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Research paper

Adhesive and Abrasive Wear Properties of Nanoclay-Modified Chopped Kenaf Fiber Reinforced Polymer Composites

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Abstract

The present work investigates the effect of nanoclay incorporation on wear properties of kenaf fiber reinforced polymer (KFRP) composites. The nanoclay/epoxy composites with 1.0wt%, 3.0wt% and 5.0wt% nanoclay contents were mixed using mechanical stirrer and high shear three roll mill machine, while chopped KFRP composites were fabricated using high vacuum and hand lay-up methods.The composites were tested under adhesive and abrasive wear conditions, where the specimens slide against smooth pin and vitrified bonded silicon carbide wheel, respectively. The operating parameters were fixed at 30N load, 300rpm speed and 10km distance in order to evaluate the effect of nanoclay on adhesive and abrasive wear properties of chopped kenaffibre reinforced epoxy polymer composites. The presence of kenaf fiber has significantly improved the wear properties of epoxy resin in both test conditions. Nanoclay incorporation has improved wear properties of KFRP composite up to 50.9% under adhesive wear and 59.2% under abrasive wear. Therefore, reinforcing kenaf fiber and nanoclay together can give synergistic impact and potentially improve the adhesive and abrasive wear properties of epoxy polymer.

Keywords: *Abrasion; Adhesion; Epoxy; Kenaf fiber; Nanoclay; Wear rate.*

1. Introduction

Polymers are usually reinforced with various kinds of reinforcement, in order to increase their physical and mechanical properties, such as continuous fibers, chopped fibre and particles [1]. Fiber reinforced polymer (FRP) composites are one of the most versatile materials because of their low density, good mechanical properties and chemical resistance [2]. Synthetic and natural fibers are classified as one of the most effective reinforcement material types for polymer materials; in which one of increasing interest is short fibers. Short FRP (SFRP) composites have been used in the automotive industry to substitute metallic alloys because of its good corrosion resistant properties, high strength and stiffness and low density. The advantages of SFRP composites are lower materials cost and higher manufacturing rate, particularly for obtaining complex geometries compared with continuous fiber composites.

Recently, development of new green natural fiber reinforced composite materials are evolving in a number of significant industries, such as the automotive, construction and packaging industries [1]. The increased environmental awareness and strict environmental regulations leads to the development of renewable, recyclable, biodegradable, sustainable and ecofriendly natural fibers materials. Natural fiber reinforced polymers (NFRP) are light-weight, low-cost, easier to handle and have good thermal and acoustic insulation properties in comparison with many synthetic composites[3].Among all various kinds of natural fiber, one of promising high potential natural fiber is kenaf (Hibiscus cannabinus, L. family malvaceae) fiber. Kenaf fiber is an herbaceous annual plant that can be grown under a wide range of weather conditions.The ability of kenaf to absorb nitrogen, phosphorus and accumulated carbon dioxide at a clearly high rate have become an attractive feature for kenaf cultivation in preventing global warming[4], [5].

In recent years, polymer nanocomposites have also received considerable attention due to their high stiffness, strength, and excellent barrier properties with the addition of lower nanofiller content[6]. The extremely high specific surface area of nanofiller creates a great amount of interphase in composite and a strong interaction between the fillers and the matrix. These materials have demonstrated the ability in reducing the friction and enhancing the wear resistance of polymers, depending on the filler size, shape, and the homogeneity of the particle distribution[2]. The interest in clay polymer nanocomposites is because of their potentially high aspect ratio and unique interaction/exfoliation characteristics[7]. Good nanoclay dispersion and exfoliation degree should be obtained during the sample preparation process to ensure efficient load transfer that aids in improving mechanical as well as tribological properties of composites [8].

Friction and wear are two important tribological properties during relativemotion of solid surfaces where it involved dissipationof energy and deterioration of materials[1]. Abrasive wear occurs when hard particles or hard protuberances are forced against and move along a solid surface to cause damage or material removal [5]. Abrasive wear is the most important among all the forms of wear as it contributes almost 65% of the total cost of wear[7]. Adhesive wear occurs when the friction pairs form intimate adhesive bond, especially with surface material having similar composition or particular affinity for one another. Various studies have been conducted to investigate the tribological properties of NFRP composites. Fazillah et. al [9] have studied the wear rate comparison between oil palm fiber and kenaf fiber at different fiber loading under dry sliding and found that each fiber exhibited lowest wear rate at different fiber loading[9]. Nasir and Ghazali [10] conducted research on glass pultruded-kenaf and paddy straw sliding under adhesive wear. It was found that bio-fiber inclusion on polymer matrix has reduced the wear rate by two folds [10]. More advanced polymer composite research was conducted by Rajini et.al [6] where nanoclay filler was incorporated into coconut sheath fiber composite. It was found that nanoclay content of 2wt% exhibited maximum reduction of wear rate when added with silane-treated coconut sheath fiber [6].

Although enhanced mechanical properties of nanoclay filled polymer and continuous fibre composite have extensively been investigated, the wear properties of advanced nano-filled natural fiber reinforced polymer composites have not yet been fully studied. In the present work, wear properties of nanoclay-filled chopped kenaf fiber reinforced polymer composites under adhesive and abrasive condition are studied.

2. Methodology

2.1. Material

Polymer matrix used in present work was epoxy resin (Miracast 1517) supplied by Miracon (M) Sdn. Bhd while the nanofiller used was Nanomer I.30 Montmorillonite Clay supplied by Sigma Aldrich. Miracast 1517 came with two parts which are Part A as epoxy and Part B as hardener. Nanomer I.30 is white powder clay with a dry particle size of 8-10μm and density of $1.9 g/cm^3$. Its surface was modified with 25-30wt% trimethyl stearyl ammonium. Fiber used was roving form Kenaf fiber supplied by Innovative Pultrusion Sdn Bhd. The fiber was chopped by SCP Automation Machine to produce short fiber of 3-5mm length as shown in Fig. 1.

Fig. 1: Chopped Kenaf Fiber

2.2. Fabrication of Composite

Epoxy polymer specimen was fabricated by manually mixing Miracast 1517 Part A DGEBA epoxy and Miracast 1517 Part B amine-curing hardener with ratio of 100:30. For the fabrication of unmodified/pureKFRP composite, epoxy resin was first mixed with kenaf fiber using mechanical stirrer for 30mins before hardener was added. For nanoclay-modified KFRP composites, nanoclay of 1.0, 3.0 and 5.0wt% content were prepared before mixed with epoxy resin. The epoxy resin and nanoclay was first mixed manually in room temperature before using three roll milling machine. The mixture was milled three timesat 60°C temperatureand 14.5 m/s speed to reduce its viscosity and ensure uniform dispersion of nanoclay. Kenaf fiber was then added into nanoclay-modified epoxy resin before mixed with hardener at ratio of 100:30. The mixture then was further mixed using mechanical stirrer for 15mins before poured into silicon mold. The specimens were vacuumed for 15 minutes and left cured at room temperature for 24 hours. The summary of composites specimen designation and composition is shown in Table 1.

Table 1: Designation and composition of specimens

Composites Designation	Weight fraction (wt%)		
	Epoxy	Kenaf fiber	Nanoclay
Pure Epoxy	100	-	-
Pure KFRP	90	10	-
1.0wt% NC KFRP	89	10	1
3.0wt% NC KFRP	87	10	3
5.0wt% NC KFRP	85	10	5

2.3. Characterization of Composite

The dispersion of nanoclay was observed using Transmission Electron Microscopy (TEM). The specimen was cut using Leica UC2 Ultra-microtome machine and was observed under FEI Tecnai TEM machine at accelerating voltage of 80kV. The density of specimen was determined using Archimedes' principle using density balance in accordance to ASTM D792. The hardness of specimen was measured using Instron 600R Rockwell Hardness according to ASTM D785-08. The scale chosen was type R scale that uses minor load of 10kg, major load of 60kg and 12.7mm diameter ball indenter.

2.4. Wear Test

The wear tests conducted were adhesion test and abrasion test and their setup are shown in Fig. 2(a) and Fig. 2(b) respectively.

(a)
(b)

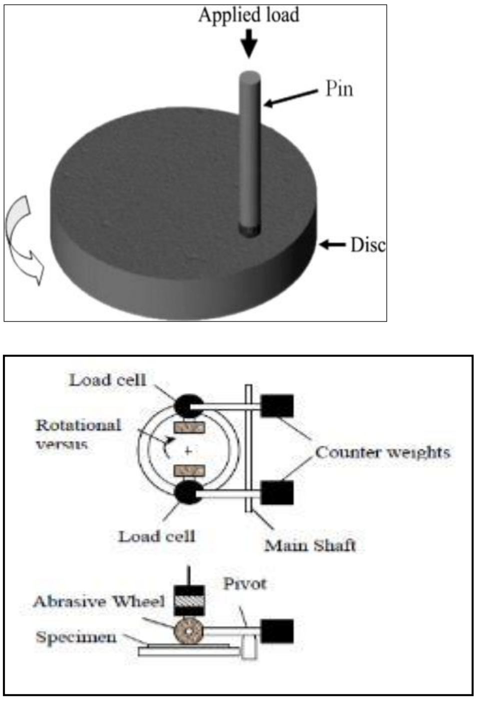


Fig. 2: Schematic diagram of a) pin-on-disc adhesion test configuration and b) abrasion resistance tribometer

Adhesion test was conducted using pin-on-disc tribometer (MAGNUM TE-165-SPOD) in accordance to ASTM G99-95a. The tribometer comprised of a horizontal rotating disc (specimen) sliding against a non-rotating pin cylinder (stainless steel), as shown in Fig. 2(a). The disc was fabricated in dimension of 75mm diameter and 4mm thickness, while the pin has dimension of 10mm diameter and 30mm length. Abrasion test was conducted using abrasion resistance tester (TR-600) in accordance to ASTM D3389. The tribometer comprised of a horizontal rotating disc (specimen) sliding against two rotating abrasive wheel made from vitrified bonded silicon carbide, as shown in Fig. 2(b). The disc specimen was fabricated with dimension of 123mm diameter and 5mm thickness. Both tests were conducted at 30N load, 300rpm speed and 10km distance. The initial mass of specimen and at every 2km distance was taken using precision balance. Based on mass loss recorded, the wear volume (ΔV) and specific wear rate (Ws) was calculated using Equation (1) and Equation (2), respectively.

$$\Delta V = \frac{\Delta m}{\rho} \quad (1)$$

$$W_S = \frac{\Delta V}{L \times F} \quad (2)$$

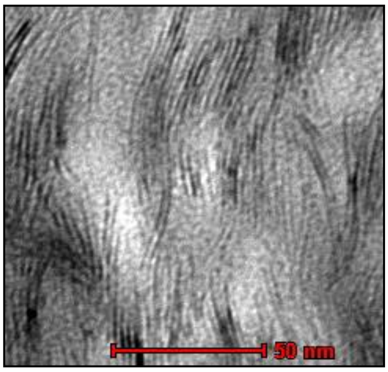
Where ΔV is in mm^3, Ws is in (mm^3/Nm), Δm is mass loss (g), L is sliding distance (m), ρ is density (g/mm^3) and F is applied force (N)

3. Results and Discussion

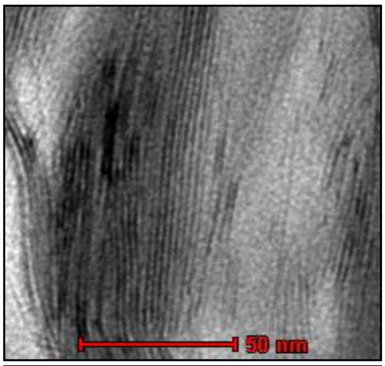
3.1. Characterization of Composites

The dispersion of 1.0wt%, 3.0wt% and 5.0wt% nanoclay is shown in Fig. 3. The images show that nanoclay platelets has uniformly dispersed where epoxy matrix has flowed in between the adjacent platelets, presenting intercalated and exfoliated structure of epoxy-clay resin. No sign of tactoids present in all images, even at high nanoclay content. These results showed that the high shear force applied by the three rollers which rotate at three different speeds hasefficiently disperse nanoclay in the polymer matrix. This had also been observed by Amir et. al [11].

(a)



(b)



(c)

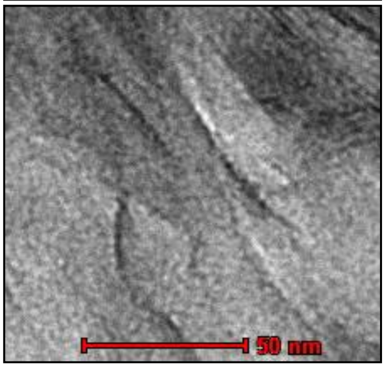


Fig. 3: TEM micrographs of a) 1.0wt%, b) 3.0wt% and c) 5.0wt% nanoclay at 220000x magnification

The results of density and hardness of composites are shown in Table 2. The density of epoxy was increased when reinforced with kenaf fiber. The density of KFRP was also increased when nanoclaywas incorporated. With increasing nanoclay content, the density increased as well whereby highest density by 5.0w% NC KFRP composite has increment up to 2.04% compared to Pure KFRP composite. The increments were mainly due to higher density of kenaf fiber and nanoclay compared to epoxy resin [12],[13]. On the other hand, the hardness value also exhibit almost similar trend as density. The lowest hardness is shown by Pure Epoxy with 109.80HRR. As kenaf fiber was added, the hardness of epoxy improved slightly, about 0.46%. The hardness of KFRP composite then further increased with nanoclay incorporation up to 3.0wt% content, and then slightly decreased as nanoclay content reach 5.0wt%. The high content of nanoclaymay cause microsized or nanosized entrapped air in the epoxy matrix that limits bonding between matrix and nanofiller and slightly reduced the hardness[8].

Table 2: Density and hardness of composites

Composites	Density (g/cm^3)	Hardness (HRR)
Pure Epoxy	1.1025	109.80
Pure KFRP	1.1224	110.30
1.0wt% NC KFRP	1.1266	111.30
3.0wt% NC KFRP	1.1332	113.16
5.0wt% NC KFRP	1.1453	110.26

3.2. Wear Properties of Composites

The specific wear rate of Pure epoxy and Pure KFRP composite against distance under adhesive sliding is shown in Fig. 4. Comparing between the two curves, the performance of Pure KFPP composite was significantly improved specific wear rate of epoxy polymer. Kenaf fiber has lowered the specific wear rate of epoxy by about 74.3%. Besides that, it can also be seen from the figure that Pure KFRP has a very low run-in phase as compared to Pure epoxy. It also managed to attain steady-state phase faster than the latter. The addition of reinforcing material increases the ultimate tensile strength, reducing its ability to chip off easily, therefore reducing its wear rate [10]. Therefore, this figure concluded that kenaf fiber gave siignificant impact on specific wear rate of epoxy polymer when sliding under adhesivecondition.

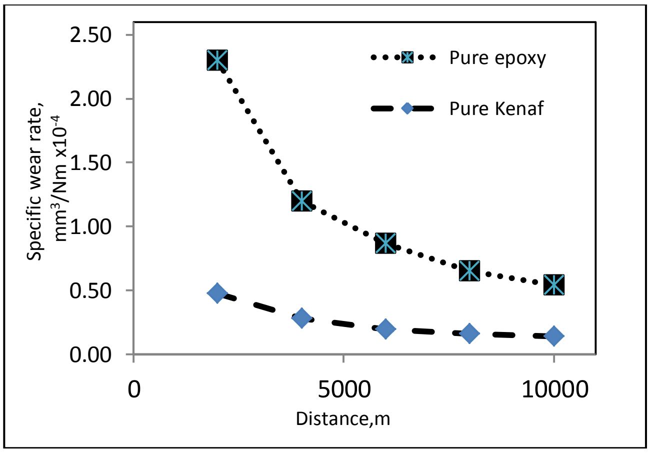


Fig. 4: Specific wear rate of Pure epoxy and KFRP composite against distance under adhesive wear

Fig. 5 shows the specific wear rate of Pure KFRP, and its composites against distance sliding under adhesivecondition. The figure shows typical trend of specific wear rate of polymer composites. The specific wear rate of KFRP composites were improved when incorporated with nanoclay except for 1.0wt% nanoclay content. The latter exhibited deterioration of about 39.6% compared to Pure KFRP composite. However, theincorporation of 3.0wt% and 5.0wt% nanoclay content have significantly improved specific wear rate of Pure KFRP composite by about 27.8% and 50.9% improvement respectively. The nanoclay incorporation inhibited kenaf fiber failures through reducing the stress concentration on kenaf fiber interface and the shear stress between two sliding surfaces [2]. The overallperformance sequence of composites after adhesive sliding for 10km distance starting from the worst to the best are as follows; Pure Epoxy, 1.0wt% NC KFRP, Pure KFRP, 3.0wt% NC KFRP, and 5.0wt% NC KFRP composites.

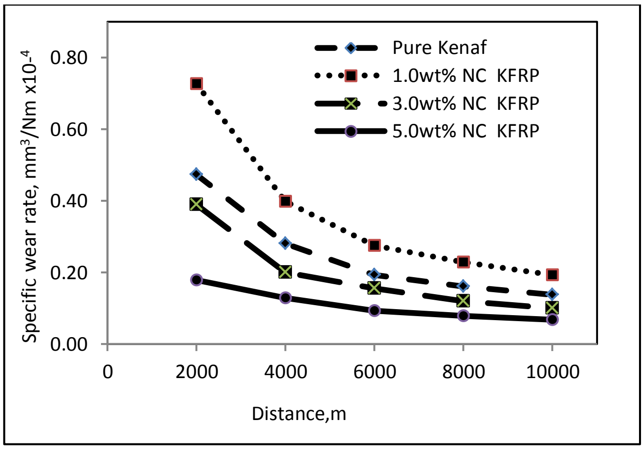


Fig. 5: Specific wear rate of KFRP composites against distance under adhesive wear

The specific wear rate of Pure epoxy and Pure KFRP composites against distance under abrasive sliding is shown in Fig. 6. The figure again, shows typical curve of specific wear rate where the trend was high at the beginning of sliding (run-in phase) and then reduced significantly towards steady state phase, although not very smooth towards steady state phase. From the figure, it can be seen that Pure KFRP composite has slightly lower specific wear rate than Pure epoxy. The improvement is about 24.1%,where the fiber have improved macroscopic wear resistance of polymers [14]. Therefore, it can be said that kenaf fiber are able to improve the specific wear rate of epoxy polymer when sliding under abrasive wear.

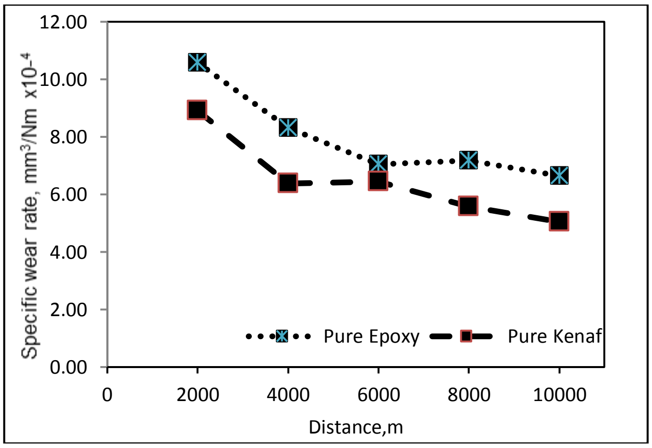


Fig. 6: Specific wear rate of Pure epoxy and Pure KFRP composites against distance under abrasive wear

Fig. 7 shows the specific wear rate of Pure KFRP and its composites against distance sliding under abrasive condition. The figure shows typical trend of specific wear rate of polymer composites. When nanoclay is incorporated into KFRP composite, the specific wear rate has improved significantly. The specific wear rate also has further improved with increasing nanoclay content, up to 3.0w% nanoclay, then it decreased slightly at 5.0wt% nanoclay. The highest performance of 3.0wt% NC KFRP composite exhibited improvement of about 59.2% compared to Pure KFRP composite. The result was dependent on the well-disersed nanoclay platelets and hardness of the composites [6]. However, the specific wear rate increased at 5.0wt% nanoclay content, might due to the agglomeration of nanoclay that reduces interaction between matrix, nanoclay and fiber [7]. The sequence of wear performance of KFRP composite compared to its pure state ae as follows; 1.0wt% NC, 5.0wt% NC and 3.0wt% NC with improvement by 29.7%, 42.4% and 59.2% respectively.

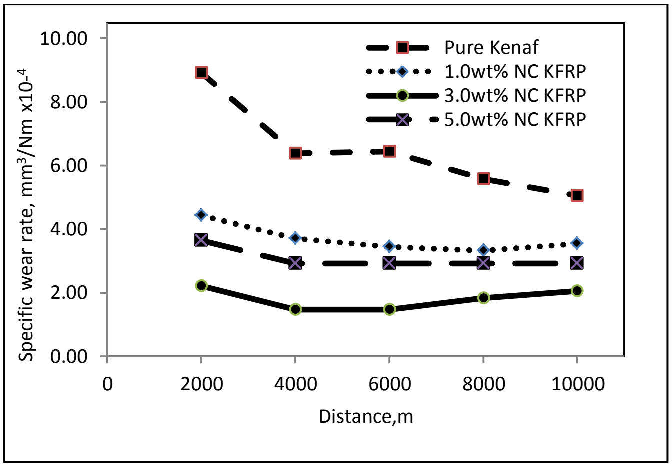


Fig. 7: Specific wear rate of Pure epoxy and KFRP composite against distance under adhesive wear

The difference in performance of Pure KFRP and its composites at adhesive and abrasive wear can be observed in Fig. 8. Adhesive wear value is much lower than abrasive wear. The rough surface of vitrified bonded siliconcarbide wheels has created much more damage on the surface of composites compared to polished pin counterpart. The effect of nanoclay on wear rate of KFRP composites also exhibiteddistinct results. Lowest specific wear rate was shown by 5.0wt% nanoclay in adhesivewear, while in abrasive wear, lowest specific wear rate was shown by 3.0wt% nanooclay content. This might due to the different wear mechanisms that occur in each wear condition since wear properties are very closely related to the surrounding systems of sliding bodies [9].

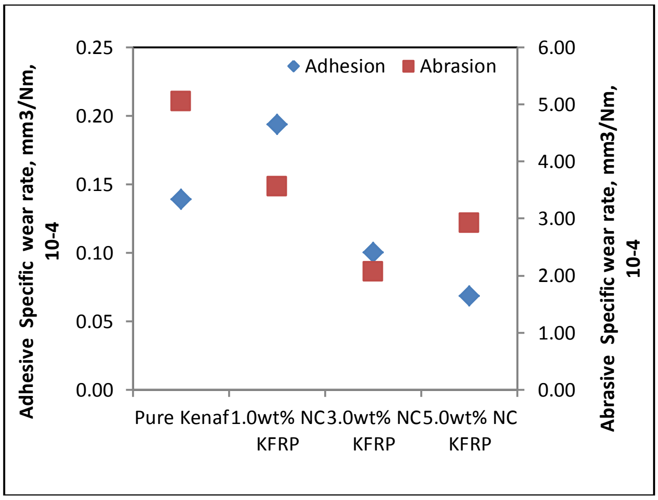


Fig. 8: Comparison of specific wear rate of KFRP composites at adhesive and abrasive sliding of 10km distance

4. Conclusion

Adhesion and abrasion sliding tests were conducted to investigate the effect of nanoclay on specific wear rate of chopped kenaf fiber reinforced polymer (KFRP) composite. Nanoclay-modified KFRP composite with 1.0wt%, 3.0wt% and 5.0wt% content were successfullyfabricated and tested. The density and hardness of KFRP composite showed increasing values as nanoclay content increased, except for hardness value at 5.0wt% nanoclay content. Under adhesive sliding, wear rate was improved for 3.0wt% and 5.0wt% nanoclay content, but deteriorate at 1.0wt% nanoclay content. Under abrasive sliding, the wear rates were improved with nanoclay addition up to 3.0wt%, and then deteriorate slightly at higher nanoclay content. Different types of wear mechanism may be involved during different types of sliding conditions. In conclusion, nanoclay incorporation into KFRP composite is a promising method to improve its adhesive and abrasive wear properties.

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