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Wear Properties of Nanoclay-Modified Short Basalt Fiber Reinforced Polymer Composites

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Abstract**: *This paper presents the effect of 1.0, 3.0 and 5.0wt% nanoclay filler inclusion on wear properties of basalt fiber reinforced polymer (BFRP) composite. Short basalt fiber was reinforced with nanoclay modified epoxy matrix using a manual hand layup system. The nanoclay was dispersed in epoxy matrix using mechanical stirrer and three roll mill high shearing technique. The composites were tested under dry and two-body abrasive wear conditions through pin-on-disc tester and abrasion resistance tester respectively. The operating condition was fixed at 30N load, 30rpm speed and 10km distance. The results showed that the addition of basalt fiber had improved the wear properties of epoxy polymer under both test conditions. The inclusion of nanoclay has also improved wear properties of pure BFRP composite of up to 38% and 42% exhibited by 5.0wt% nanoclay content under dry sliding and abrasive wear, respectively.***

Index Terms**: *Basalt, Nanoclay, Dry sliding, Abrasive, Wear***

I. INTRODUCTION

Basalt fiber is known today as a 21st-century green industrial material that is extensively in interest for usage in infrastructural, civil, military defense and aeronautical industries [1]. Basalt fiber is made from extrusion of basalt-based molten igneous volcanic rock and was developed in 1960s after 30 years of research and development since World War II [2]. It exhibits enhanced mechanical properties such as extremely good modulus, excellent stability, good chemical resistance, high mechanical strength, improved strain to failure, high temperature resistance, easy to produce, non-toxic, natural, eco-friendly and also inexpensive, all suitable for light, high-end hybrid composite material [3], [4]. Basalt fiber is considered the most viable option to replace synthetic glass fibers for their comparable mechanical properties, and for its far lower cost than carbon fiber [1], [2], [5].

Fiber reinforced polymer (FRP) composites have gained extensive attention over the last two decades in various industries including tribological sectors because of their specific characteristics such as light weight, excellent specific strength and stiffness, excellent strength-to-weight ratios, corrosion resistance, non-toxic nature, easy to fabricate, design flexibility and better wear resistance [3], [5]. When FRP composites are subjected to harsh environmental conditions, their mechanical, physical and physic-chemical properties can be improved by introducing foreign fillers [1]. The synergistic effect from two types of reinforcing materials embedded in a matrix will improved not only elastic modulus, ductility and wear performance of the composite, but also able to reduce the cost of composite [6]. The reinforcing fiber is believed to alleviate stress concentration and improve load-carrying capability of matrix, while the nanoparticles is believed to create a “rolling effect” and promote the formation of transfer film on sliding counterface [7].

The inclusion of nanofiller has been in focus for various researches since it was proven to improve mechanical and tribological properties more effectively at only small amount compared to micro-sized filler [8]. The nano-sized scale filler are said to influence the mobility of the polymer chains due to bonding between the nanoparticles and the polymer and bridging of the polymer chains between the nanoparticles [9]. Strong interaction between filler and matrix are able to maintain from extremely large surface area of the filler. One of popular nanofiller used is layered montmorillonite or nanoclay. Nanoclay is composed of stacks of nanoclay platelets with each sheet has two tetrahedral silicate layer sandwiched one octahedral alumina layer, giving it a unique interaction/exfoliation characteristics and high aspect ratio [10].

The study of tribology; wear and friction are important in today’s industries as they affect a lot on cost and maintenance. Adhesive and abrasive wear are two significant wear mechanisms in the wear of friction composite [11]. Multiple factors are affecting the wear and friction performance of a material, for example hardness and roughness of the materials, contact pressure, distance, velocities, temperature and lubrication [9]. Various studies have been conducted to investigate each and every factor that may affect tribological properties of the material according to real-life applications. However, the tribological research on short basalt fiber with incorporation of nanoclay was still limited. Therefore, this paper is aimed to investigate the effect of nanoclay incorporation on wear properties of basalt fiber reinforced polymer (BFRP) composite under two most significant type of wear conditions; dry and abrasive wear.

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II. METHODOLOGY

The composite material investigated in recent study consists of short basalt fiber as shown in Fig 1 of about 3-5mm length, 9-15µm diameter as reinforcement (supplied by Innovative Pultrusion Sdn. Bhd.), Miracast Part A epoxy resin with Miracast Part B room temperature amine-cured hardener (supplied by Miracon (M) Sdn. Bhd.) as matrix material, and filler material Nanomer I.30 Montmorillonite clay powder of particle size in range of 8-10µm. The percentage of carbon fiber and nanoclay filler in composite are 10.0wt% and 1.0, 3.0, 5.0wt%, respectively. The details of composites investigated are given in Table 1. The dry sliding wear and two-body wear test samples were prepared of size diameter 75mm x 4mm and diameter 25mm x 5mm, respectively.

Fig 1 Short basalt fiber

Table 1 Designation and composition of specimens

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

The epoxy composites were prepared by firstly mixing the pre-weighted quantities of epoxy and nanoclay (1.0wt%, 3.0wt% and 5.0wt%) using mechanical mixer at 80°C for 30 minutes. Then the mixture was sheared using three roll mill machine a 60°C, 12m/s for 3 repeated cycles. Afterwards, the compounds were mixed with short basalt fiber and stirred manually for 5 minutes. After ensuring epoxy composites has flowed thoroughly in between basalt fibers, curing agent was added at ratio of 100:30. Then, the composites were poured into silicon mold of respective dimensions and left to cure at room temperature for 24hours.

To evaluate the dispersion of nanoclay in the epoxy matrix, Transmission Electron Microscopy (TEM) was carried out. Specimen was cut using Leica UC2 Ultra-microtome machine and observed under FEI Tecnai TEM machine. Density measurement was carried out in accordance to ASM D792 using Archimedes Principle. Rockwell hardness measurements of composite samples were taken using Instron A654 R Rockwell Hardness tester. Scale R was chosen (minor load 10kg, major load 60kg, steel ball indenter 12.7mm diameter) in accordance with ASTM D78508. The obtained HRR values are based on the average values of at least five tests.

Dry wear test of composites was performed by using a pin-on-disc tester (MAGNUM TE-165-SPOD). Stainless steel pin (diameter 10mm, length 30mm) was fixed on load arm and the specimen disc was placed on a rotating holder with diameter of 76mm, 4mm thickness. Two-body abrasive wear test was performed by using abrasion resistance tribometer (TR-600). Two vitrified bonded silicon carbide wheels were fixed at load arm and the specimen disc was placed on rotating holder of diameter 125mm, 5mm thickness. Schematic diagram for mentioned tests is shown in Fig 2. Both wear tests were conducted at dry environment, room temperature and the contact load, speed and sliding distance were fixed at 20N, 300rpm and 10km, respectively. Specimens were weighed before and after test at interval of 2km distance and weight loss was calculated for each specimen.

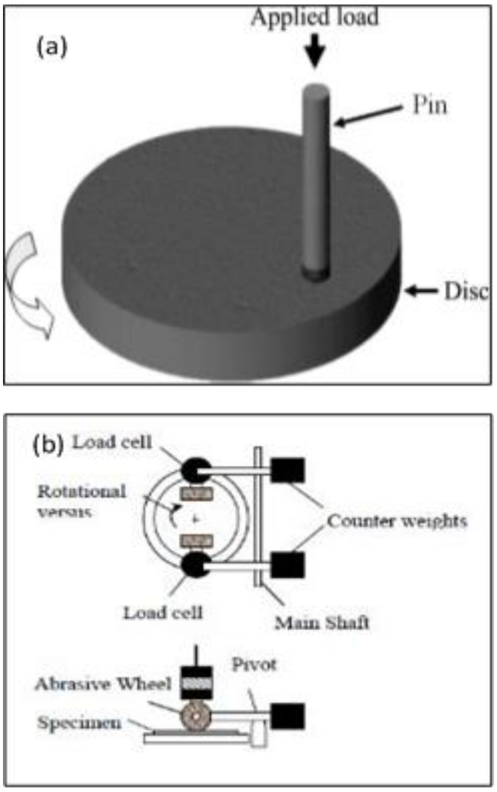

Fig 2 Schematic diagram of (a) pin-on-disc and (b) abrasion resistance tribometer

Specific wear rate is calculated from the following equation;

$$W_S=\Delta m/(\rho\times L\times F) \quad (1)$$

Where 'Ws' is the specific wear rate of specimen (mm3/Nm), 'Δm' is weight loss of specimen (g), 'ρ' is density of specimen (g/mm3), 'L' is sliding distance (m) and 'F' is applied normal load (N).

III. RESULTS AND DISCUSSION

A. Characterization of Composites

Different nanoclay concentration in epoxy matrix can be seen from Transmission Electron Microscopy (TEM) as shown in Fig 3. The dispersion images show that these modified matrices have intercalated and exfoliated structures, in which the dispersed phase between the layers of the silicates is in nanometer-length scale and hence these modified matrices can be classified as nanocomposites.

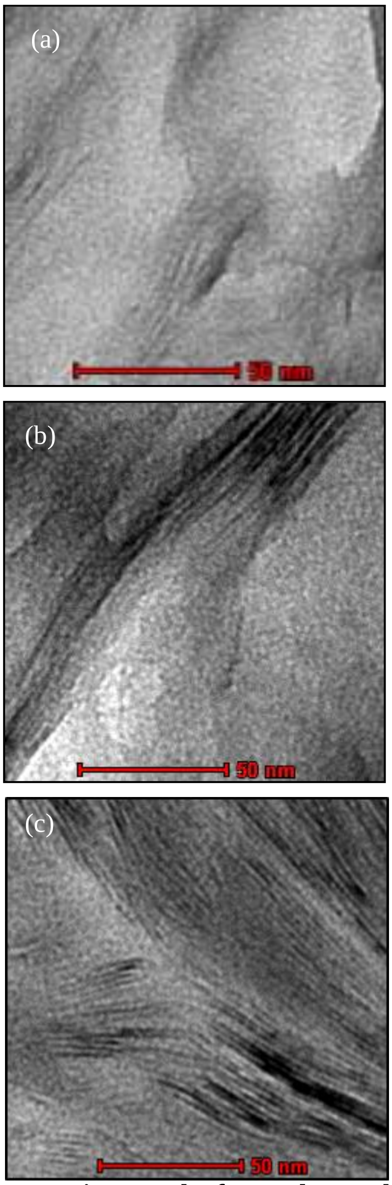

Fig 3 TEM micrograph of nanoclay modified epoxy resin at (a) 1.0wt% NC, (b) 3.0wt% NC and (c) 5.0wt% NC

The density and hardness measurement of composites specimen are tabulated in Table 2. The density of Pure BFRP composite was slightly higher than density of pure epoxy. This generally due to higher density of basalt fiber compared to pure epoxy alone [12]. Besides that, the density was further increased as nanoclay is added and increasing content [13]. On the other hand, hardness measurements were similar to density measurement, except at highest nanoclay content (5.0wt%), the hardness decreased sharply compared to hardness value at 3.0wt% nanoclay content. This might due to higher porosity in the composite that was caused by higher viscosity of nanoclay-modified epoxy matrix [14].

Table 1 Density and hardness of composites

Composites	Density (g/cm^3)	Hardness (HRR)
Pure Epoxy	1.1025	109.80
Pure BFRP	1.1164	114.26
1.0wt% NC BFRP	1.1751	114.88
3.0wt% NC BFRP	1.1793	119.40
5.0wt% NC BFRP	1.1889	113.08

B. Wear Properties

Specific wear rate of re epoxy and Pure BFRP composite over distance under dry sliding can be observed in Figure 4. The curve shows significant improvement of pure epoxy wear rate when basalt fiber is reinforced in the matrix. The improvement was up to 72.4%. The basalt fiber has increased hardness of epoxy matrix therefore increasing its wear resistance properties [15].

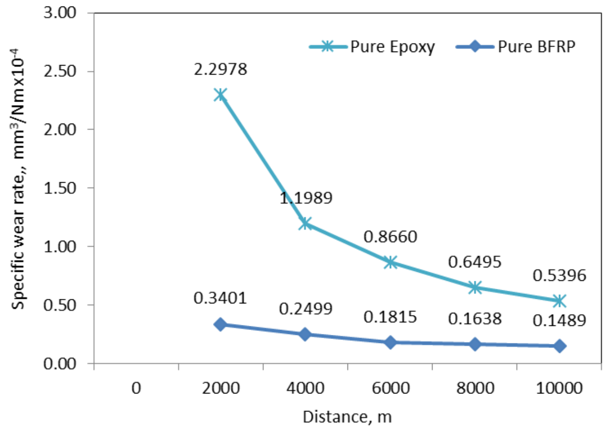

Fig 1 Specific wear rate of pure epoxy and pure BFRP composites against distance under dry sliding test

The effect of nanoclay incorporation on specific wear rate of pure BFRP composite under dry wear condition is shown in Fig5. The figure shows typical wear rate curve of polymeric composites. The first 2000m distance was high due to run-in stage, then it reduced steadily as it is reaching steady-state stage. During dry sliding, the contact between sliding bodies is believed to reduce due to formation of transfer film [8]. Transfer film contributes to steady state wear that achieved as travel distance increases.

The highest wear rate shown by pure BFRP composite indicates worst wear properties. When nanoclay is added into the system, the wear rate seemed to be improving for all nanoclay-modified BFRP composites. The lowest wear rate was shown by 5.0wt% NC BFRP which indicates that higher nanoclay content is better than lower nanoclay content [11]. The improvement was up to 38.21% compared to pure BFRP composite. Nanoclay have acted as effective barrier to prevent large scale fragmentation of matrix by steel counterface [10].

However, the wear rate of 3.0wt% NC BFRP was higher than 1.0wt% NC BFRP composite. Therefore, the overall sequence of wear performance of BFRP composites are; 5.0wt%, 1.0wt% and 3.0wt% nanoclay content, each represent improvement of 38.21%, 34.18% and 27.47% from its pure state respectively.

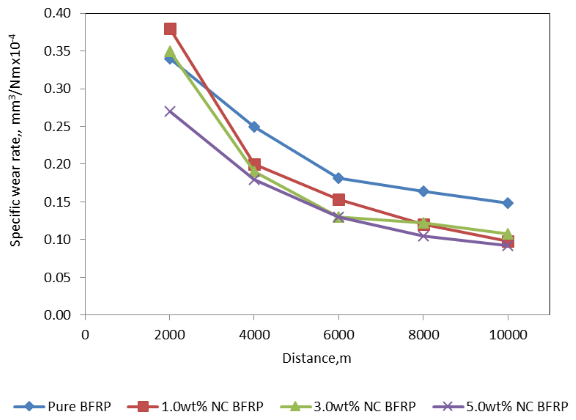

Fig 5 Specific wear rate of pure BFRP and its composites against distance under dry sliding test

The typical curve of specific wear rate for pure epoxy, pure BFRP and BFRP composites under abrasive wear is shown in Fig 6. As the curve reaching steady state curve, there were some inconsistencies in the wear rate where it should be decreasing steadily instead of increasing. The reason might be due to the presence of debris that was inconsistent throughout the tests, as the debris affects the effectiveness of abrasive roller during the two-body abrasive test.

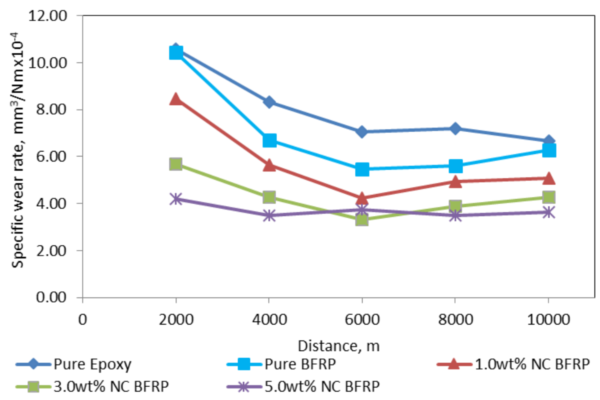

Fig 6 Specific wear rate of pure epoxy, pure BFRP and BFRP composites against distance under two-body abrasive wear

From the figure, the worse wear rate was shown by pure epoxy followed by pure BFRP composite. The reinforcement of basalt fiber improved only 5.74% wear rate of pure epoxy. When nanoclay was added into the system, the wear rates of BFRP composites have shown reduction. The wear rate continued to reduce as nanoclay content was increased. The lowest wear rate which indicated highest wear performance exhibited by 5.0wt% NC BFRP composite. Also, 41.87% percentage improvement is observed as compared against the pure BFRP composite. The nanoclay might have helped to strengthen the interface bonding between particles, resin and fibers therefore increasing its wear resistance [16].

Overall view of specific wear rate of composites after travelling for 10km distance can be compared in Figure 7. Abrasion wear rate was almost 10 times higher than dry sliding wear rate. This was due to the different type of counterface bodies faced by the composites. During the abrasion procedure, the composite may have experienced brittle fatigue and three body abrasive wear. While, during adhesion wear, the wear mechanism was limited to only fatigue wear and mild abrasive wear [11]. Besides that, it can also be observed that the effect of basalt fiber reinforcement in epoxy was more prominent in the adhesion wear compared to the abrasion wear. Thus, the percentage difference from pure epoxy was up to 72.41%. In both tests, nanoclay filler did improve wear properties of BFRP composites, whereby highest nanoclay content resulted in highest wear performance.

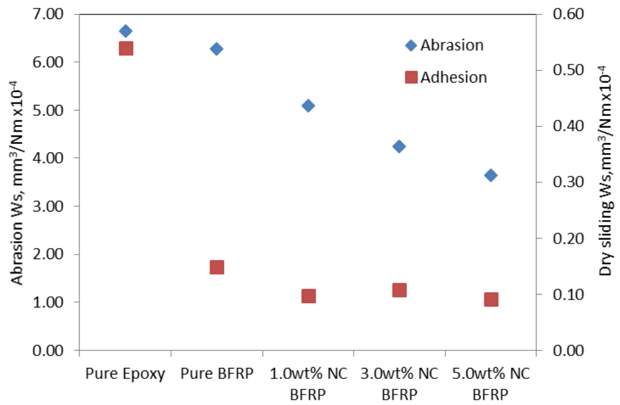

Fig 7 Specific wear rate comparison of epoxy and BFRP composites under two-body abrasive and dry sliding wear condition

IV. CONCLUSION

Specific wear rate of nanoclay-modified short basalt fiber reinforced polymer (BFRP) composite was successfully conducted under dry and two-body abrasive sliding test. Nanoclay of 1.0wt%, 3.0wt% and 5.0wt% content was mixed using mechanical mixing and three roll mill to ensure uniform dispersion. The density of BFRP composite was increased with increasing nanoclay content. However, the hardness of BFRP composite although increased with nanoclay addition and content, it actually decreased at 5.0wt% nanoclay content. Under dry sliding test, the lowest wear rate of the BFRP composite was at 5.0wt% nanoclay content with 38.21% improvement from its pure state. Under two-body abrasive sliding test, the lowest wear rate was also exhibited by 5.0wt% nanoclay-filled BFRP composite with 41.87% improvement. It can be concluded that the presence of two types of reinforcements; basalt fiber and nanosized clay filler have given synergistic impact on improving the wear properties of epoxy matrix when testing under dry sliding and two-body abrasive wear condition.

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Anis Adilah Abu Talib completed her Bachelor Degree (Hons) in Mechanical Engineering from Universiti Tenaga Nasional (UNITEN) in March 2014. She then worked at Test Tooling Solutions Sdn. Bhd. as Mechanical Design Engineer for 1 year. She then pursued her Master in Science (Mechanical Engineering) at Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM) starting from September 2015. She was a research assistant for 600-RMI/FRGS 5/3 (145/2014) research project from 2015 to 2017. Her main research of interest is polymer tribology and green tribology.

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