International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-9 Issue-1, October 2019

Slurry Pot Erosion Wear of Nanoclay-Modified Short Fiber Reinforced Polymer (SFRP) Composites

Aidah Jumahat, Nurul Ain Haris, Fatin Najwa Che Mohamad

Abstract: The present study aims to investigate slurry pot erosion wear behavior of nanoclay-modified short fiber reinforced polymer (SFRP) composites. Epoxy matrix modified with 5wt% nanoclay was prepared using high shear three roll milling mixing system at 60°C and 12.7 m/s speed. Two short synthetic fibers and two short natural fibers were used as reinforcements, i.e. carbon, glass, basalt, and kenaf. Slurry pot erosion wear tests were conducted using a mixture of sand and water as erosive materials and at a running speed of 300rpm for 10km sliding distance. The results showed that the inclusion of short fibres improved the erosion wear behavior of epoxy polymer, in which basalt reinforced polymer composite showing the best performance when compared to the other types of SFRP composites. The addition of 5.0wt% nanoclay filler also reduced the specific erosion wear rate of the SFRP composites. Nanoclay had significantly improved wear rate of glass fiber reinforced polymer composites of up to 53% compared to its pure state. Basalt fiber was also found to be a potential alternative to synthetic fiber; i.e carbon and glass fiber, based on its lowest wear rate among all the SFRP composites.

Keywords: Carbon fiber, Glass fiber, Basalt fiber, Kenaf fiber, Slurry, Erosion, Wear Rate

I. INTRODUCTION

Erosion of engineering materials is a degradation of material surface due to mechanical action [1]. Erosive wear is a type of wear occur commonly in pipeline transportation, gas turbine, pump impeller and heat exchangers. There are several types of erosion occur in industrial applications such as solid particle erosion, slurry erosion, cavitation erosion, liquid impingement and impact wear [2]. Each type of erosion requires different environmental condition for testing to determine the erosion durability of the materials [3]. Slurry erosion typically included abrasive particles suspended in liquid medium, mainly occur in pipeline transportation. Increased number of slurry handling processes has triggered researchers to explore the properties of materials specifically operating under slurry erosive conditions. Several factors can affect the slurry erosive wear behavior, such as slurry properties, slurry concentration, particle properties, flow properties, and temperature [4].

Composite material is a combination of two or more constituents that usually have different physical form or chemical compositions. Polymer composite materials have replaced many conventional materials such as metals, ceramics, woods and polymers due to their advantages such as high specific strength and stiffness. Epoxy resins have generally been used for coating, electronic devices, adhesives and matrices for fiber-reinforced composites due to their good mechanical properties, high adhesion strength, good heat resistance, and high electrical resistance [5]. However, due to the brittleness of epoxy, this material needs to be modified with other material called fillers to improve its properties. Many researchers reported that the epoxy resins which were modified with nanofillers such as nanoclay, nanosilica and carbon nanotubes (CNT) have better properties when compared to their pure systems [6].

Clay is one of the most important minerals used in various industries. Nanosized-clay has interesting properties such as high specific strength, low density, high elastic modulus, low materials price, high specific surface area and low thermal coefficient. These properties have attracted many researchers to study the effect of nanosized-clay on mechanical, thermal, tribological, physical and chemical properties of polymers and fiber composites. Nanoclay helps to enhance the quality of product, saves the cost and protects the environment. Its availability and nature make it one of the expanding nanofillers used to improve mechanical and tribological properties of composites [7]. Study conducted by Zhang et al. [8] found that 3wt% of nanoclay dispersed in epoxy resulted in improved impact and tensile strength by about 88% and 21% respectively.

Nowadays, synthetic fibers, such as glass and carbon, have widely been used in various applications. The other types of synthetic fibers are aramid and polypropylene fiber. Glass fiber offers very good stiffness and strength, chemical, impact resistance and thermal stability. Carbon fiber is used instead of glass fiber when higher stiffness property is required but carbon fiber is usually more expensive than glass fiber. However, due to increasing environmental concern, synthetic fibers are slowly being replaced by natural fibers such as basalt fiber, kenaf fiber, sisal fiber and many more [9]. Natural fibers have attracted the interest of researches because of their specific advantages compared to synthetic fibers. The

Revised Manuscript Received on 20 October, 2019.

* Corresponding Author

Aidah Jumahat*, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia. Email: aidahjumahat@uitm.edu.my

Nurul Ain Haris, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Cawangan Johor, Kampus Pasir Gudang, Malaysia. Email: nurul6008@johor.uitm.edu.my

Fatin Najwa Che Mohamad, Faculty of Mechanical Engineering, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia. Email: fatinnajwa0894@gmail.com

advantages of natural fiber included properties such as lightweight, low density, low cost, non-toxic, biodegradable and acceptable specific strength, which make them suitable to use as filler in polymer composites [10]. Kenaf fiber is a type of plant-based natural fiber that may be modified either chemically or physically and used for either thermoplastic or thermoset polymer systems. Basalt is one of mineral-based natural fiber that comes from volcanic rocks. Due to its high stability of thermal and high electrical properties, basalt offers better features than synthetic fiber such as glass [11].

A comprehensive study was conducted by Zhao et al. [12] on carbon fiber (CF), glass fiber (GF) and Aramid fiber (AF) reinforced polyimide composite under dry sliding and erosive wear. The erosive wear tested was centrifugal particle impact wear type with impact angle and velocity varied. The study found that all three composites were ineffective in improving erosion resistance of polyimide matrix under 30° and 90° angle, whereby the impact particles cuts material and generate stresses leading to subsurface lateral cracking [12]. Hybrid composite material consists of long kenaf and glass fiber reinforced polyester composite was tested by Ghani et al. for its slurry erosion behavior. It was found that the hybrid material has comparable mechanical properties as long kenaf polyester composite, but better erosion wear properties since glass fiber prevents kenaf fiber from absorbing water after matrix fractured during erosion test [13]. The advances in material sciences has influenced researches to explore the erosive performance of advanced fiber reinforced polymer composite in which fiber and filler exists together as reinforcement to the polymer matrix. Studies by Mahesha et al., Joshi et al., Rao et al., and Ray et al. [6], [14], [15] focused on solid particle erosion behavior of these materials with variable factors of erodent concentrations, erodent size, impingement angle, speed, and temperature.

Although there are a lot of researches conducted on the erosion wear behavior of polymers composites, there are still limited research on slurry pot erosive wear type of behavior on advanced composites of nanoclay filler and short fibers. Therefore, the present study is aimed to investigate the impact of nanoclay filler modification on slurry pot erosion wear behavior of short fiber reinforced polymer (SFRP) composites of synthetic fibers; namely carbon fiber (CF) and glass fiber (GF), and natural fibers; namely basalt fiber (BF) and kenaf fiber (KF).

II. METHODOLOGY

A. Material

The epoxy resin namely Miracast 1517 was supplied by Miracon (M) Sdn. Bhd. The Miracast epoxy resin consists of two parts which are Part A (epoxy resin) and Part B (amine-curing agent) as its hardener. The mixing ratio was fixed at 100:30, epoxy: hardener. Nanomer I.30 Montmorillonite (MMT) clay (particle size 8-10µm, density 1.9g/cm3) was used as nanofiller supplied by Sigma Aldrich. The surface of MMT clay was modified with 25-30wt% of trimethyl stearyl ammonium to produce nanomer I.30. Nanomers I.30 is supplied as a white powder that has a mean dry particle size of 8-10 µm and density of 1.9g/cm^3. The synthetic fibers; carbon fibers (diameter 6-10µm, density 1.77g/cm^3) and glass fibers (diameter 10-17µm, density 2.54g/cm^3) were supplied by Vistec Technologies Sdn. Bhd., while natural fibers; basalt fibers (diameter 9-15µm, density 2.65g/cm^3) and kenaf fibers (diameter 1mm, density 1.45g/cm^3) were supplied by Innovative Pultrusion Sdn.Bhd. All the fibers were chopped using crusher machine to get length size of 3-5 mm, as shown in Fig. 1.


(a) (b) (c) (d)

Fig. 1. Chopped a) Carbon, b) Glass, c) Basalt and d) Kenaf fibers

B. Sample Fabrication

Two types of short fiber reinforced polymer (SFRP) composite system were fabricated; pure SFRP system and nanoclay-modified SFRP system. In each system, four types of chopped fibers were used; carbon fiber, glass fiber, basalt fiber, and kenaf fiber. In nanoclay-modified SFRP system, the epoxy resin was modified with nanoclay to produce polymer nanocomposites before mixing with the fibers.

In order to fabricate pure SFRP composites, 10wt% of fibers (carbon, glass, basalt and kenaf) were weighed and mixed together with 90wt% epoxy and hardener using hand layup method. The mixtures were cured in a silicon mold according to the required testing size, i.e. 25mm wide, 75mm length and 6mm thick, at room temperature for 24 hours. To fabricate nanoclay-modified SFRP composites, nanoclay modified epoxy polymer was first prepared. The nanoclay was weighed and mixed with epoxy resin using mechanical stirrer and three roll mill machine. The nanoclay content of 5.0wt% in epoxy resin was milled using the three roll mill machine at 60 °C temperature and 12 m/s speed. The shear force generated between the adjacent rollers allows nanoclay to disperse easily and reduce epoxy's viscosity since the roller was heated. The chopped fibers were then mixed in the epoxy mixture using mechanical stirring, before the hardener was added. The composite mixtures were left to cure in a silicon mold at room temperature for 24 hours. The designations of composites are shown in Table-I.

Table-I: Designation of specimen

Designation	Content (wt%)		
	Epoxy	Fiber	Nanoclay
Pure System			
EP	100	0	0
EP/CF	90	10	0
EP/GF	90	10	0
EP/BF	90	10	0
EP/KF	90	10	0
Nanoclay-modified System			
EP/5NC	95	0	5
EP/CF/5NC	85	10	5
EP/GF/5NC	85	10	5
EP/BF/5NC	85	10	5
EP/KF/5NC	85	10	5

C. Sample Characterization

The modified and unmodified SFRP composite samples were proceed with density and hardness test. The density of samples was calculated using Equation (1) using Archimedes Principle. Hardness test was conducted to determine the hardness of the samples in each system using Instron A654 R Rockwell Hardness Tester machine. The Rockwell type R (HRR) hardness test was conducted according to ASTM D785-08 standard.

$$\rho = \frac{A}{A-B} \times (\rho_o - d) + d \qquad (1)$$

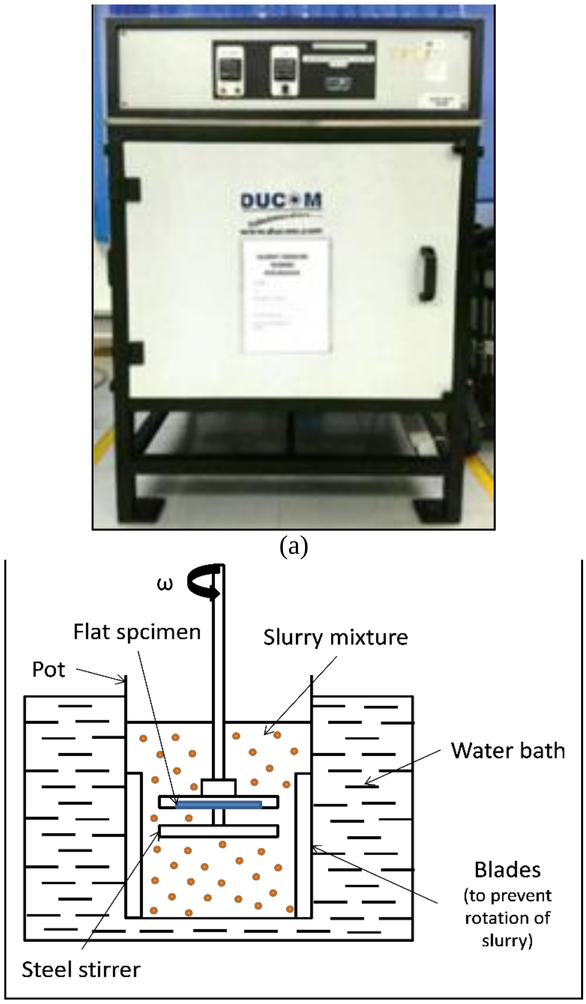
where:
ρ = Density of sample
A = Weight in air
B = Weight in liquid
ρ_o = Density of liquid (0.99594 g/cm^3)
d = Density of air (0.001 g/cm^3)

D. Slurry Pot Erosion Test

Slurry pot erosion tester Tribometer (TR – 40) was used to investigate the erosive wear behaviour of the SFRP composites, as shown in **Fig. 2**(a). The samples were attached to a rotational holder in a pot which contained a mixture of sand and water. Medium type of sand between ranges of 0.2mm – 0.63mm and water were used as slurry item. In one run, six pot containers were simultaneously run. The pots were immersed in a water bath to prevent overheating of the sand mixture. The weight of each samples was recorded at initial condition and at every 2000m interval until the distance travel reached 10000m. The operating parameters for present study are summarized in Table-II. The specific wear rate was calculated using Equation (2):

$$W_s = \frac{\Delta m}{m \times \rho} \qquad (2)$$

where
Ws : Specific erosion rate (mm^3/g)
Δm: Mass loss of sample (g)
m : Mass of erodent (g)
ρ : Density of sample (g/mm^3)



(a) (b)

Fig. 2. Slurry erosion tester Tribometer (TR – 40) a) Machine b) Schematic diagram of the set up [16]

Table-II: Operating parameter of slurry test

Parameters	Experimental Condition
Type of motion	Unidirectional sliding
Type of erosive	Medium size sand (0.2 mm- 0.63 mm)
Sliding speed	300 rpm
Sliding distance	10000 m at interval 2000 m

III. RESULTS AND DISCUSSION

A. Characterization of Composites

Table-III shows the density of composites. EP has the lowest density, while EP/GF composite has the highest density in the pure composite system. The addition of carbon, glass, basalt, and kenaf fiber have increased the density of epoxy matrix by 0.93%, 2.59%, 1.26%, and 2.19% respectively.

The density of all composites showed increment as 5wt% nanoclay was added. The results showed that the EP/BF/5NC composite has the highest density of 1.1889 g/cm3, while EP/5NC has the lowest density of 1.1285 g/cm3 for nanoclay-modified composite system. The increment of density for EP/CF/5NC, EP/GF/5NC, EP/BF/5NC and EP/KF/5NC composites was 6.08%, 4.86%, 6.5%, and 0.59%, compared to their pure state respectively. These increments were due to higher density of fibers and nanoclay compared to the epoxy resin.

Table-III: Density of Composites

Nanoclay content (wt%)	Density (g/cm3)				
	EP	EP/CF	EP/GF	EP/BF	EP/KF
0	1.1025	1.1128	1.1311	1.1164	1.1266
5	1.1285	1.1805	1.1861	1.1889	1.1332

The hardness test was carried out to investigate the strength of composites by their resistance towards penetration. Table-IV shows the hardness of the composites prepared. Pure epoxy has a hardness of 109.8 HRR. When fibers were reinforced into epoxy matrix, the hardness showed increment for 2.3%, 2.15%, 4.06% and 0.46% for EP/CF, EP/GF, EP/BF and EP/KF composites respectively, compared to hardness of pure epoxy. EP/BF composites exhibited highest hardness compared to other composites due to the presence of iron oxides in basalt fiber's content, where these elements have high atomic weight [17].

However, when modified with nanoclay, the hardness of all composites showed decrement compared to their pure state. The highest decrement was shown by EP/BF/5NC composites with percentage of 1.03% compared to its pure EP/BF composites. This decrement may be due to the presence of porosity in the matrix that leads to property degradation. The high nanofiller content, such as 5wt% of nanoclay, causes high viscosity of the epoxy matrix and difficulty in processing and removing the air entrapped in the mixtures [18]. This results in high porosity of the cured fibre composites. However, since the decrement percentage was quite low (<~1.0%), therefore this is considered as insignificant to the wear behavior of the composites.

Table-IV: Hardness of Composites

Nanoclay content (wt%)	Hardness (HRR)				
	EP	EP/CF	EP/GF	EP/BF	EP/KF
0	109.80	112.32	112.16	114.26	110.30
5	108.74	112.10	111.24	113.08	110.26

B. Wear Behavior

Wear volume of EP and EP/5NC composites against distance are recorded in **Fig. 3**. In general, wear volume increased as sliding distance increased [13]. EP/5NC composites exhibited lower wear volume compared to that of EP that showed improvement of wear behavior by 13.89%. The graph also showed a drastic increasing trend of wear volume at first 4000m distance compared to last 6000m distance travel. The former phase (up to 4000m) is believed to be the run-in phase, while the latter phase (4000m to 10000m) is called steady-state phase, which is a typical wear trend for polymeric material [7].

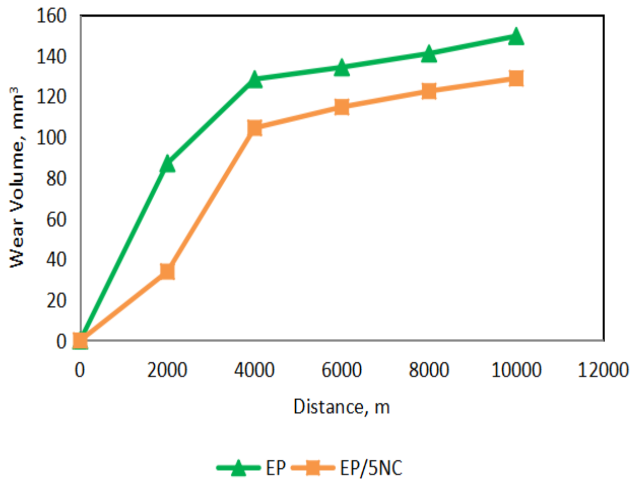


Fig. 3. Wear volume vs sliding distance of EP and EP/5NC composites

Fig. 4 shows the plots of wear volume against sliding distance for pure SFRP and nanoclay-modified SFRP composites containing synthetic fibers. Plot of EP matrix was also included for comparison. All plots show increasing wear volume as sliding distance increased. Besides that, all plots also illustrate the typical trend of wear for polymeric materials with the presence of run-in phase and steady-state phase. However, the run-in phase for EP/CF and EP/GF/5NC took shorter time; at first 2000m distance, instead of first 4000m distance in the case of EP, EP/5NC, EP/CF/5NC composites.

In the pure SFRP composite system of synthetic fibers, wear volume of EP/CF and EP/GF composite was lower than wear volume of EP matrix by 56.06% and 24.90% respectively. This indicates that CF and GF reinforcement have improved the wear behavior of the EP matrix. The synthetic fibers have strengthened the interface between the fibers and the epoxy matrix and possibly increased the Young's modulus of the epoxy composites. The hard phase of the fibers may influence on reducing plow and adhesion between epoxy and erosive [19]. Between them, the EP/GF composites showed higher wear volume than EP/CF composites. This might be due to the increase in collision between erosive materials and GF that leads to more wear effect because of GF is more brittle in nature compared to CF [12], [20]. When nanoclay was incorporated into the SFRP composites, the wear volume showed even lower value for both composites. The nanoclay-modified SFRP composites of synthetic fibers; EP/CF/5NC and EP/GF/5NC each exhibited improvement in wear behavior up to 25% and 53.68% compared to their pure SFRP composites respectively.

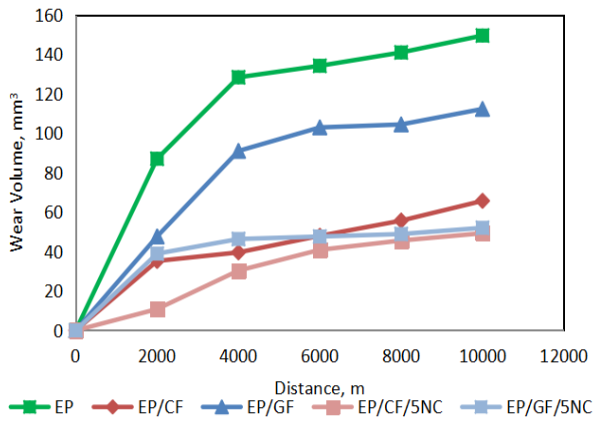


Fig. 4. Comparative plot of wear volume vs sliding distance of EP, pure SFRP and nanoclay-modified SFRP composites system of synthetic fibers

Plots of wear volume against distance for pure SFRP and nanoclay-modified SFRP composites for natural fibers are shown in **Fig. 5**. Plot of EP matrix was also included for comparison. All composites showed increasing trend as sliding distance increased. The drastic increment of run-in phase is shown at first 4000m distance by only EP/KF composites, while the other composites reached steady-state phase earlier, at 2000m distance. The trend was a typical trend of wear for polymeric material, similar to other composites mentioned beforehand [21].

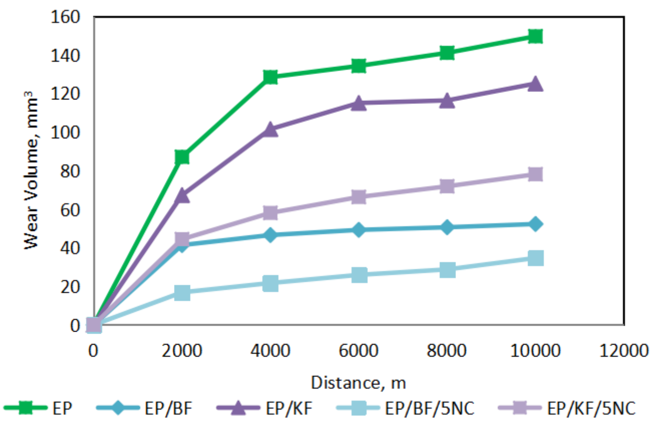


Fig. 5. Comparative plot of wear volume as a function of sliding distance of EP, pure SFRP and nanoclay-modified SFRP composites system of natural fibers

From **Fig. 5**, the wear volume of EP/BF and EP/KF composites are lower than EP matrix, indicating that the fiber reinforcements have improved wear behavior of EP matrix during erosion. Similar to those made of synthetic fibers, the natural fibers seemed to have strengthened the interface between epoxy matrix and fibers that leads to effective load carrying capacity, therefore improved their wear resistance [22]. EP/BF and EP/KF composites each has exhibited improvement of up to 65.04% and 16.38% compared to pure EP matrix respectively, with BF more significant than KF. EP/KF composites showed higher wear volume than EP/BF composites due to KF's higher moisture absorption property that also leads to its lower hardness (as stated in Table-IV) compared to BF [23]. For nanoclay-modified SFRP composites system, the wear volume has decreased even more. EP/BF/5NC composites has improved wear behavior of EP/BF composites up to 33.70%, while EP/KF/5NC composites has improved wear behavior of EP/KF composites up to 37.58%.

The specific erosion rate (Ws) of the composites is calculated using Equation (1) and is plotted in Fig. **6**. The highest wear rate is shown by epoxy polymer in both pure state and nanoclay-modified state. As fibers were reinforced in epoxy matrix, the wear rate decreased with sequence of EP/KF, EP/GF, EP/CF, and EP/BF composites from highest to lowest value. EP/BF composites exhibited the lowest value among pure natural SFRP composites, while EP/CF composites exhibited the lowest value among pure synthetic SFRP composites, indicating their better erosion wear resistant property. It is worth noticing that EP/BF and EP/CF composites also recorded higher hardness value compared to EP/KF and EP/GF composites respectively. Hardness property is related to wear properties of a material as it can accommodate the surface deformation and absorb shock loads without failure [24].

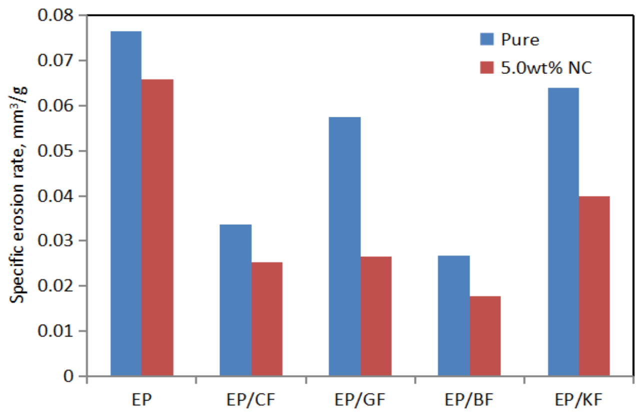


Fig. 6. Specific erosion rate of pure composites system and nanoclay-modified composites system for different types of short fibers

As nanoclay was incorporated in SFRP composites system, the erosion rate of all composites has improved. The lowest wear rate was shown by EP/BF/5NC composites with improvement of up to 76.81% corresponding to the pure epoxy matrix. The sequence of composites from highest to lowest wear rate was still similar to pure SFRP composites system; EP/KF/5NC, EP/GF/5NC, EP/CF/5NC and EP/BF/5NC. Therefore, it can be seen that basalt fiber has a very promising future as a natural fiber that can replace synthetic fibers, based on the wear rate obtained. Basalt fiber's ability and behavior to resist erosion wear of epoxy polymer might become one of the key factor in material selection for application under adhesive and abrasive wear [14].

On the other hand, the percentage of improvement in erosion rate for each SFRP composite as a result of nanoclay filler addition was promising. The presence of nanoclay resulted in significant improvement of wear rate up to 53.68% for EP/GF/5NC. It is followed by EP/KF/5NC, EP/BF/5NC and EP/CF/5NC with improvements of 37.58%, 33.7%, and 25% compared to their respective pure SFRP composites. Nanoclay filler has acted as energy barrier towards the slurry erosives, preventing severe wear of the composites [1]. Nanoclay filler also is believed to have strengthen the interface between epoxy matrix and short fibers due to its greater aspect ratio and specific surface area properties [25]. The stronger interaction between matrix-fiber-filler has improved overall load carrying capacity of the composites, leading to improved erosive wear resistance of the material. Besides that, the dispersion of nanoclay in epoxy matrix is also believed to be uniform and homogenous allowing effective load transfer between the reinforcements in the composite, due to the effective dispersion method [26].

On the other hand, it is also noted that although EP/BF/5NC and EP/CF/5NC composites exhibited best erosion wear resistant behavior for natural fiber and synthetic fiber group respectively, they both did not demonstrate highest wear improvement percentage in the presence of nanoclay filler. Further investigation is suggested to venture further into this finding.

IV. CONCLUSION

The wear volume and specific erosion rate of pure short reinforced polymer (SFRP) and 5.0wt% nanoclay-modified short reinforced polymer (SFRP) composites of carbon, glass, basalt and kenaf fiber were successfully conducted and analyzed for their slurry pot erosion wear behavior. Their density and hardness measurement were taken prior to the slurry pot erosion test. The following conclusions can be drawn from the present study;

- Pure epoxy polymer and nanoclay-modified epoxy polymer composite exhibited highest wear volume and specific erosion wear rate.
- Fiber reinforcement of synthetic fibers; carbon and glass, and natural fibers; basalt and kenaf, all have improved the erosion wear behavior of pure epoxy matrix polymer. Overall lowest wear volume was shown by EP/BF composites, with improved wear resistance behavior of about 65%.
- For synthetic fiber group, EP/CF composites have better wear resistance property than EP/GF composites, while for natural fiber group, EP/BF composites has better wear resistance property than EP/KF composites.
- Nanoclay filler has improved the wear resistance for all SFRP composites. The highest improvement percentage was shown by EP/KF/5NC composites at about 53%, while the overall best wear performance was shown by EP/BF/5NC composites, an improvement of about 76% from pure epoxy matrix.
- Nanoclay filler gave more significant impact on glass fiber and kenaf fiber reinforced polymer composites compared to carbon fiber and basalt fiber reinforced polymer composites, although they did not exhibit best wear resistance behavior.
- Basalt fiber is a promising alternative natural fiber to replace synthetic carbon fiber and glass fiber in an erosive environment.

ACKNOWLEDGMENT

The authors would like to acknowledge the Universiti Teknologi MARA (UiTM), Ministry of Education Malaysia and Institute of Graduate Studies (IPSIS) for the financial supports. The research is performed at the Faculty of Mechanical Engineering, UiTM, Malaysia under the support of Fundamental Research Grant Scheme (FRGS) no: 600-IRMI/FRGS 5/3 (336/2019).

REFERENCES

1. A. G. Joshi, M. P. Kumar, and S. Basavarajappa, “Influence of Al2O3 Filler on Slurry Erosion Behavior of Glass/Epoxy Composites,” *Procedia Materials Science*, vol. 5, pp. 863–872, 2014.
2. A. Devaraju, "A Critical Review on Different Types of Wear of Materials," *International Journal of Mechanical Engineering and Technology, vol.* 6, no. 11, pp. 77-83, 2015.
3. A. Akinci, E. Ercenk, S. Yilmaz, and U. Sen, “Slurry erosion behaviors of basalt filled low density polyethylene composites,” *Materials & Design*, vol. 32, no. 5, pp. 3106–3111, 2011.
4. S. L. Sinha, S. K. Dewangan, and A. Sharma, “A review on particulate slurry erosive wear of industrial materials: In context with pipeline transportation of mineral−slurry,” *Particulate Science and Technology*, vol. 35, no. 1, pp. 103–118, 2017.
5. F.-L. Jin, X. Li, and S.-J. Park, “Synthesis and application of epoxy resins: A review,” *Journal of Industrial and Engineering Chemistry*, vol. 29, pp. 1–11, Sep. 2015.
6. S. Ray, A. K. Rout, and A. KuSahoo, “A Study on Tribological Behavior of Glass-Epoxy Composite Filled with Granite Dust,” *IOP Conference Series: Materials Science and Engineering*, vol. 225, no. 1, p. 012097, Aug. 2017.
7. A. Jumahat, A. A. A. Talib, and A. Abdullah, “Wear properties of nanoclay filled epoxy polymers and fiber reinforced hybrid composites,” in *Nanoclay Reinforced Polymer Composites*, M. Jawaid, A. E. K. Qaiss, and R. Bouhfid, Eds. Springer Nature, 2016, pp. 247–260.
8. K. Zhang, L. Wang, F. Wang, G. Wang, and Z. Li, “Preparation and characterization of modified-clay-reinforced and toughened epoxy-resin nanocomposites,” *Journal of Applied Polymer Science*, vol. 91, no. 4, pp. 2649–2652, Feb. 2004.
9. N.-M. Barkoula, B. Alcock, N. O. Cabrera, and T. Peijs, “Fatigue Properties of Highly Oriented Polypropylene Tapes and All-Polypropylene Composites,” *Polymers and Polymer Composites*, vol. 16, no. 2, pp. 101–113, Feb. 2008.
10. N. Saba, P. Tahir, M. Jawaid, N. Saba, P. M. Tahir, and M. Jawaid, “A Review on Potentiality of Nano Filler/Natural Fiber Filled Polymer Hybrid Composites,” *Polymers (Basel).*, vol. 6, no. 8, pp. 2247–2273, Aug. 2014.
11. V. Fiore, T. Scalici, G. Di Bella, and A. Valenza, “A review on basalt fibre and its composites,” *Composites Part B: Engineering*, vol. 74, pp. 74–94, Jun. 2015.
12. G. Zhao, I. Hussainova, M. Antonov, Q. Wang, T. Wang, and D. L. Yung, “Effect of temperature on sliding and erosive wear of fiber reinforced polyimide hybrids,” *Tribology International*, vol. 82, no. PB, pp. 525–533, 2015.
13. M. A. A. Ghani, A. F. A. Kamal, M. A. Ahmad, Y. M. D. Taib, Z. Salleh, and S. K. Alias, “Slurry Wear Test of Long Kenaf Polyester Composite (LKPC) and Long Kenaf Polyester with Fiberglass Composite,” *Applied Mechanics and Materials*, vol. 393, pp. 919–924, 2013.
14. C. R. Mahesha, Shivarudraiah, C. R. Chandra, and R. Suprabha, “Effect of Nano TiO2/Clay on the Erosive Wear Behavior of Basalt-Epoxy Hybrid Composites at Elevated Temperatures,” *Applied Mechanics and Materials*, vol. 813–814, pp. 40–45, 2015.
15. K. S. Rao, Y. S. Varadarajan, and N. Rajendra, “Erosive Wear Behaviour of Carbon Fiber-reinforced Epoxy Composite,” *Materials Today: Proceedings*, vol. 2, no. 4–5, pp. 2975–2983, Jan. 2015.
16. A. A. A. Talib, “Friction and Wear Properties of FRP Composites and Nanoclay-filled BFRP Composites,” MSc Thesis, Universiti Teknologi MARA, 2018.
17. C. A. Chairman and S. P. K. Babu, “Mechanical and Abrasive Wear Behavior of Glass and Basalt Fabric-Reinforced Epoxy Composites,” *Journal of Applied Polymer Science*, vol. 130, no. 1, pp. 120–130, 2013.
18. J. J. Karippal, H. N. Narasimha Murthy, K. S. Rai, M. Sreejith, and M. Krishna, “Study of

mechanical properties of epoxy/glass/nanoclay hybrid composites," *Journal of Composite Materials*, vol. 45, no. 18, pp. 1893–1899, Aug. 2011.
19. B. Suresha, K. Shiva Kumar, S. Seetharamu, and P. Sampath Kumaran, "Friction and dry sliding wear behavior of carbon and glass fabric reinforced vinyl ester composites," *Tribology International*, vol. 43, no. 3, pp. 602–609, 2010.
20. T. Ø. Larsen, T. L. Andersen, B. Thorning, and M. E. Vigild, "The effect of particle addition and fibrous reinforcement on epoxy-matrix composites for severe sliding conditions," *Wear*, vol. 264, no. 9–10, pp. 857–868, 2008.
21. N. A. Nordin, F. M. Yussof, S. Kasolang, Z. Salleh, and M. A. Ahmad, "Wear Rate of Natural Fibre: Long Kenaf Composite," in *The Malaysia International Tribology Conference*, 2013, vol. 68, pp. 145–151.
22. L. Mohammed, M. N. M. Ansari, G. Pua, M. Jawaid, and M. S. Islam, "A Review on Natural Fiber Reinforced Polymer Composite and Its Applications," *International Journal of Polymer Science*, vol. 2015, 2015.
23. F. Fazillah, M. Fadzli, B. Abdollah, A. Kalam, M. Hassan, and H. Amiruddin, "Tribological characteristics comparison for oil palm fi bre / epoxy and kenaf fi bre / epoxy composites under dry sliding conditions," *Tribology International*, vol. 101, pp. 247–254, 2016.
24. O. Chernogorova, E. Drozdova, I. Ovchinnikova, A. V. Soldatov, and E. Ekimov, "Structure and properties of superelastic hard carbon phase created in fullerene-metal composites by high temperature-high pressure treatment," *Journal of Applied Physics*, vol. 111, no. 11, p. 112601, Jun. 2012.
25. M. Campo, A. Jimenez-Suarez, and A. Ureña, "Effect of type, percentage and dispersion method of multi-walled carbon nanotubes on tribological properties of epoxy composites," *Wear*, vol. 324–325, pp. 100–108, 2015.
26. N. Sapiai, A. Jumahat, N. Manap, and M. A. I. Usoff, "Effect of Nanofillers Dispersion on Mechanical Properties of Clay/Epoxy and Silica/Epoxy Nanocomposites," *Jurnal Teknologi*, vol. 76, no. 9, pp. 107–111, 2015.

AUTHORS PROFILE

Associate Professor Dr. Aidah Jumahat has a PhD degree in Mechanical Engineering from the University of Sheffield United Kingdom, a MSc (Mechanical Engineering) degree and a B.Eng. (Hons.) Mechanical and Materials Engineering degree from the Universiti Kebangsaan Malaysia. She joined the Faculty of Mechanical Engineering UiTM as a lecturer in 2001. Currently, she is an Associate Professor at the Faculty of Mechanical Engineering and the Director at Community of Research Frontier Materials and Industrial Application (CoRe FMIA) Institute of Research Management and Innovation (IRMI) Universiti Teknologi MARA Shah Alam Selangor Malaysia. Dr. A Jumahat has been lecturing on Composite Materials, Finite Element Method, Mechanics of Materials, Manufacturing Processes, Product Design and Advanced Materials, which happens to be her areas of research interest. She has published more than 100 technical papers in journals and conference proceedings locally and internationally in these research areas. She is an esteemed member of the panel of judges for the International Invention, Innovation & Technology Exhibition (ITEX) since 2012 and an executive member of several professional bodies.

Nurul Ain Haris is involved in Fabrication of Glass and Ceramics since her Master degree in 2011 at University of Sheffield, UK. Then, she starts working at UiTM Johor, Pasir Gudang Campus and has been a leader of Research Acculturation Grant Scheme (RAGS) entitled Scaffold Structured Beta Phase Titanium-Niobium Alloy. She is the member of Board of Engineers Malaysia (BEM) and Society of Engineering Education Malaysia (SEEM)

Fatin Najwa Che Mohamad completed her Bachelor Degree (Hons) in Mechanical Engineering from Universiti Teknologi MARA (UiTM) in 2018. Her main research of interest is in fibres reinforced composites. Her final year project involved investigation on wear properties of chopped basalt, kenaf, glass and carbon fibres reinforced polymer composites with addition of carbon nanotubes and nanoclay as nanofillers.