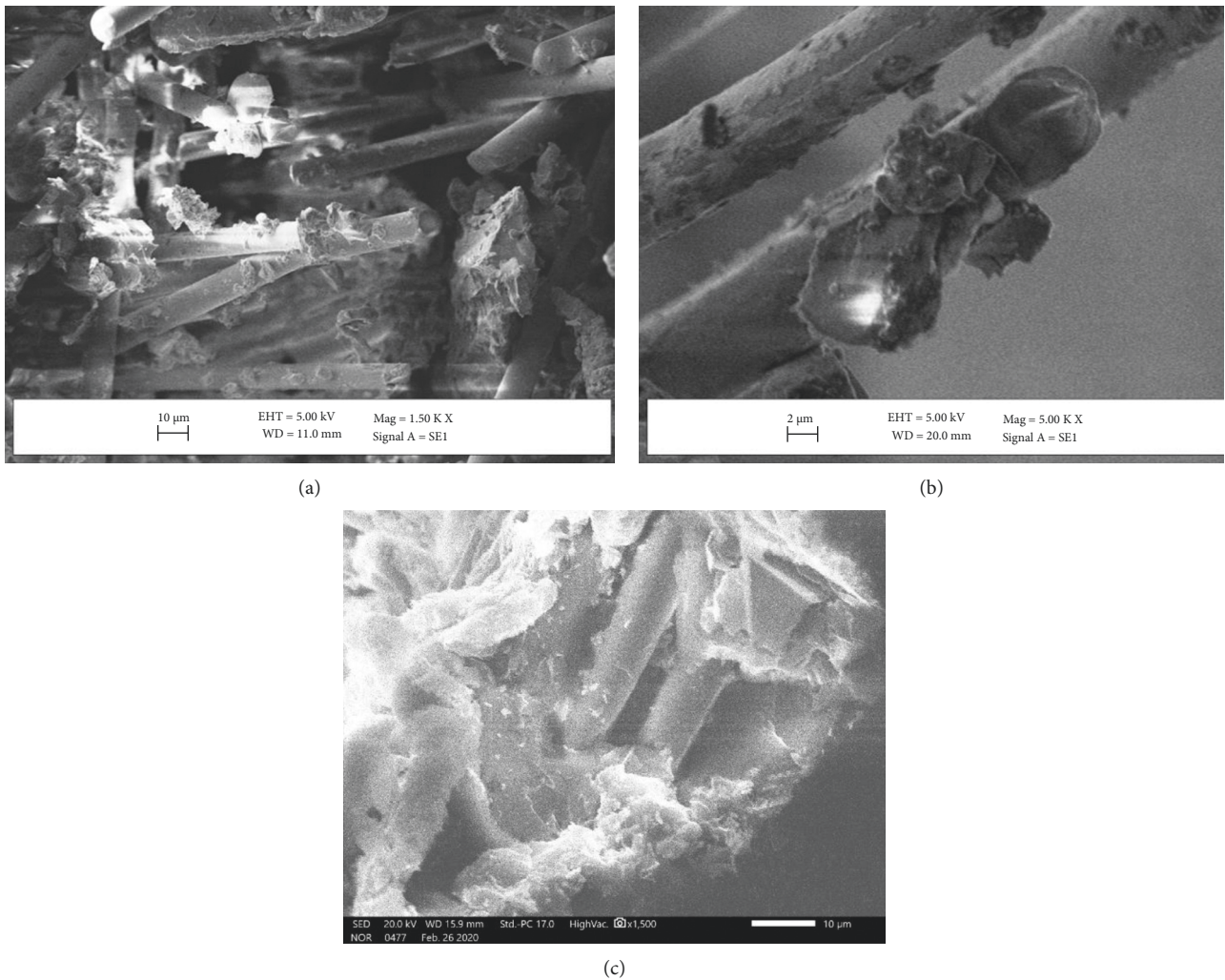


FIGURE 13: SEM of nanocarbon filler dispersed composite under erosion wear in (a) MWCNTs composite, (b) fibre pullout in erosion, and (c) filler dispersed in composite.

resulted in damage between fibres and resin. It is also visible that there is a stack of epoxy based composites.

5. Conclusion

From the present investigation, the abrasive jet erosive wear property analyzed with micro carbon powder-filled GFRP composite and nanocarbon powder-filled GFRP composite dispersion has been concluded with the following points:

- (1) The erosion wear behaviour of the composite has shown better results at jet angle of 30° and with 45° with a peak erosion rate. From the present result, it can be well noted for various composites have better erosion rate lying between 30° and 45°.
- (2) In present study, for 60° and 90° have shown declining behaviour but more than that of 30° impact angle and a pressure of 1 bar for 2 minutes interval for over ten minutes.
- (3) The SEM micrographs confirm that there was very poor resistance offered by the fibres and matrix against erosion for 60° and 90° angle.
- (4) Erosion rates increased with impingement velocity shown semiductile erosion behavior and as a result maximum erosion rate was observed at 30° to 45°. The failure mechanism clearly indicates few micro-cuts and immediate cracking occurred until 45°.
- (5) The indentation involves compressive stress because micro carbons exhibit high micro bending, and as a result, local removal of resin material from the composite can be observed.

Data Availability

No data were used to support the findings of this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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