M. Venkatesan*, K. Palanikumar and S. Rajendra Boopathy

Experimental investigation and analysis on the wear properties of glass fiber and CNT reinforced hybrid polymer composites

https://doi.org/10.1515/secm-2017-0068
Received February 17, 2017; accepted July 30, 2017; previously published online October 14, 2017

Abstract: The aviation, automobile, and consumer products industry requires long-life, durable, lightweight high-performance polymer matrix composites. Polymer fiber reinforced materials possess low weight and high specific quality along with high specific stiffness. The addition of carbon nanoparticles in the composites improves their mechanical properties, including wear enhancement, which leads to the utilization of these composites in different fields. The present work investigates the wear performance of glass fiber and carbon nanotube (CNT) reinforced hybrid polymer composites. Dry sliding tests for wear were conducted using a pin-on-disc wear tester by varying the load and speed. The worn surfaces were examined by utilizing scanning electron microscopy, X-ray diffraction, energy-dispersive X-ray spectroscopy, and atomic force microscopy. The result shows that the increase in volume percentage of CNTs in glass fiber reinforced polymer composites decreases the wear rate. The result also clearly states that the coefficient of friction increases with an increase in the CNT percentage.

Keywords: carbon nanotubes (CNTs); coefficient of friction; glass fiber reinforced polymer (GFRP) composite materials; SEM; wear rate.

1 Introduction

In the past 30 years, there has been a highlight on the advancement of polymeric nanocomposites, where no less than one of the measurements of the filler material is of the request of a nanometer. The end product does not need to be in nanoscale, but can be micro- or macroscopic in size [1]. Wear is one of the most regularly experienced mechanical issues, leading to the substitution of components and assemblies in design, followed by fatigue and corrosion. Many tribological components such as gears, cams, driving wheels, bolts and nuts, impellers, brakes, seals, bushes, and bearings are used in machinery. Work is done by overcoming the friction in bearing, whereas other mechanical components are dissipated as heat, and its reduction leads to an increase in overall efficiency. Because of the better tribological designs, energy losses in these tribological components are reduced drastically. The research in tribology leads to better performance of machines. Polymer composite tribology is one of the main subjects used as an application, which is composed of gears, cams, bearing cages, artificially simulated joints, etc. Wang et al. [2] conducted an investigation on composite carbon nanotube (CNT) materials based on tribological performance, which includes polymer atomic structures, handling, treatment techniques, and their properties [3].

Glass fiber reinforced epoxy resin composites play an important role in enhancing the mechanical properties. With the addition of CNTs in glass fiber reinforced polymer (GFRP), the wear properties are significantly improved, and CNTs are presently considered as high potential filler materials for the improvement of mechanical and physical polymer properties. The available literature has not yet focused on the influence of a typical load and sliding distance on the tribological attributes of multiwalled CNT (MWCNT) E-glass/epoxy composites. The tribological properties of such materials, when subjected to corresponding contacts, rely on both reinforced components and their interface. Reciprocating contacts depend on the characteristic properties of both matrices and reinforcement elements and their interface. When these epoxy resins are reinforced with high-strength glass fibers and CNTs, the resulting product finds structural applications in the form of lightweightness and high stiffness. The inclusion of MWCNTs in the epoxy matrix considerably enhances its sliding wear behavior. The percentage of reinforcement has a significant effect on the specific wear rate and coefficient of friction (COF) in both of these composites [4].

***Corresponding author: M. Venkatesan,** Department of Mechanical Engineering, Thangavelu Engineering College, Chennai, India, Phone: +91-9445749048, e-mail: msvenkat1980@gmail.com
K. Palanikumar: Department of Mechanical Engineering, Sri Sai Ram Institute of Technology, Chennai, India
S. Rajendra Boopathy: Department of Mechanical Engineering, College of Engineering Guindy, Anna University, Chennai 600 025, India

Suresh et al. [5] studied the friction of reinforced materials by examining the slide and wear characteristics of the composite mixture of glass and epoxy. The result shows that the friction and wear-out properties of composite specimens are impacted vigorously by test parameters, for example, the sliding pace and distance travelled. Chauhan et al. [6] performed a test on the dry sliding and abrasive wear behaviors of nanostructured Zr-W-N coatings. It was observed that the COF increases with an increase in applied load and sliding distance under the dry sliding wear test, whereas under the abrasive wear test, the COF increases with applied load and remains unaffected with travelling distance. By using SEM analysis, the interface attributes of the materials, an internal structure of the ruptured surfaces, and the material failure morphology are noted. The results indicate that the sisal fiber with GFRP is superior to the jute fiber reinforced GFRP composites. Even though the performance of the natural fiber composites is low, it has been utilized in many applications [7].

Satheesh Raja and Manisekar [8] conducted an experimental investigation and found that the nano fly-ash impregnated composite mixture of GFRP is synthesized by fluctuating the molecule size of the filler material alone by setting the proportion of resin to 70 wt%, fiber to 20 wt% and filler to 10 wt%. The study noted that there is a decrease in structured molecular size from micro to nano particle of fly-ash fillers that prompts the improvement of the properties, such as mechanical property (e.g. rigidity, compressive strength, hardness and strength of impact), of GFRP composites. Two pairs of the composite mixture of GFRP are created by utilizing a blend of compression technique. The hand lay-up method assures perfect wetting of the fiber as well as uniform distribution of the same through the layers of the fabric. The immediate development of CNTs on glass fiber sheets for composites is a promising course for enhancing the vitality dissipation of structures at both low and high strain rates [9].

Friction, the imperviousness to motion, happens at the point when one strong body is in contact with another strong body. The surface harm of the material from one or both sides is in contact during motion, which represents wear. In major cases, wear happens when surfaces collide at first-glance anomalies. Increasing interest inputs and their applications in the industry act as an efficient replacement for metals and other materials. It is also based on our ability to create and change their structure over a vast range. This enables property improvement and also includes the change of wear properties [3]. Bastwros et al. [10] conducted experiments in Al-CNT composites, which are fabricated by mixing the aluminium particles and the MWCNTs using high ball milling energy, which is followed by a cold compaction mix and, finally, by a hot extrusion process. The CNT content varies from 0 wt% to 5 wt%, which results in a significant increment in the hardness and wear resistance, resulting in a reduction in the COF.

Grewal et al. [11] directed high temperature with erosion performance of materials, which are made of nanostructured and normal TiAlN coatings on the AISI-304 substrate of boiler steel, whose principal goal is to expand the life of boiler tubes by utilizing nanostructures and normal coatings of TiAlN. They also contrasted the AISI-304 grade oil steel. Experiments utilizing atomic force microscopy (AFM) were carried out to explore the correlation of wear properties, surface topography, and lateral forces of polymer composites that have CNTs.

Ashok Gandhi et al. [12] studied the abrasive, adhesion, and wear behaviors of polypropylene (PP)/CNT mixed steel against its counterparts. The expansion of load causes an increment in the wear as well as the loss of the material composite. The rubbing term dissects the surface layers, which increases the temperature stream flow between them. The adhesiveness of the steel disc material leads to an increase in the wear loss value. The specific rate of wear and their rate of decrease in an expansion of CNTs are recorded. If there are higher CNT proportions, then the greater wear resistance is observed. The part of the nanotubes made from carbon (CNTs) enhances the properties of wear for PP in the condition of dry sliding motion. Investigations are completed on a pin-on-disc test for wear to gauge the properties of wear in the CNT/PP mixture. The results show that the expansion of the CNT % rate builds resistance to wear.

Friction and wear investigations are processed in fiber orientation, in a typical direction towards the cylindrical counterpart, utilizing a pin-on-disc testing method for various changes in sliding conditions [13]. COF and rate of wear at different typical applications of loads determine the slide against a clean dry surface of steel (case B) and enhance the friction through contact and properties of wear. Friction coefficient and wear rate are diminished by around 33%–62% and 30%–75%, respectively. This depends on the normal value of applied load or speed [13]. The analyses were performed to break down the wear properties of hybrid metal matrix composites, and they additionally build up numerical relations of hybrid metal matrix composites amongst wear and influencing parameters. The fraction volume of the reinforcement material acts as a compelling element that influences the wear. The scanning electron micrographs were used to study the worn out surfaces of the hybrid material composites, which demonstrate the worn-out surface of the compound mixture composite, and it is more rough than the unreinforced composites. This outcome demonstrates that the hard ceramic particles influence the worn-out surface [14].

In this study, the tribological performance of the GFRP composites along with 1%, 3% and 5% CNTs was investigated to find the influence of CNT inclusion in polymer composites. Tribological performances such as wear loss and COF were studied in detail. To analyze the results, X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDAX), scanning electron microscopy (SEM) and AFM were utilized. The results were analyzed and discussed in detail.

2 Materials and methods

The investigation in the present work was carried out twofold. First, the CNT-GFRP reinforced composites were fabricated using the hand pultrusion method. Second, to analyze the wear performance, wear tests were carried out by using a pin-on-disc wear tester and are briefly discussed below.

2.1 Fabrication of CNT-GFRP reinforced hybrid composites by the pultrusion method

The glass fiber was fabricated with reinforced epoxy resin and reinforced CNT. Epoxy is a solid adhesion substance, which is utilized for adhering diverse materials, which are covered upon the surfaces together. Epoxy resin mixture has an extensive range of utilizations, such as coatings of metal in both electronic and electrical components. Industries have high tensioned electrical covers, and structured adhesion is utilized in root canal treatments [15]. For securing, nanotubes of carbon with a composite mixture of resin and glass fiber along with a hardener are utilized. The hardener used in this experiment is Ardur (HY951), which is utilized as a part of the composite parts performance. Ardur (HY951) is cured under normal room temperature alongside a mixture of resin composites, which has a long life and a very low viscous property. This kind of system is simple to handle and has decent properties of fiber impregnation, which shows amazing mechanical properties. It consists of chemical compound resistance against acids at a high temperature raised to 80°C [16]. This resin material composite has a great resistant property towards chemical degradation because of atmospheric conditions. Glass fiber filaments were utilized as a reinforced medium in the present experiment. Glass fibers were treated along with sizing, coupled operating agents to decrease the impact of the abrasion of fiber, that are degraded in the property of mechanical strength for the individual content of fiber. The glass fiber utilized as a part of the experiment has a low alkali base glass. It is composed of the combinations of SiO_2 5.4 wt%, CaO + MgO 22 wt%, B_2O_3 10 wt%, $Na_2O + K_2O$ under 2 wt% and Al_2O_3 14 wt%. Numerous different materials were present as pollutants. Glass fiber has the most astounding strength property with high stiffness, great resistance towards heat, better chemical compound resistance, and insensitivity to moisture [15].

Table 1: Composition of nano glass fiber reinforced composite.

Components	Sample 1	Sample 2	Sample 3
Epoxy (LY-556)	39.6%	37.8%	36%
Hardener (HY951)	4.4%	4.2%	4%
Glass fiber	55%	55%	55%
CNTs	1%	3%	5%

In this experiment, the GFRP composites were prepared for directing the test for wear. GFRP (mixture of resin, CNTs and glass fiber) composite samples were prepared for the investigations. In the primary sample, epoxy resins were blended with CNTs and also with glass fiber reinforcement materials. In the fabrication procedure, the LY-556 mixture of epoxy resin was solidified by utilizing the hardener HY951 at room temperature by the hand pultrusion method in an approximate ratio of 10:1 proportion. In this method, the glass tubes were made to be used as the mould. The dried fibers, mixed with resin and CNTs, were pulled through the glass tubes to produce the CNT composite rods. CNTs 1%, 3% and 5% were considered to fabricate different samples. The prepared proportionate test samples of CNTs with glass fiber, resin, and hardener are shown in Table 1. Figure 1 displays the preliminary arrangement of the composites used for fabrication. Figure 2 displays the scheme for the strategic arrangement of the hand pultrusion process, which was utilized for the composite fabrication procedure. Figure 3 shows the fabricated composite test samples.

2.2 The wear testing of hybrid composites

The specimen of the test was a pin with a round tip, which was placed perpendicular to another specimen, which

Figure 1: Preliminary arrangement of the fabrication process.

Figure 2: Strategic arrangement for the fabrication process.

Figure 3: Fabricated hybrid composite samples.

is normally a flat circular disc. A rigidly held composite sample is often used as the pin specimen; it revolves around the disc center. In this case, the sliding path was a circle on the disc surface. The plane was slanted vertically. The specified load was used to press the disc against the pin specimen by means of an arm and attached weights. Since it is a single material, the specimen was used as pin. The wear was determined by weighing the specimen before and after the test and by measuring the linear dimensions of both specimens, which were used in the test, both before and after the test. A suitable metrological technique, such as electronic distance gauging or stylus profiling, was used to measure the length change and shape change of the pin. Appropriate geometric relations were used to convert linear measures of wear into wear volume. The precise loss was measured using linear measures because mass loss is very small.

A pin-on-disc tester with 10 mm diameter and 60 mm length with dead weight loading system was used to keep the pins. The disc piece was 55 mm in diameter and 10 mm in thickness, which was slided at a diameter of 50 mm and was made of hardened steel HV 698. The specimen of reinforced glass fibers was tested at varying applied loads of 29.43 N (3 Kgf), 39.24 N (4 Kgf) and 49.05 N (5 Kgf) at different sliding speeds of 200, 300 and 500 rpm. The sliding distances were 1000, 2000 and 3000 m in the experiment. The test was conducted at room temperature with 50% relative humidity. Figure 4 shows the pin-on-disc wear tester with an experimental arrangement.

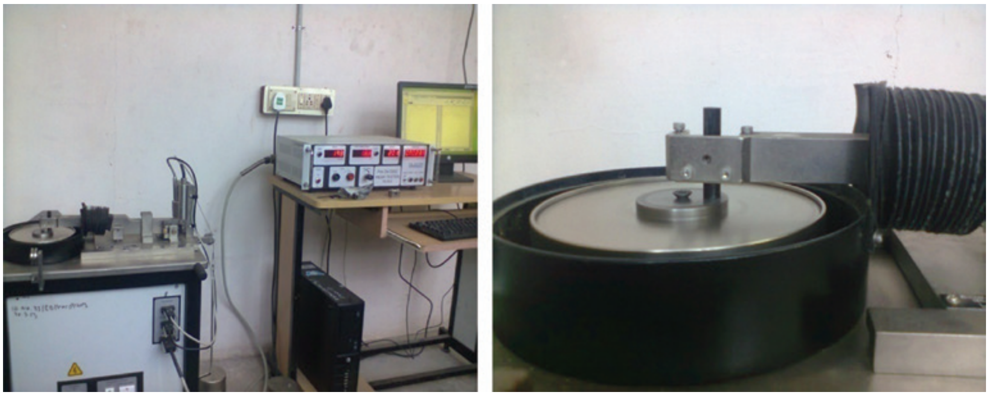

Figure 4: Pin-on-disc wear testing arrangement.

3 Results and discussion

The composites of fiber and particle reinforced materials are finding numerous applications in industries. Wear performance analysis of these composites is essentially required to convert these materials into end products [17]. The addition of CNTs on these materials improves their strength (normally up to 5%) and wear properties. To establish the products in engineering industries, the wear properties were studied.

In the present experiment, the CNT content of the wear properties was investigated. Figures 5 and 6 show graphs generated during the wear test on a pin-on-disc wear tester. Figure 5 shows the wear with respect to time. The figure keenly indicates that wear increases correspondingly with respect to time. Figure 6 demonstrates the COF with respect to time.

From the abovementioned figures, it has been noted that the COF increases correspondingly with respect to the load applied. After it reaches a certain height, there is a variation, and afterwards, it reaches a particular state.

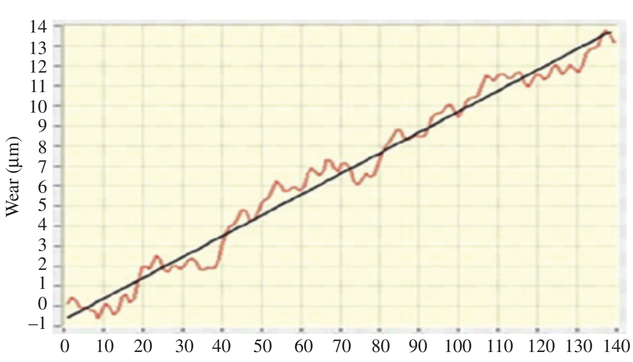

Figure 5: Graph generated at the time of the wear test on the pin-on-disc machine for wear.

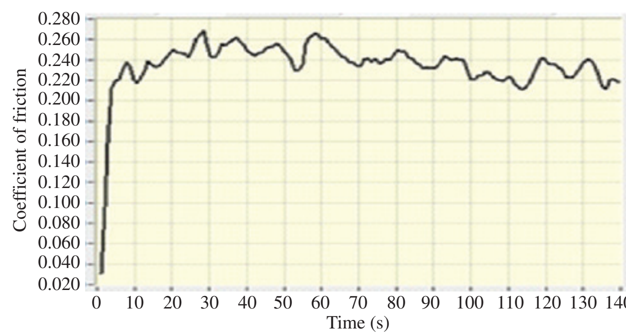

Figure 6: Graph generated at the time of the wear test on the pin-on-disc machine for coefficient of friction.

This study discusses the impact of the parameters on wear rate and COF in detail.

3.1 The influence of sliding distance and applied load on the wear properties

The remarkable mechanical properties of the CNTs have inspired the researchers to produce composites by combining CNTs with glass/carbon fibers. Very little work has been done to describe the sliding wear of CNT-based composites. The CNT content in the composite shows a steady rise in properties. The result indicates that the addition of CNTs decreases the wear rate, but it is observed that up to 3%, the wear rate reduces drastically, whereas a further addition of CNT (5 wt%) did not reduce the appreciable wear as observed earlier.

The study on the COF and the wear of nanocomposite materials is very important for material scientists and manufacturing engineers. Especially, when GFRP nanocomposite materials are to be used for a particular application, the response to wear and COF has to be analyzed [16]. The COF and wear rate of GFRP nanocomposite materials are different from those of polymer composite materials.

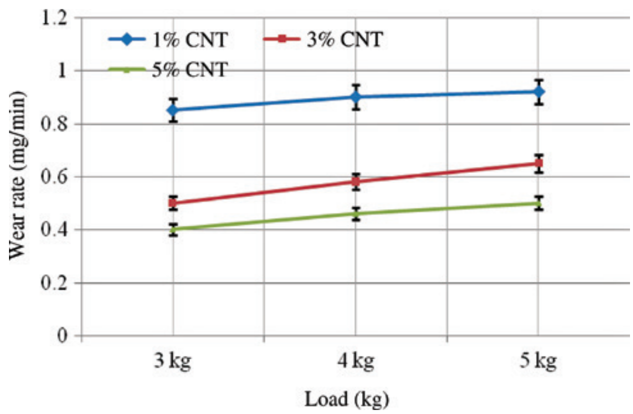

Figure 7: Difference in wear rate to applied load for various % of CNTs.

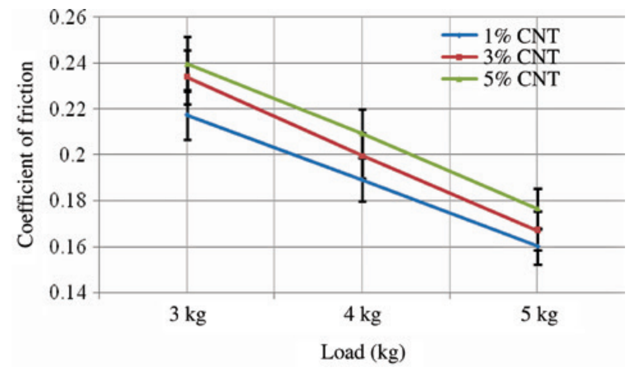

Figure 8: Difference in COF with respect to load for different % of CNT.

Wear performance graphs were used to analyze the properties of the composite material. The wear test results for the GFRP (glass fiber + CNTs and epoxy resin) composites under the dry sliding condition are presented in Figure 7. Figure 7 demonstrates the variation of the rate of corresponding wear with respect to loads for the different CNT content in the volume of the GFRP composites. It reveals that there is an increase in wear rate with an increase in the applied load. Table 2 shows the weight loss ratio for the increase of the wear due to the increase of the load for various wt% of CNTs. The weight loss ratio is the ratio between the weights of the specimen after the wear and the original weight of the specimen. If the ratio is high, the weight loss is less, and vice versa.

The result indicates that the increase in the CNT percentage decreases the wear rate. The result shows that the CNTs improve the wear performance of GFRP composites. Figure 8 shows the COF for GFRP composites at a sliding speed of 300 rpm with varying load conditions. The outcome shows that the COF increases naturally as the percentage of CNTs increases. The same result is also reported by Johnson et al. [18]. Also, it shows that the COF has a decrement with an increment in the applied sliding load. The force of friction developed during contact is substantially low because of the top layer of the pin-on-disc. Gradually, the increase in rubbing action leads to the wear of the disc and the pin material, because the contact took place between the pin and the disc, which in return causes the impact of ploughing effect. Hence, the COF increases with the increase in the duration of rubbing [19]. The presence of a typical load and sliding speed significantly influences the friction force. Within the observing range, the estimations of the COF decrease along with an increase in a typical load, though the COF increases with an increase in the sliding speed for gear fiber as well as glass fiber slide against the smooth or rough surface of mild steel pin [20].

Table 2: Weight loss ratio with respect to load for various wt% of CNTs.

Kg			wt
	1% CNT	3% CNT	5% CNT
3	0.934	0.966	0.982
4	0.933	0.965	0.981
5	0.910	0.954	0.978

3.2 The influence of speed and load on wear properties

COF is obtained from the impact of sliding velocity under the same loading condition and wear property of the GFRP composites with varying volume percentage rates of reinforcement. The specimens at the time of sliding are plotted against the sliding speed, which is shown below. It is clear that an increase in sliding speed results in an increase in wear rate. It also shows that an increase in the volume percentage of CNTs with GFRP composites leads to a decrease in the wear rate.

Figure 9 discloses the rise in the rate of wear with an increased sliding velocity under the same load condition. It also shows that a decrement in the rate of wear increases the volume percentage of CNTs in GFRP composites. Table 3 shows the weight loss ratio for the increase of the wear due to the increase of the speed for various wt% of CNTs. The weight loss ratio is the ratio of the weights of the specimen after the wear to the original weight of the specimen. If the ratio is high, the weight loss is less, and vice versa.

Figure 10 shows a linear increase in the COF during the variation in sliding speeds under the same load conditions. The same figure also shows that the increased volume percentage of CNTs in GFRP composites increases the COF.

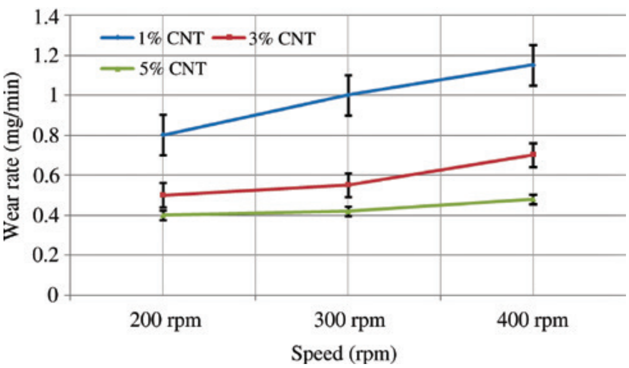

Figure 9: Difference in the rate of wear with respect to sliding speed for variation in % of CNT.

Table 3: Weight loss ratio with respect to speed for various wt% of CNTs.

RPM	wt		
	1% CNT	3% CNT	5% CNT
200	0.933	0.955	0.967
300	0.921	0.944	0.966
400	0.933	0.955	0.967

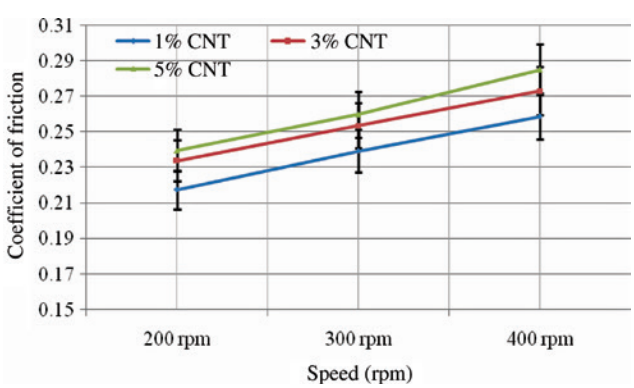

Figure 10: Difference in COF with respect to sliding velocity for different % of CNT.

3.3 SEM analysis

The surface prior to the wear test and the well-used worn-out reinforced surfaces of the material composites of glass fiber are shown in Figures 11–16. Figures 11 and 12 show the SEM examination of the resin casting mixed with the composites of the glass fiber with 1% CNTs before and after the wear test. Figures 13 and 14 display the CNTs, which are not uniformly distributed in the composite matrix. It is observed that there is porosity in the sample. Figures 15 and 16 indicate that there is a worn-out surface which is formed later in the execution of test for wear.

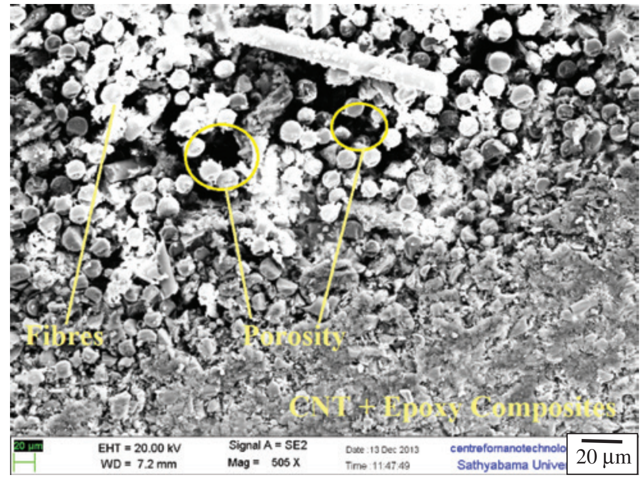

Figure 11: GFRP with CNTs 1% before wear.

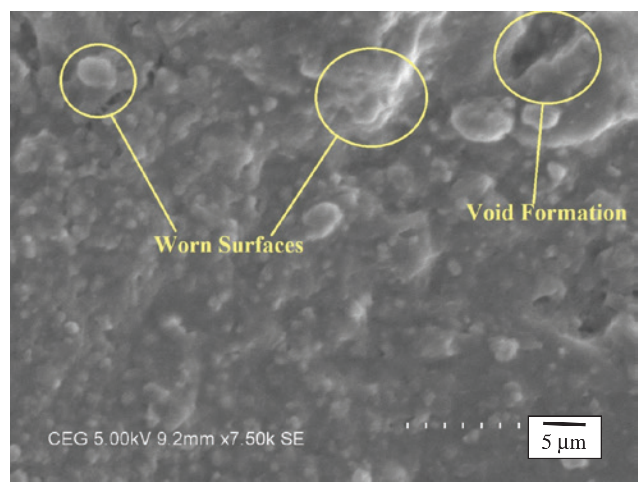

Figure 12: GFRP with CNTs 1% after wear.

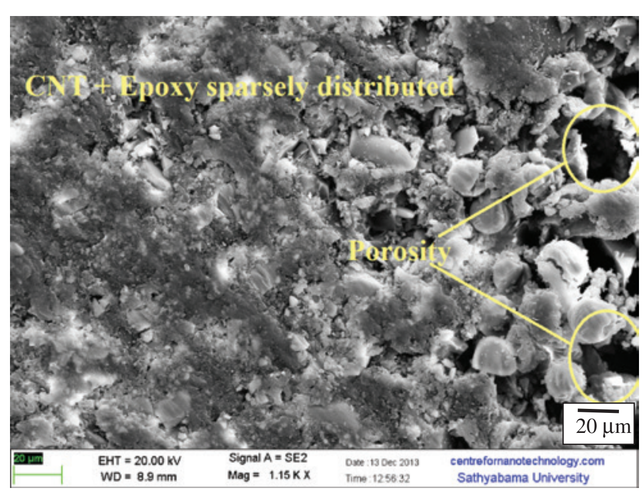

Figure 13: GFRP with CNTs 3% before wear.

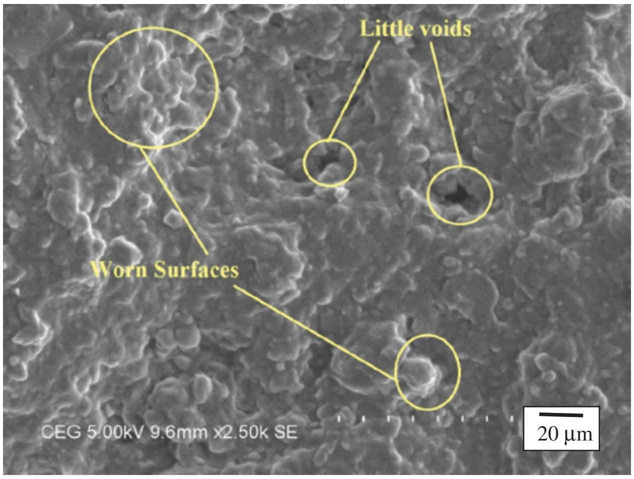

Figure 14: GFRP with CNTs 3% after wear.

Figure 15: GFRP with CNTs 5% before wear.

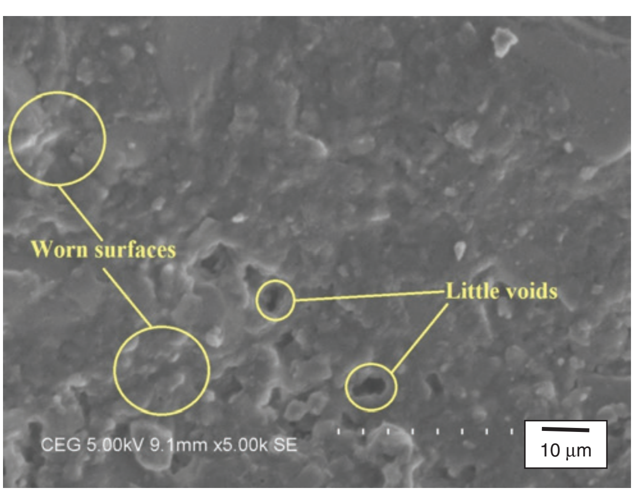

Figure 16: GFRP with CNTs 5% after wear.

This image indicates that the surface formed after wear consists of little pits and abnormalities in the specimen, which is made from reinforced composites of glass fiber. As a result, voids are formed, which are also keenly noted. This is because of the fabrication procedure, and this wear might be reduced by adopting the proper tribological conditions [15].

Figures 13 and 14 show the SEM images of the GFRP composites with 3% CNTs prior to and after the test for wear. Figure 13 shows that the grain size is a little bigger when it is compared with the previous one. The CNTs are sparsely distributed in the matrix. It is keenly noted that the porosity of the test sample reduces with an increase in the fraction volume of CNTs in the composites of GFRP [21]. Figure 14 shows that the wear tracks are observed on the surfaces of the GFRP composites. The graphs clearly indicate how the wear happens on the top layers of the composites. The surface finish is observed better after the wear test. Little voids are observed with the formation of a regular pattern.

Figures 15 and 16 show the SEM images of the composites of GFRP with 5% CNTs prior to and after the test for wear. In Figure 15, a large grain size is observed when it is compared with 1% and 3% CNT-mixed GFRP composites. The CNTs are uniformly distributed in this matrix. It is noted that the porosity of the specimen tends to decrease, corresponding to the increase in the fraction volume of CNTs in the GFRP composites. Figure 16 shows the fine, smooth grain size, which is observed after the wear test, and later, equal distribution of the glass fiber is observed. Minimum wear tracks observed on the surfaces of the GFRP composites have a better surface finish after the wear test. No voids are observed in 5% of CNT-GFRP composites.

3.4 EDAX analysis

Figures 17–19 show the EDAX analysis graph for fabricating composite samples. Figure 17 shows the EDAX report

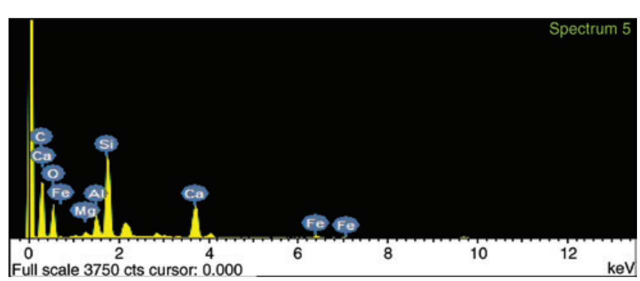

Figure 17: EDAX report of GFRP composites with 1% CNTs.

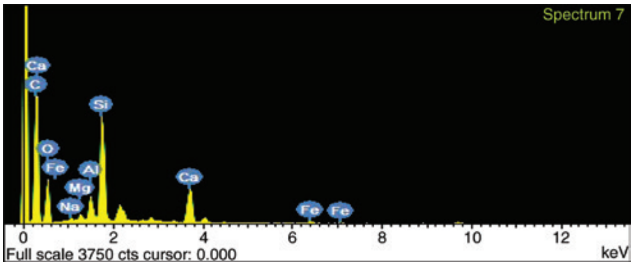

Figure 18: EDAX report of GFRP composites with 3% CNTs.

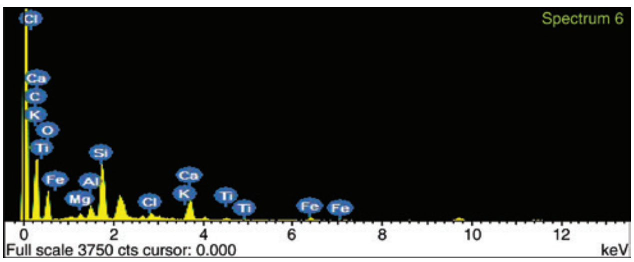

Figure 19: EDAX report of GFRP composites with 5% CNTs.

of GFRP composites with 1% CNTs. On the basis of the spectrum analysis, the zones are classified as 0–2, 2–4, 4–6 and 6–8. In zone 0–2, a small number of chemical compositions are observed, and in zones 2–4 and 6–8, only two chemical elements are observed. In zone 4–6, no element is observed. From this figure, it is also noted that the compositions of elements present in the specimen are C, O, Si, Ca, Fe, Mg, Al and Si, which gives information about the undesirable elements other than C, Ca, O, Al, Si and Mg. It is recognized that the mixture consists of high peaks of different elements. This result affects the properties of composite elements because of poor interracial bonding within the fiber and the matrix [22, 23].

Figure 18 shows the EDAX report of GFRP composites with 3% CNTs. On the basis of the spectrum analysis, the zones are classified the same. In zone 0–2, a large number of chemical compositions are observed; in zone 2–4, there is only one element present; and in zone 6–8, only two chemical elements are observed. In zone 4–6, no elements are observed. The same chemical composition is observed other than “Na”, which gives the data that there exist undesirable composite elements other than C, Ca, O, Al, Si and Mg. It is noted that the composites are composed of high peaks of various different elements. The result impacts the properties of composites because of the poor radical blended bond within the fiber and the matrix.

Figure 19 shows the EDAX report of GFRP composites with 5% CNTs. On the basis of the spectrum analysis, the zones are classified the same. In zone 0–2, a large number of chemical compositions are observed compared with the 1% and 3% CNT composites. In zone 2–4, three elements are observed. Two chemical elements are observed in zone 4–6 and in zone 6–8, only two chemical elements are observed. This figure also shows that other elements like K, Cl and Ti exist as undesirable composite elements other than C, Ca, O, Al, Si and Mg. It is noted that the composites comprise the high peaks of various different elements. The result impacts the properties of composites because of the poor radical blended bond within the fiber and matrix. The K, Cl and Ti peaks are generated because of the reinforcement of fibers in the nanopolymer composites. The peaks are generated at different zones with respect to the percentage weight of CNT.

3.5 XRD test

XRD is a technique used to distinguish both the molecular atom as well as the molecular subatomic structure of the specimen, whose crystalline particle of molecular atoms emits lights of incident beams of X-rays that are diffracted into various particular directions, which emits a three-dimensional (3D) pictorial rendering of the thickness of electrons present inside the composite crystal [24]. An XRD examination is completed for reinforced materials with CNT composites. Their crystalline size is measured for the reinforced glass fiber with 1%, 3%, and 5% CNTs with prominent peaks in the diffracted pattern. The observed results for the different compositions are presented in Figures 20–22.

Phase identification using XRD relies mainly on the positions of the peaks in a diffraction profile and to some extent on the relative intensities of these peaks. The shapes of the peaks, however, contain additional and often valuable information. It is observed from the XRD analysis that the particle size is increased proportionally with the increase in the wt% of CNTs. From the observed results, the XRD pattern shows prominent peaks only at one region. In Figure 22, the XRD patterns show a strong diffraction peak at 20°–30°. The results observed from the XRD test reveal that there are no diffraction peaks existing in the materials, but that there is a broadband observed at 2θ values in the range of 20–30. The spacing between bonding materials was also observed. The XRD pattern of the three different compositions of the nanoparticle inclusion indicates that the bonding is better for the 3% and 5% CNT inclusion.

The result from the XRD studies further indicates that the intensity observed for the 1% CNT content is higher

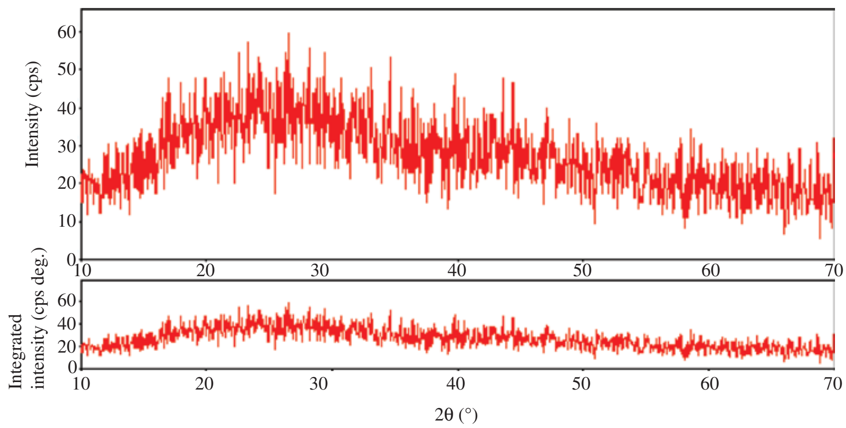

Figure 20: XRD analysis of GFRP composites with 3% CNTs.

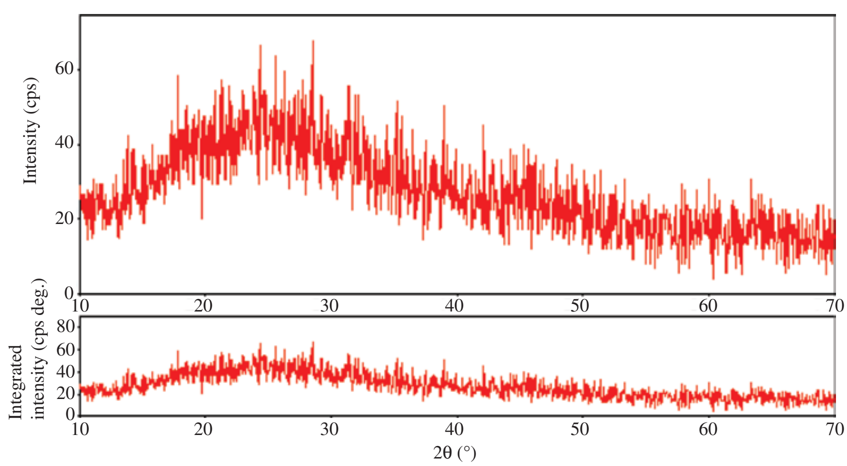

Figure 21: XRD analysis of GFRP composites with 5% CNTs.

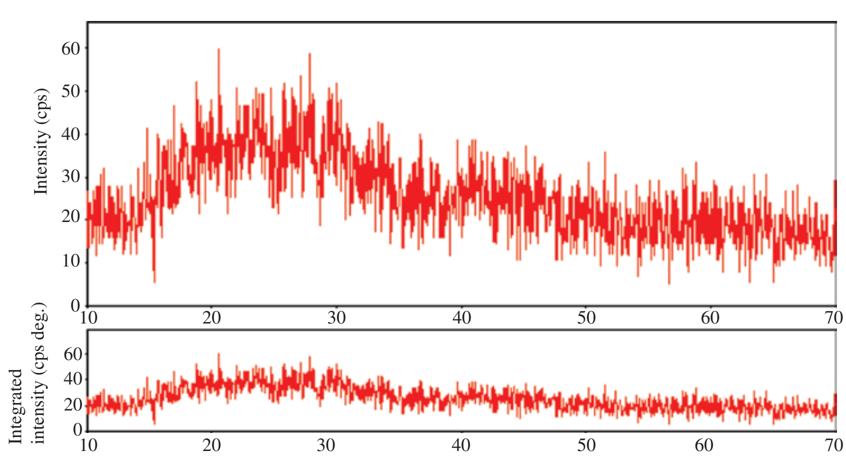

Figure 22: XRD analysis of GFRP composites with 1% CNTs.

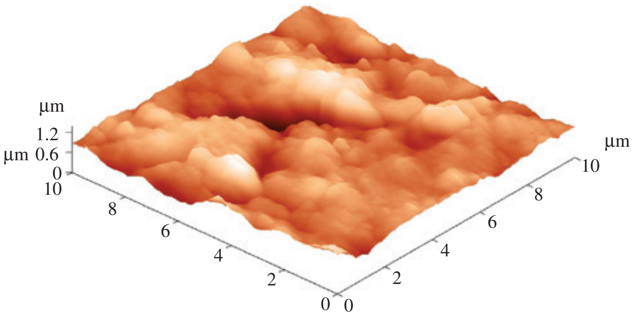

Figure 23: AFM analysis of GFRP with 1% CNTs–3D analysis.

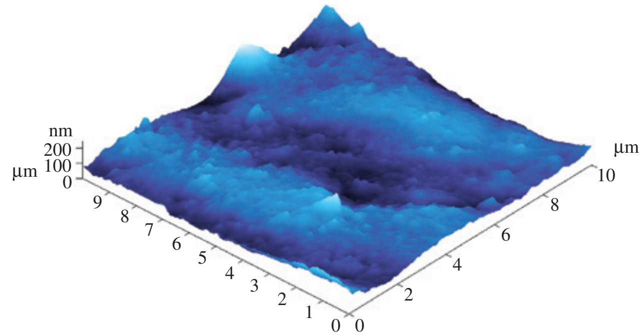

Figure 25: AFM analysis of GFRP with 5% CNTs–3D analysis.

than that for the 5% CNT content, which reveals the bonding between the molecules of the composites.

3.6 AFM analysis

The AFM study was carried out on the nanoscale to analyze the worn surface of the GFRP composites. The AFM utilizes a sharp pointed tip to scan across the sample. Figures 23, 24 and 25 show the AFM images of the GFRP composites with 1%, 3% and 5% CNTs after the wear test. A commercial AFM was used to obtained topography images for typical nanoparticle distributions. The manipulated study of the nanoparticles with the help of AFM has clearly shown that there is an area of contact depending on the COF [25]. Because of the higher wear rate in the 1% CNTs, the surface roughness was observed to be higher, whereas in the 3% and 5% CNT reinforced samples, the wear rate is comparatively low. For an easy comparison of the surfaces, the length and breadth of the sample were considered to be uniform and were 10 μm.

The AFM analysis of the wear properties of GFRP composites shows that the pattern with 1% CNTs has an average thickness of 150 nm, whereas the GFRP with 3% CNTs has an average thickness of 450 nm. However, the GFRP with 5% CNTs has an average thickness of around 0.75 nm. This shows that the % increase in CNTs has an effect on the size of the nanoparticles. The GFRP composites with medium % CNT are more prone to void and wear. Also, the GFRP with 3% CNTs has a rougher surface than the GFRP with 5% CNTs.

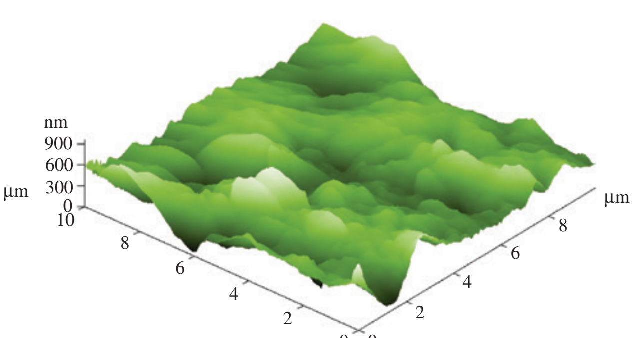

Figure 24: AFM analysis of GFRP with 3% CNTs–3D analysis.

The variation in the COF with high CNT concentrations is negligible, with no practical significance. This is because of the absence of the lubricating capabilities of CNTs, but the specific wear rate gradually decreases with an increase in the percentage of CNTs [26]. There are nonuniformity and high roughness after the addition of CNTs because of the agglomeration of nanotubes to some extent. Change in the COF is the contrast to the specific rate of wear. The COF increases in concentrated proportion with an increase in the rate of CNTs.

4 Conclusion

In this examination, reinforced glass fibers of 1% CNT, 3% CNT and 5% CNT polymer composites were fabricated by hand pultrusion casting. The wear characteristics of these materials were subjected to a wear test by the use of a pin-on-disc apparatus. From this examination, the following conclusions are drawn:

– The result shows that the increment in applied load leads to an increase in the rate of wear, which is based on the time span of scrubbing. The increment in the volume percentage of CNTs in GFRP composites decreases the wear rate;
– The result clearly states that the COF increases with an increase in the CNT percentage. Also, it displays the decrease in COF corresponding to the increase in the capacity of sliding load;

- The COF increases with a change in sliding speeds along with the same load conditions, and also, it shows that the increase of the volume percentage in CNTs increases the COF in the material composite of the GFRP;
- The top surface layer and tattered surfaces of the material composite specimens were examined by SEM. The image shows that pits are covered with voids and other defects on the specimen surface. Also, it shows that the porosity of the specimen decreases with the increase in the fraction volume of CNTs in the composites of the GFRP;
- Spectrum analysis, XRD analysis, and AFM were used for the analysis of wear, and these analyses show that an increase in the percentage of CNTs has an effect on the size of the nanoparticles. The GFRP composites with medium % CNT are more prone to void and wear.
- The change of the COF is in contrast to that of the specific rate of wear. The COF increases in a concentrated proportion with an increase in the rate of CNTs;
- The wear rate of the 5 wt% CNT composite decreased when compared to the 1 wt% and 3 wt% CNT composites. It is noted that upon the addition of 3 wt% CNT, the wear rate decreased modestly. However, as the CNT content increased up to 5 wt%, the wear rate was observed to decrease significantly to reach 53%. Also, the weight loss ratio of the 5 wt% CNT sample, with respect to the load and revolutions per minute, decreased when compared to the other two samples.

From this research, nano GFRP composites posses superior wear properties. It is a perfect alternative material for mating surfaces.

References

[1] Hojjati FHM, Okamoto M, Gorga RE. *J. Compos. Mater*. 2006, 40, 1511–1575.
[2] Wang C, Dong B, Gao G-Y, Xu M-W, Li H-L. *Mater. Sci. Eng. A.* 2008, 478, 314–318.
[3] Brostow W, Kovačević V, Vrsaljko D, Whitworth J. *J. Mater. Educ.* 2010, 32, 273–290.
[4] Bobbili R, Madhu V. *Eng. Sci. Technol. Int. J.* 2016, 19, 8–14.
[5] Suresh B, Chandramohan G, Prakash JN, Balusamy V, Sankaranarayanasamy K. *J. Miner. Mater. Charact. Eng.* 2006, 5, 87–101.
[6] Chauhan V, Dubey P, Verma S, Jayaganthan R, Chandra R. *Trans. Indian Inst. Met.* 2015, 68, 799.
[7] Ramesh M, Palanikumar K, Hemachandra K. *Procedia. Eng.* 2013, 51, 745–750.
[8] Satheesh Raja R, Manisekar K. *Mater. Des.* 2016, 89, 884–892.
[9] Boddu VM, Brenner MW, Patel JS, Kumar A, Mantena PR, Tadepalli T, Pramanik B. *Composites B.* 2016, 88, 44–54.
[10] Bastwros M, Esawi AMK, Wifi A. *Wear* 2013, 307, 164–173.
[11] Grewal JS, Sidhu SB, Prakash S. *Trans. Indian. Inst. Met.* 2014, 64, 889–902.
[12] Ashok Gandhi R, Palanikumar K, Ragunath BK. *Mater. Des.* 2013, 48, 52–57.
[13] El-Tayeb NS, Gadelrab RM. *Wear* 1996, 192, 112–117.
[14] Umanath K, Palanikumar K, Selvamani ST. *Composites B.* 2013, 53, 159–168.
[15] Venkatesan M, Palanikumar K, Rajendra Boopathy S. *Trans. Indian. Inst. Met.* 2015, 68, s91–s97.
[16] Venkatesan M, Palanikumar K. *Appl. Mech. Mater.* 2015, 766–767, 362–367.
[17] Elango G, Ragunath BK, Palanikumar K. *Mater. Tehnol.* 2004, 48, 803–810.
[18] Johnson BB, Santare MH, Novotny JE, Advani SG. *Mech. Mater.* 2009, 41, 1108–1115.
[19] Nuruzzaman DM, Chowdhury MA. *Int. Trans. J. Eng. Manage. App. Sci. Technol.* 2012, 4, 29–40.
[20] Chowdhury MA, Nuruzzaman DM, Roy BK, Samad S, Sarker R, Rezwan AHM. *Tribol. Ind.* 2013, 35, 286–296.
[21] Stamopoulos AG, Tserpes KI, Prucha P, Vavrik D. *J. Compos. Mater.* 2015, 50, 2087–2098.
[22] Stamopoulos AG, Tserpes KI, Prucha P, Vavrik D. Characterization of Porous CFRP Laminates by Mechanical Testing and X-ray Computed Tomography, 6th International Symposium on NDT in Aerospace, 12–14th November 2014, Madrid, Spain.
[23] Ranjeth Kumar Reddy T, Subba Rao T, Padma Suvarna R, Srinivas Ula Reddy P. *Int. J. Nanotechnol. Appl.* 2014, 4, 19–22.
[24] Tzeng SS, Chr YG. *Mater. Chem. Phys.* 2002, 73, 162–169.
[25] Maharaj D, Bhushan B. *Beilstein J. Nanotechnol.* 2012, 3, 759–772.
[26] Cho M. *Mater. Trans.* 2008, 49, 2801–2807.