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Wear Behavior of Short Glass Fiber Reinforced Polymer Composite with Nanoclay Modification

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***Abstract:** This study is aimed to evaluate the effect of nanoclay incorporation on wear properties of short glass fiber reinforced polymer (GFRP) composite. Three different nanoclay contents of 1.0, 3.0 and 5.0wt% were dispersed into epoxy resin using a three-roll mill machine. The fibers were dispersed using mechanical mixer machine. Dry sliding and abrasive wear tests were conducted using pin-on-disc and abrasive resistance tribometer, respectively. The tests were conducted under 30N load and at 300rpm speed for 10000m sliding distance. The addition of nanoclay filler in epoxy polymer has shown improvement towards wear properties of GFRP composite, of up to 65% and 45% under dry sliding and abrasive wear resistance, respectively. The nanoclay appears to improve the microstructural strength leading to better load carrying capacity of the composite, advancing its effect as secondary reinforcement to the polymer composite.*

***Keywords:** fiber reinforced composites, nanoclay, dry sliding, abrasive.*

I. INTRODUCTION

Polymer composites are one of the most trusted materials to be utilized in tribological applications due to their lower weight and self-lubrication properties [1]. They are chosen as better alternatives from metallic materials where they can provide maintenance free operation especially under today's modern industries practices that requires harsh working operation, speed variation and high load [2]. Materials with unique mechanical and tribological properties with low weight and density, high specific strength and stiffness, and high resistance to degradation are always in need to ensure safety and financial efficiency in tribological industries [3]. Composites are materials that embed reinforcement either fibrous or non-fibrous (particulates) into matrix to improve the properties of the material, in which the reinforcement have better strength and modulus than the polymer matrix itself. The reinforcement became the principal load bearing members while matrix acts as a load transfer medium between then and protects them from environmental damages [4], [5].

Fiber reinforced composites are one of the most utilized type of engineering materials in various industries today due to their lightweight properties, excellent specific strength and stiffness, as well as their flexibility in design which owed to their anisotropy behavior [6]. Glass fibers are one of the most popular among them due to its high strength to weight ratio, high corrosion and chemical resistance, high heat distortion temperature, widely available and inexpensive, compared to fibers like carbon [7]. The properties of the materials basically depend on fiber type, orientation, content, length, compatibility to matrix and its interface strength. Siddharta and Gupta [5] have studied the mechanical and abrasive wear of bi-directional and chopped glass fiber reinforced polymer (GFRP) composite. It was found that the mechanical strength of bi-directional GFRP composite was better than chopped GFRP composite due to enhanced interface strength, while under abrasive wear condition, chopped GFRP composite was observed to perform better than bi-directional GFRP composites [5]. On the other hand, Zhao et al. [2] has conducted a tribological research on short GFRP composite under oil condition. It was observed that glass fiber may hinder wear resistance of the materials in dry sliding, due to its high hardness, where it has high potential to scratch the metallic counterface during sliding [2].

The usage of nano-scale fillers is expanding in engineering materials today due to their outstanding properties. Various nano-scaled materials such as Al_2O_3, TiO_2, ZnO, CuO, SiC, ZrO_2, Si_3N_4, SiO_2 and $CaCO_3$ have been added to polymer matrices that promote better stiffness, strength, toughness, dimensional stability and thermal properties to the materials [4], [8]. Significant improvement in wear rate and friction coefficient are reported with only small amount of nanofiller, mainly due to their high specific surface area that lead to strong interfacial interaction between material interfaces [1]. Among these inorganic fillers, nanoclay accounts for almost 25% by volume of the total nanocomposites usage in the market [9]. Nanoclay has high aspect ratio and a unique interaction/exfoliation characteristics, which reported to improve tensile and flexural strength, moisture barrier, hardness, toughness, impact, solvent resistance properties, flame retardancy and reduce gas permeability of a material [6], [10].

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However, nanoclay performance are very much dependent on its dispersion state since it has high surface energy that tend to agglomerate easily especially at high content which may lead to property degradation [3]. Studies conducted by Suresha et al. [10] and Singh et al. [6] have reported that 5wt% and 3wt% nanoclay content exhibited best wear, tensile strength and modulus, hardness and flexural strength in each experiment conducted.

In tribological applications, the performance of material also influenced by its operating parameters such as sliding velocity, temperature, normal load, contact geometry and relative motion between two contacting surfaces [11]. Various studies have been conducted to replicate real-time application of the materials as friction and wear are not intrinsic material properties but rather depend on the system of which the material functions. Kim et al. [12] studied friction and wear of short glass fiber reinforced polymer composite using different fiber content, orientation and loading conditions and found that the tribological performance were more depended on fiber content and temperature compared to fiber orientation. Rashmi et al. [9] reported that the tribological performance are most effected by distance, followed by load, filler content and velocity when they conducted research on nanoclay-filled epoxy composite.

The concept of incorporating both fiber reinforcement and fillers to create advanced polymer composite or hybrid composite are being explored deeper today to further improved mechanical and tribological properties of polymeric materials [11]. Therefore, the aim of the present work is to investigate the wear properties of nanoclay modified short glass fiber reinforced epoxy polymer composites that operates under both dry sliding and abrasive wear conditions.

II. METHODOLOGY

A. Materials

A commercially available epoxy resin (Miracast 1517 Part A) cured by an amine hardener (Miiracast 1517 Part B) supplied by Miracon (M) Sdn. Bhd. was considered as the matrix material in this study. Short glass fibers (SGF) supplied by Vistec Technologies Sdn Bhd and nanoclay (Nanomer I.30) supplied by Sigma Aldrich were selected as fiber reinforcement and filler respectively. Nanomer I.30 was in the form of white powder clay of 8-10µm particle size, 1.9g/cm3, and was surface modified with 25-30wt% trimethyl stearyle ammonium. Short glass fiber was in 3-5mm length as shown in Fig.1.

Fig. 1. Short glass fiber

Fabrication of short glass fibre composites

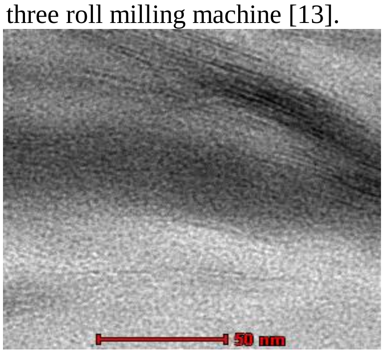
Nanoclay-modified epoxy matrix of 1.0, 3.0 and 5.0wt% content were prepared using three roll mill mixing technique. The three roll mill machine used concept of shear force and heat to disperse the nanoclay platelets, an effective technique to achieve more homogeneous and good dispersion of nanoclay as reported in [13]. The roller was set at 14.5 m/s speed, 60°C temperature and three cycles. SGF was weighed at 10wt% and was added into the homogenous nanoclay-modified epoxy mixture using mechanical mixer before being added with hardener. The epoxy to hardener ratio was 100:30 according to the supplier's technical specification. The glass fiber reinforced polymer (GFRP) composites were left to cure at room temperature in its respective silicon mould for 24 hours. The designation of composites fabricated for present research is shown in Table-I.

Table-I: Designation and composition of specimens prepared

Composites Designation	Weight fraction (wt%)		
	Epoxy	Glass fiber	Nano-clay
Pure Epoxy	100	-	-
Pure GFRP	90	10	-
1.0wt% NC GFRP	89	10	1
3.0wt% NC GFRP	87	10	3
5.0wt% NC GFRP	85	10	5

B. Characterization of nanoclay filled epoxy and composites

The nanoclay modified epoxy and chopped glass fibre composites (GFRP) specimens were characterised by examining under transmission electron microscopy (TEM) and conducting density and hardness tests. TEM was conducted by FEI Tecnai TEM machine to observe the dispersion of nanoclay platelets in the epoxy matrix. The TEM image of the nanoclay-filled epoxy is presented in **Fig. 2**. The morphology of nanoclay was predominantly intercalation and exfoliation at some regions. At low nanoclay content of 1.0wt%, the structure was in ordered exfoliation with presence of randonmly oriented nanoclay. At high nanoclay content (3.0wt% and 5.0wt%), the TEM shows intercalated structure of nanocomposites. Intercalated and exfoliated structure of nanoclay layers indicates that the nanoclay was uniformly dispersed in epoxy matrix using the shear mixing technique of three roll milling machine [13].



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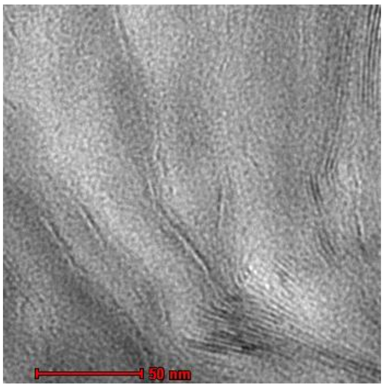

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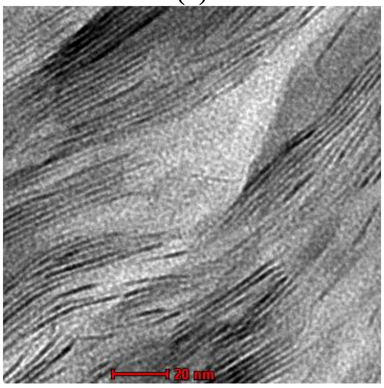


(c)

Fig. 2. TEM micrographs of a) 1.0wt%, b) 3.0wt% and c) 5.0wt% nanoclay filled epoxy at 220000x magnification.

Density test was conducted according to ASTM D792 using density balance based on Archimedes principle. Hardness test was conducted using Instron 600R Rockwell Hardness according to ASTM D785-08. The scale chosen was R-type scale that uses 12.7mm diameter ball indenter with minor load of 10kg and major load of 60kg. The results of density and hardness measurement are tabulated in Table-II. The density of Pure GFRP composite was higher than Pure Epoxy by 2.53%. Besides that, the density of Pure GFRP composite was also increased when the nanoclay was added. The density increased as the content of glass fibers increased. This increment is ascribed to the higher density of glass fiber and nanoclay particles compared to the density of epoxy itself [14]. Hardness measurement showed that glass fiber has hardened the pure epoxy composite by 2.10%. Hardness determined the ability of material to be scratched or indented which indirectly reflect the stiffness of the materials [15]. The hardness also increased with the nanoclay incorporation of up to 3.0wt% nanoclay content. Further incorporation of nanoclay has deteriorated the hardness of the GFRP composites. This may be attributed by the presence of entrapped air that limits the bonding of epoxy with nanoclay and glass fiber. Entrapped air was more likely to occur during fabrication process of the GFRP containing high nanoclay content due to high viscosity mixture [3].

Table-II: Density and hardess of specimens

Composites	Density (g/cm^3)	Hardness (HRR)
Pure Epoxy	1.1025	109.8
Pure GFRP	1.1311	112.16
1.0wt% NC GFRP	1.1634	114.48
3.0wt% NC GFRP	1.1841	114.6
5.0wt% NC GFRP	1.1861	111.24

C. Wear Test

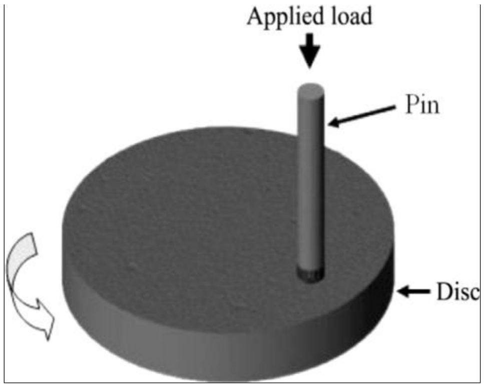
The nanoclay modified chopped GFRP specimens were subjected to two types of tests, dry sliding and two-body abrasive tests using MAGNUM TE-165-SPOD pin-on-disc tribometer and TR-600 abrasion resistance tribometer, respectively. The test parameters used in each test and their schematic diagrams are shown in Table-III and **Fig. 3**, respectively. The weight of specimen was measured with precision balance at each 2000m distance interval, and specific wear rate (Ws) was calculated from Equation 1 [8];

$$Ws = \frac{\Delta V}{L\ x\ F} = \frac{\Delta m}{L\ x\ F\ x\ \rho} \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

where; Ws is specific wear rate (mm3/Nm), ΔV is wear volume (mm3), Δm is mass loss (g), ρ is density (g/mm3) , L is distance travel (m) , and F is normal load (N)

Table-III: Test parameters for wear tests

Testing Parameters	Dry sliding	Two-body abrasion
Test Standard	ASTM G99-95a	ASTM D3389
Contact configuration	Pin-on-disc	Cylinder-on-disc
Type of motion	Unidirectional	Unidirectional
Counterface	Stainless steel pin	Vitrified bonded silicon carbide
Applied load	30N	
Sliding speed	300rpm	
Sliding distance	10000m	
Specimen dimension	Ø75mm x 4mm	Ø123mm x 5mm



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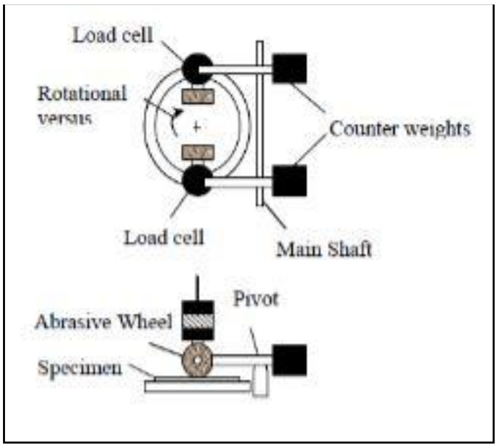

(b)

Fig. 3. Schematic diagram of a) pin-on-disc and b) abrasion resistance tribometer

III. RESULTS AND DISCUSSION

A. Mass Loss of Composites

The accumulated mass loss of GFRP composites under dry sliding test is shown in **Fig. 4**. The mass loss of the composite specimens was obtained over 10000m sliding distance. Figure 4 shows increasing trend of the mass loss as sliding distance increased. The mass loss increased sharply for the first 2000m distance, then the increment slowly reduced as the distance increased further to 10000m. The highest mass loss is shown by Pure GFRP composite with a total of 0.0587g. The mass loss result of GFRP composite decreased when the composite was incorporated with nanoclay filler. The mass loss of 1.0wt% NC, 3.0wt% NC and 5.0wt% NC GFRP composite recorded a total mass loss of 0.0512g, 0.0412g and 0.0212g, respectively. The lowest mass loss was attained from the 5.0wt% NC GFRP, which exhibits improvement of 175.59% from its pure state.

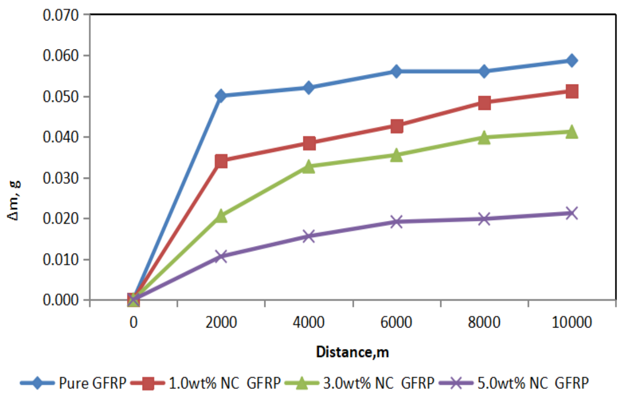

Fig. 4. Accumulated mass loss of GFRP composites over 10000 distance under dry sliding test

Fig. 5 shows the accumulated mass loss of GFRP composites after sliding under abrasive wear test. The result was obtained from the specimens that were subjected to 10000m distance of sliding, whereby the mass loss increased sharply from start to the end of the test. Freshness of abrasive wheel grit that resulted in a maximum damage from consistent contact points between the abrasive and surface of the composites [16] is the main reason contributes to this finding. The highest mass loss is shown by Pure GFRP composite with total mass loss of 0.33g. The mass loss exhibited decrement with nanoclay incorporation to GFRP composites. The lowest mass loss was obtained from 5.0wt% NC GFRP composite specimen that marked only 0.28g mass loss and 42.43% improvement compared to Pure GFRP composite.

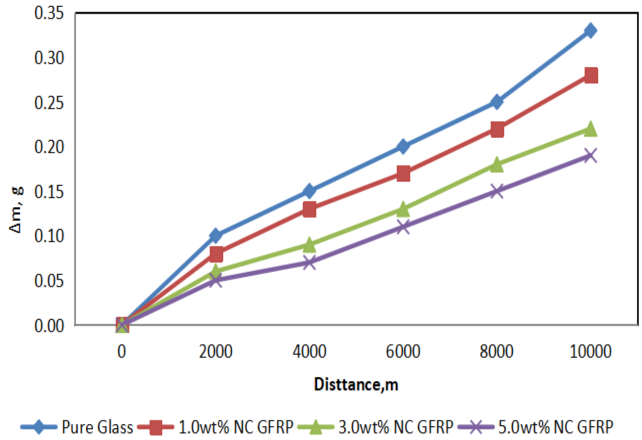

Fig. 5. Accumulated mass loss of GFRP composites against distance under abrasive test

B. Wear Properties of Composites

Fig. 6 shows the trend of specific wear rate, Ws of GFRP composites against distance under dry sliding test. A sharp decrease at first 2000m distance was observed, indicating a run-in phase. This followed by a steady decrease as the distance reaching 10000m, inferring a steady-state phase, which is a typical form of trend for polymeric material undergoing wear test. It was reported that the presence of loss wear debris from the material would assist occurrence of sliding between two contact area [3], [17]. From the figure, the highest wear rate is shown by Pure GFRP composite recorded Ws value of 1.76x10-4mm3/Nm. With incorporation of nanoclay filler, the wear rate has clearly improved. The highest improvement recorded is 65.9%., attained from 5.0wt% NC GFRP composite, followed by 3.0wt% NC and 1.0wt% NC each improved by 34.6% and 18.1% respectively. It appears that nanoclay filler has improved the microstructural homogeneity between epoxy and fibers, therefore increasing its load-carrying capacity and increased its wear properties [1]. The wear rate was also reported dependence on the hardness value of the composite, whereby the higher the hardness of composite, the higher its sliding wear resistance [18].

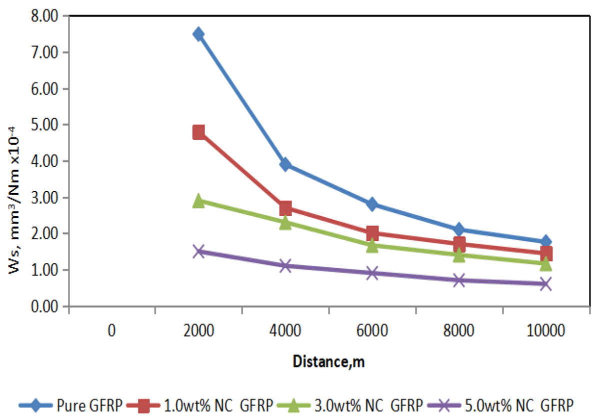

Fig. 6. Specific wear rate of GFRP composites against distance under dry sliding test

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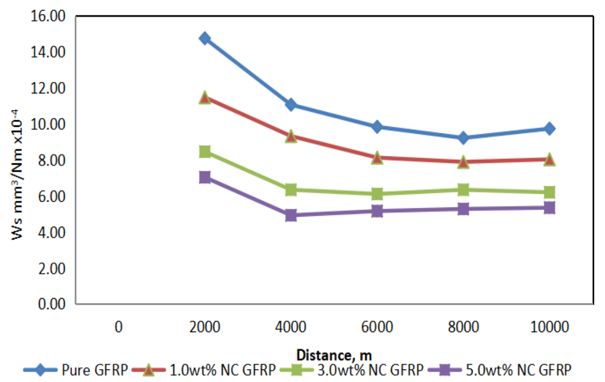

Fig. 7. Specific wear rate of GFRP composites against distance under abrasive wear

The specific wear rate, Ws of GFRP composites sliding under abrasive wear test is shown in Fig. 7. The trend was observed to be generally similar as those that underwent dry sliding test (Fig. **6**) where run-in stage occurred at first 2000m distance, followed by steady state stage when distance increased further to 10000m distance, which is typical plot for polymeric composite material [19]. Similar to mass loss, the highest wear rate is shown by Pure GFRP charted Ws of 9.73x10-4mm^3/Nm, while lowest wear rate is shown by 5.0wt% NC GFRP composite marked Ws of 5.34 x10-4mm3/Nm. The wear rate of 1.0wt% NC, 3.0wt% NC and 5.0wt% NC GFRP composite each has exhibited improvement up to 17.5%, 36.3% and 45.1% compared to Pure GFRP composite respectively. The nanoclay filler has clearly improved the abrasive wear resistance of GFRP composite by acting as barrier to prevent large scale fragmentation of epoxy and reinforced the structure of glass and epoxy [10].

The overall result of wear rate of GFRP composites under dry sliding and abrasive wear is shown in **Fig. 8**. The wear rate of abrasive wear test was five times larger than wear rate obtained from dry sliding test. This was due to the difference in wear mechanism that occurred during contact between rough abrasive wheel and composites, and between the smooth pin surface and the composite specimen. In both cases, nanoclay incorporation had improved the wear rate of GFRP composite with best performance observed at 5.0wt% NC. Besides that, at 5.0wt% nanoclay content, the composite specimen demonstrated more dominant improvement under dry sliding wear compared to abrasive wear.

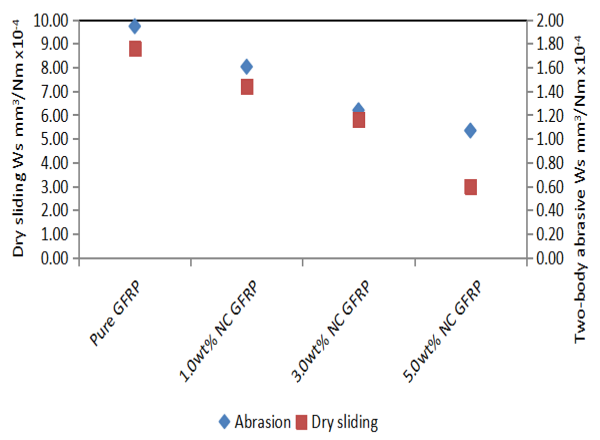

Fig. 8. Specific wear rate comparison of epoxy and GFRP composites under abrasive and adhesive wear condition

IV. CONCLUSIONS

The present study has investigated the effect of nanoclay incorporation on wear properties of short glass fiber reinforced polymer composites under dry sliding and abrasive wear conditions. Based on the results, the following conclusions are found;

- Three roll mill mixing technique produced uniformly dispersed nanoclay platelets in intercalated and exfoliated structure.
- The density and hardness of GFRP composite were increased with nanoclay incorporation, and both properties were increased as the nanoclay content increased.
- Accumulated mass loss and specific wear rate of GFRP composite was improved with nanoclay incorporation under both dry sliding and abrasive wear test conditions.
- Highest wear performance was exhibited by 5.0wt% NC GFRP composite with improvements up to 65% and 45% compared to its pure state, under dry sliding and abrasive wear respectively.
- Nanoclay incorporation have potential to improve dry sliding and abrasive wear properties of GFRP composite by improving the load carrying capacity between epoxy, glass fiber and nanoclay filler.

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