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RESEARCH

The Influence of Fibre Orientation on Tribological Performance of Jute Fibre Reinforced Epoxy Composites Considering Different Mat Orientations

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A B S T R A C T

In this study, hand lay-up technique was used to fabricate epoxy composite based on jute fibre mates. Three different orientations wew considered in the fabrication of the composites. The characteristics of the material removal from the surface of the composite due to sliding condition was investigated. Different applied loads were considered to gain different shear force in the interface. Scanning electron microscopy was used to examine the influence of the shear force on the interaction between the fibre and the resin after sliding at different orientations. The outcome would be significantly contributed to the knowledge of composite science and tribology. The main findings of the work was that fibre orientation has very significant influence of the wear and frictional performance of jute fibre reinforced epoxy composites. Sliding distance controls the running in and steady state wear behaviour of the composites especially when the composite was tested in parallel and antiparallel orientations. Wear resistance of the composites found to be better in the antiparallel orientation followed by parallel and then normal. Jute fibres gave very promising results to replace glass fibres for the same composites at the same operating conditions.

1. INTRODUCTION

Nowadays, polymers and their composites are increasingly used by many industries due to their characteristics of lightweight, low cost in manufacturing, and low cost of raw materials. This increase generates an environmental issue in term of degradation of those materials since it is very challengeable to recycle thermosets and thermosets composites. To reduce the impact of the thermosets and their composites on the environment, engineering researchers and physical scientist are owing to explore biomaterials to substitute the synthetic thermosets. However, there are many limitations in those works especially with the degradation and the poor performance of the biomaterials under wet, hot or chemical conditions. Therefore, the combination of synthetic and biomaterials in a composite may be the solution.

The combinations of bio-reinforcements with a syndetic polymer to form polymeric composites are attracting many academics since there are many recent reported attempts in the literature. Mainly, these attempts are focusing on using natural resources such as natural fibres or fillers as reinforcement for epoxy, polyester or vinyl ester composites [1,2]. Since this concept is new, there are many works need to be done, and there is no comprehensive understanding of how those reinforcements influence the composites design, and performance under different loading conditions. In polymeric composites design, there are many considerations need to be taken such as fibre length, fibre orientation, the volume fraction of the fibres and the fibre characteristics as well.

From the literature, fibre orientation found to be the most effective parameter in composite design. The research in this area is going on as reported by recent works such as [3-6]. On the other hand, the composites have different performance at each different load. For example, the fibres in parallel orientation to the tensile load may give a good performance, but under tribological loading, pull out of the fibres could take place [7]. Therefore, at each loading conditions, the orientation of the fibres should be comprehensively studied about the performance of the composites.

In the literature, there are many works have been done to study the influence of natural fibres on mechanical, tribological and machinability of fibre polymer composites. Xie, Hill [8] addressed the importance of surface incompatibility between natural fibres which are hydrophilic and nonpolar polymers like thermoplastics and thermosets are studied. Surface incompatibility leads to poor fibre-matrix interfacial adhesion which in turn leads to poor mechanical properties. In this case, silanes are used as coupling agents to promote interfacial adhesion. The results show the effective silane family as coupling agents to promote interfacial adhesion and explain the interaction mechanisms between natural fibres and polymer matrices.

Herrera-Franco and Valadez-Gonzalez [9] studies the degree of fibre-matrix adhesion and mechanical improvement of a polyethene matrix by short henequen fibres. For this, different samples were fabricated using different surface treatments such as alkali treatment, a silane coupling agent and the pre-impregnation process HDPE-xylene solution. To determine the efficiency of the treatments, the fibre-matrix interface shear strength was used. This was also used to determine an optimum value of fibre length to be able to process the composite with relative ease. The results showed that the silane treatment and the matrix-resin pre-impregnation process of the fibre produced a remarkable increase in tensile strength. The shear properties of the composites also increased significantly, but, only when the henequen fibres were treated with silane coupling agent. Furthermore, Shalwan and Yousif [10] studied the influence of NaOH composition for the chemical treatment of fibres and fibre diameter on the interfacial adhesion behaviour is investigated using fragmentation technique. SEM was used to investigate the fibre polymer interaction after each experiment. The results show the maximum NaOH concentration and fibre diameter to obtain high composite performance. Results also showed that the interfacial adhesion increases with increasing NaOH concentration but great deterioration in the strength of the fibre is produced, which shows that there has to be a compromise between interfacial adhesion and strength in composite performance. Also, Alsaeed, Yousif [11] comprehensively studied the interfacial adhesion of date palm fibre in an epoxy matrix is investigated using the single fibre pull-out technique, as it is a key parameter in fibre polymeric composites design. Samples were treated with NaOH at different concentrations to determine the influence of NaOH in maintaining high interfacial adhesion and strength with the epoxy matrix. Similar findings were reported by [12]. The length of the fibres and its diameter were also studied for the interfacial adhesion. SEM was used to observe the surface morphology on the fibre and bonding area after conducting the experiments. The optimal concentration of NaOH to treat the fibres as well as the optimum embedded length was determined. Yousif, Shalwan [13] determined the influence of chemical treatment of kenaf fibres in a kenaf epoxy composite, in its flexural properties. For this, two types of composite samples were fabricated, treated with NaOH and untreated. The failure mechanism was studied through SEM observation. The results show that treated kenaf fibres in a kenaf fibre epoxy composite, increase the flexural strength of the matrix material by 36 % while untreated fibres increase this strength in 20 %. The reason for this increment is the great improvement of the interfacial adhesion between the fibres and the matrix and the porosity of the composites, which altogether prevented debonding, detachments and pull out of fibres.

On the degradability of polymeric composites based on natural fibres, Azwa, Yousif [14] recommended in that work to study the resistance of different natural fibre composites when exposed to moisture, thermal, fire and ultraviolet degradation. It also addresses the effect of chemical additives such as fibre treatments, fire retardants and ultraviolet stabilisers. It was determined that optimum fibre content serve as a strength enhancer but has the adverse effect of becoming a possible entry point for moisture attack. Chemically treated fibres were found to behave poorly when exposed to weather. The addition of UV stabilisers and fire retardants enhance outdoor and fire performance but sacrifice strength.

It is essential to study the tribological behaviour of newly developed materials since many designed composites will be subjected to tribological loading during the operating conditions [15,16]. With regards to the influence of the natural fibres on the tribological behaviour of polymers, there are many works have been reported [17-20].

Chin and Yousif [21] selected kenaf fibre as reinforcement for epoxy composite, and they studied the wear and frictional behaviour of the composites using the Block-On-Disk machine at different applied loads, sliding distances and sliding velocities. The effect of the fibres orientation, on the sliding direction, was studied. Regarding the fibre orientation, the paper concludes that the wear rate is lower for normal direction (N-O) as compared to parallel and anti-parallel directions. In another work, by Shalwan and Yousif [22] the mechanical and tribological performance of epoxy composites containing graphite filler and date palm fibres are studied. The microstructure of the composite, as well as tensile fracture samples and worn surfaces of tribological samples, are studied using SEM. The results indicate that interfacial adhesion of the fibre with the epoxy matrix is the key to improving the mechanical and tribological performance of natural fibre polymer composites. The results also show that graphite can assist to reduce friction, but if added in high contents, it deteriorates the mechanical properties.

Yousif Lau [23] considered betel nut fibres for polyester composites. Betelnut fibres were extracted from collected betel nut fruit and arranged to a specific length to fabricate a fibre polyester composite. The material was tested using a block on a disk machine which rotated at 2.8 m/ s to study its adhesive wear. Different loads were applied under dry and wet surface conditions to determine the specific wear rate Ws of the composite. It was established that in dry conditions, the process occurs in two stages, where the initial stage produces higher Ws at all applied loads and in the second stage, the asperities in contact stabilised and the wear rate decreased. The morphology of the worn surface was studied, and it was determined that the composite had better frictional performance and wore in wet contact conditions than in dry. El-Tayeb [24] studied the wear and frictional behaviour of sugar cane reinforced polyester (SCRP) and glass fibre polyester (GRP) composites were tested for friction coefficients and wear rates under dry sliding contact conditions in parallel (P-O) and anti-parallel (AP-O) orientations under different parameters such as load, speed and test duration. The results of friction and wear for the SCRP composite were similar to that of GRP composite thanks to smooth patches of polymer film that worked as a protective layer that was produced because of plastic deformation. The shielded the surface of the composite pin from damage contributing to the higher wear resistance. The unidirectional sugar cane polyester (U-SCRP) showed lowest wear resistance when fibre was oriented parallel to sliding direction. When it was tested in AP-O, wear resistance was as high as that of GRP composite. The coefficient of friction also exhibited this behaviour.

In the light of this, the current project is initiated to study the influence of natural fibre orientations on epoxy composites subjected to adhesive wear loading conditions. In the project, jute mats are selected as natural reinforcement for the epoxy composites. Three different orientations of the mat on the sliding distance are considered which are parallel, Anti-Parallel and normal directions. Different sliding distances are considered (from 0-12 km) to identify the running in and steady state regions.

2. MATERIALS SELECTION AND COMPOSITE PREPARATION

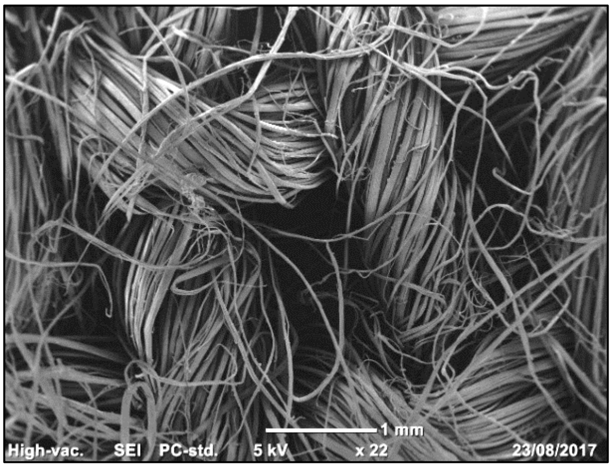
2.1 Materials selection

In the current study epoxy resin is selected for the work since it has very common industrial usage in different applications. Also, it has very good mechanical properties among other resin. Usually, the epoxy resin comes with hardener. The mixing ratio of this type of epoxy is 1:2 A and B. Natural fibre used in the current study is the jute fibres.

2.2 Composite preparation

In the composite preparation, the fibres were first treated to enhance the interfacial adhesion of the fibres with the epoxy matrices as recommended. In the treatment, the fibres Firstly soaked in 6 % NaOH solution for 24 hours and then cleaned with tap water for four-time to ensure the NaOH is removed from the fibre surface [7,10]. After that, the fibres were placed on a tray and put in an oven for 24 hours at a temperature of 40 °C. The prepared fibres were in a mat form displayed in Fig. 1.

a)



b)

Fig. 1. Jute Fibre in Mat Form, a) photo of the mat, b) the micrographs of the mat.

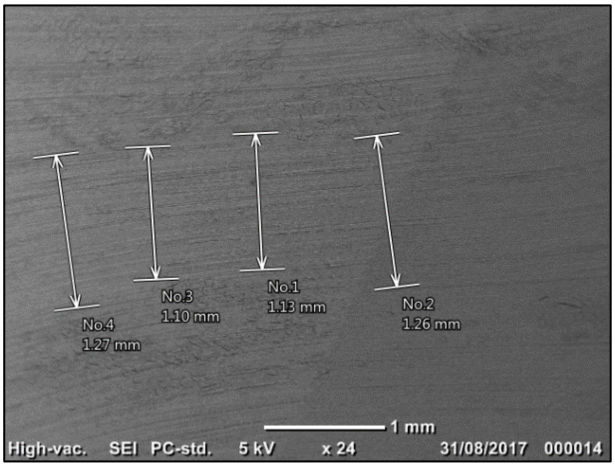


Fig. 2. Prepared Composites.

In the composite preparation, a mould of 7 cm x 7 cm x 7 cm is used to in the fabrication. At the first stage, the mould is coated with a thin layer of grease to ease the removal of the composites. In the pure epoxy fabrication, the mixture of the epoxy resin and the hardener is poured into the mould and keep it for 24 hours for self-curing. After that the block was removed and placed in an oven at a temperature of 120 °C for curing as recommend by the manufacturer, epoxy Australia Company. In the composite preparation, a similar method to the pure epoxy used with the addition of the fibre mats. 11 fibre mats were placed in the mould layer by layer with the addition of the epoxy mixture between each layer. The block of the composites is cured for 24 hours at the room temperature and then placed for 24 hours in the oven for a temperature of 120 °C. The block then machined to the required dimension of 20 mm x 20 mm x 15 mm at the desired orientation [20]. Figure 2 shows the micrograph of the composite surface before the tribological test conducted. The distance between the layer of the jute fibres and the epoxy resin layer is about 1.5 μm.

3. EXPERIMENTAL DETAILS

The experiments were conducted using tribology machine provided by the University of Southern Queensland as given in Fig. 3. The main parts of the machine are the 1.5 ph. Motor to drive the stainless steel counterface, block on ring arm, block on disk arm, two load cell, dead weights, and the container for non-dry contact conditions. The machine is multi-functional machine containing the block on disk and block on ring techniques with different operating conditions as dry or wet. The current experiments were conducted using a block on ring (BOR) configuration, [25]. The block of the composites is placed on the machine holder. The applied load is set to the desired one and the sliding speed set to the desired speed. The speed is set to 3 m/s as recommended in the literature and the applied loads set to be at 30 N. The sliding duration is between 0-60 min which is about 10 km sliding distance. The frictional force is measured via the screen on the machine and then friction coefficient was determined.

Fig. 3. Experimental Setup.

The main objective often studies to investigate the influence of the fibre mat orientations on the tribological behaviour of epoxy composites. The experiments in work were conducted considering three different orientations about the sliding direction. The orientation of the composites concerning the sliding direction is given in the illustration Fig. 4. There are three orientations of the fibres mat concerning the sliding direction which are:

1. Parallel (P-O): When the mats are in the parallel direction to the sliding direction
2. Normal Orientation (N-O) when the mat is in normal orientation to the applied force and parallel to the sliding direct.
3. Anti-Parallel (AP_O) when the mats are in the perpendicular direction to the sliding.

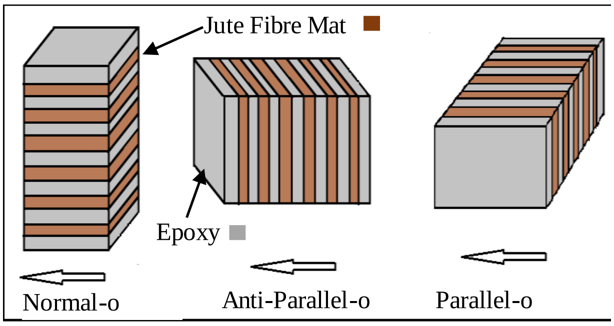


Fig. 4. Illustration Showing the Composite Orientations Concerning the Sliding Direction

Specific were rate and friction coefficient were determined using equation 1 and 2 respectively.

Specific wear rate (SWR) = ΔV/(L.SD)
Friction coefficient = frictional force/ applied force.

Were V is the volume, L is the applied load and SD is the sliding distance.

The prepared samples of the jute fibre reinforced epoxy (JFRE) composites were polished to ensure the adhesive wear will be performed at a smooth surface which has about 1 μm Ra. At the end of each test, Marh roughness device is used to measure the roughness of the counterface and the composites worn surface.

After completing the experiments, the worn surface of the samples was examined using the sacking electron microscopy. The samples for the SEM were prepared on a small EM holder and fixed using a liquid carbon and double-sided carbon tape. The sample then placed in a smart coater machine to coat the worn surface with a thin layer of gold. The process of the coating is fixed to 1 min for each sample. After the coating completed, the sample was placed in the SEM chapter and evacuation process take place. It takes a while to get the image into the computer. The computer has software which is integrated to the SEM enabling to capture the images and save it on the computer.

4. RESULTS AND DISCUSSION

4.1 Wear performance of JFRE under different orientations

4.1.1 Volume loss

The volume loss of the composites after sliding against stainless steel counterface was determined for three set of tests and the averages are presented in Fig. 5. The figure shows the volume loss of the JFRE composites at different orientations at the applied load of 30 N and sliding velocity of 3 m/s. The volume loss was determined based on the mass removal and the density of the composites. The figure shows that there is an increase in the volume loss with the increase of the sliding distance especially after about 5 km sliding distance. After 5 km sliding distance, the relation between the volume loss and the sliding distance is proportional which showed the steady volume loss.

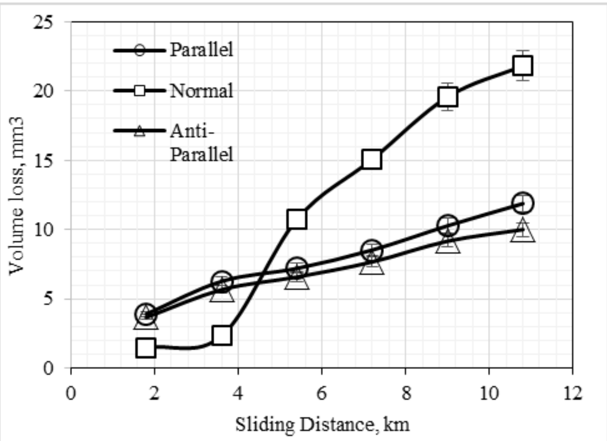


Fig. 5. Volume Loss vs. Sliding Distance of JFRE at Different Orientations.

With regards of the influence of the fibre mat orientations on the performance of the JFRE, the figure shows that the normal orientations produce high volume loss which indicates the poor wear performance of the composites at this orientation. At the normal orientation, the contact between the composites and the counterface is initiated with pure epoxy layer rubbed against stainless steel. Epoxy has poor wear performance if it is used in pure form without any reinforcement as indicated by many published works such as [26,27]. When the pure epoxy is exposed to a hard counterface such as steel, softening process can occur on the epoxy composites which significantly increase the material removal from the surface. The presence of the fibres in the interface can carry some of the shear force generated by the friction and protect the matrix.

In the case of the parallel orientation, the figure shows that the composite has better wear behaviour compared to the normal orientation. This is mainly due to the presence of the fibres while the composites are in rubbing against the steel. Sharma, Mohan Rao [28] reported similar results when carbon fibre–polyetherimide was tested against steel. In that work, the bi-directional composite was used which can be similar to the one at this work since the mat is parallel to the sliding direction. In the case of the Anti-Parallel orientation, the fibre mats are normal to the sliding direction and parallel to the applied load. In this case, the removed fibres can travel to the resinous region and adhere again to the surface and the same to the epoxy debris. This has been reported in the case of the glass fibre reinforced polyester composites by kumre, Rana [29].

4.1.2 Specific wear rate

Specific wear rate represents the volume loss considering the sliding distance and the applied load. Figure 6 shows the specific wear rate of the JFRE composites at different orientations. The trends of the specific wear rate seem to be in reduction with the increase of the sliding distance for the parallel and antiparallel orientations. This is the normal behaviour for almost all the materials since at the initial stage of the sliding there must be a large amount of material removed followed by reduction concerning the sliding distance. However, for the JFRE in normal orientation, the specific wear rate increases at the first stage and steady after that. This is not common behaviour and it is properly due to the modifications on the surface of the composites during the sliding since sometimes it is pure epoxy and another is pure fibre.

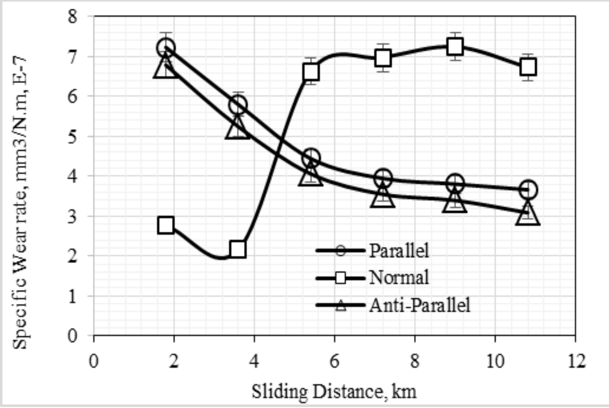


Fig. 6. Specific Wear Rate vs. Sliding Distance of JFRE at Different Orientations.

Exposing either the fibres or the epoxy individually to the rubbing zoon leads to high specific wear rate. In a report by Hutton, Johnson [30], carbon-carbon composite showed similar high specific wear rate at a longer sliding distance and the surface of the composite was severely damaged since there were breakages in the resin and decomposition. Also, there may be some influence on the roughness of the surfaces during the test which will be explained later.

4.2 Frictional performance of JFRE under different orientations

The friction force was captured at each sliding distance for three times and the average is determined. The friction coefficient plotted against sliding distance and presented in Fig. 7. From this figure, it can be seen the composite showed steady friction in the case of the parallel orientation and this is mainly due to the stability of the surface during the sliding. Since the fibre and epoxy regions are in parallel to the sliding direction and there is no transfer from one region to another. In the case of the Anti-Parallel orientation, there is transfer from one region to another which increased the friction coefficient. Also, from the wear results, Anti-parallel oriented composite exhibited good wear performance which indicates the high resistance to the shear in the interface. This can explain the high friction force for the composite in this orientation. For the normal orientations, due to the high material removal from the surface of the composites there is low resistance in the interface and low friction coefficient observed. Sarkar, Modak [26] reported that the friction coefficient of woven glass fibre reinforced composites is about 0.4 at 30 N applied load. The friction of the Anti-parallel oriented composites is quite high compared to the syntactic fibre which needs attention especially if those composites will be using for bearing applications.

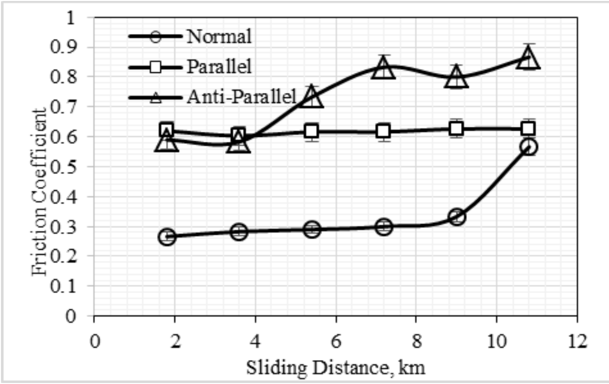


Fig. 7. Friction Coefficient vs. Sliding Distance of JFRE at Different Orientations.

Table 1 Average of friction coefficient**.**

Orientation	Average of COF
Normal	0.4 ±0.11
Parallel	0.6 ±0.03
Anti-Parallel	0.72 ±0.13

For better understanding, the average of coefficient of friction (COF) for the composites in different orientations is given in Table 1 with the variation along the sliding distance of 11 km.

4.3 Surface observations of JFRE under different orientations

The surface observation covers the scanning electron microscopy examination, roughness of the work surface and the hardness of the worn surface. Those observations should give a better understanding of the wear behaviour of the composites at different orientations.

4.3.1 Roughness of the worn surfaces

The roughness of the material controls the wear mechanism and behaviour of materials as reported by many researchers such as [31,32].in the experiments, the roughness of the counterface was fixed to less than 1 μm Ra. The modifications in the roughness of the composites which occurred after each test was determined and plotted in Fig. 8. The figure shows that the composite tested in Normal and Parallel orientations have a great increase in the roughness compared to the Anti-parallel orientation.

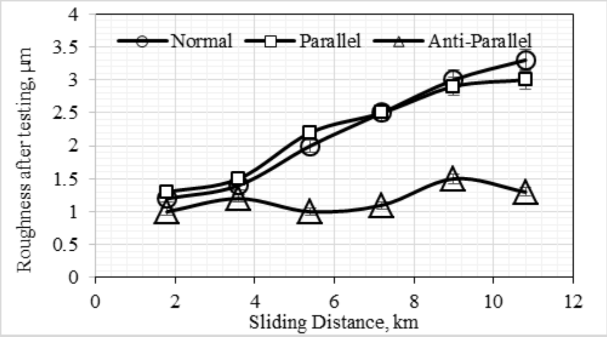


Fig. 8. The roughness of the JFRE Surface after the Testing at Different Orientations.

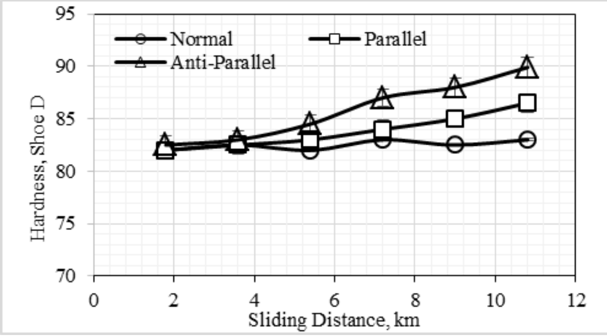


Fig. 9. The hardness of the JFRE Surface after the Testing At Different Orientations.

This can be explained by the fact that in the parallel orientation the epoxy layer was significantly damaged compared to the fibre layer. This roughened the surface of the composites when it was tested in the parallel orientation and lead to high material removal. I the case of the normal orientation, as mentioned previously, a layer of the epoxy was detached and obvious exposure of the fibre appeared which has very high rough surface. With the case of the Anti-Parallel orientation, the built up of the film on the surface as suggested previously and will be confirmed with the help of the SEM smoothen the surface and the increase in the roughness was very minor. Nunez and Polycarpou [32] done comprehensive work on the correlation between the roughness of the surface and the wear rate and friction coefficient. They found that the high roughness generates high wear rate and friction coefficient which in line with the current trend of experimental results.

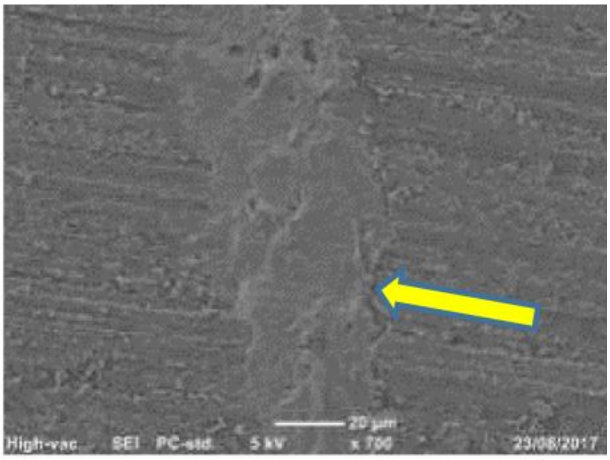
4.3.2 Hardness of the worn surfaces

The hardness of the materials is the main properties which can contribute to the wear behaviour of materials. When the hardness is high, the possibility of removing the material from the surface would be not easy. The worn surface hardness of the JFRE composites tested in three different orientations at a different sliding distance is given in Fig. 9 with the error percent since few readings were taken on the worn surface to ensure the value of the hardness is determined accurately. The figure shows that the high hardness value can be noticed when the JFRE was tested in an Anti-Parallel orientation. This can explain the better wear performance of the composite in this orientation compared to other orientations.

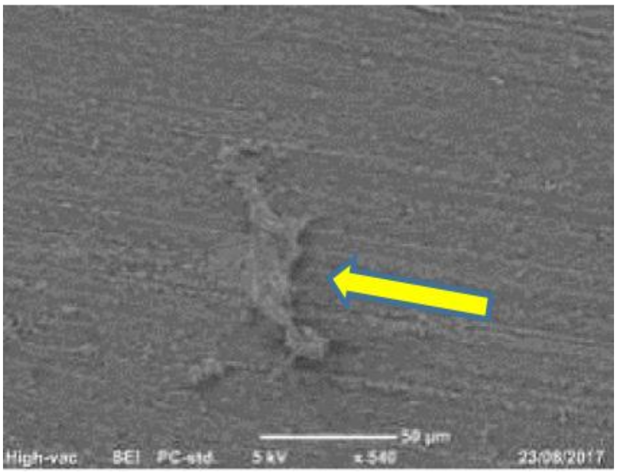
The high hardness is due to the formation of a strong layer of mixed fibre and epoxy on the surface of the composites. The original hardness of the surface was about 82-85 Shore D before testing. In other words, there is an increase in the hardness of the composite surface for all the orientations. This is not highly found in the case of the normal orientation since the individual material is exposed to the surface as seen by the eyes. In the case of the parallel orientation, the hardness increased slightly with the increase of the sliding distance and showed intermediate value among other orientations. Li and Bell [33] reported that the improvement on the hardness of UHMWPE significant contributed to the improvement of the wear resistance of the materials.

5. SEM EXAMINATIONS

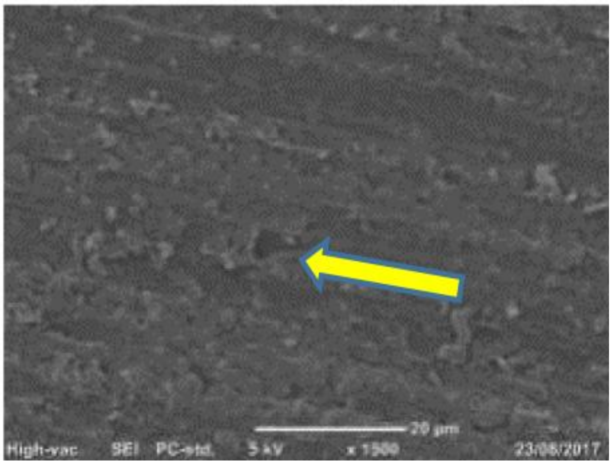
Scanning electron microscopy observation took place on the worn surface of the JFRE composite at different orientations, Figs. 10-12. Figure 10 displays different micrographs of the composite tested in antiparallel orientation.in this figure there are different wears mechanism can be seen. Firstly, Figs. 10a and 10b shows pure adhesive wear followed by exposure of the fibres in Figs. 12e and 12f. Micro-cracks can be seen on the Figs. 10g and 10h which can be due to the high resistance to the shear force. It has been reported the presence of micro-cracks on the surface of polymer represent the high resistance to the shear [34,35]. In the case of the Parallel orientation, Fig. 11 displays the graphs of the worn surface of the JFRE. The damages on the surfaces are pulled out of fibres (Figs. 11a and 11b), abrasive wear (Figs. 11c, 11d, 11e and 11f), breakage in the fibres (Figs. 11c and 11d), debonding of fibres (Fig. 11b). In this orientation, Fig. 11b shows the whole fibre exposed to the running area and there is slight deboning of the fibres. There is no detachment can be seen which gives very good indication that the interfacial adhesion of the jute fibres with the epoxy. This is due to the effect of the 6 % NaOH treatment. This put the performance of the JFRE in a parallel orientation as good but not as the Anti-parallel orientation.



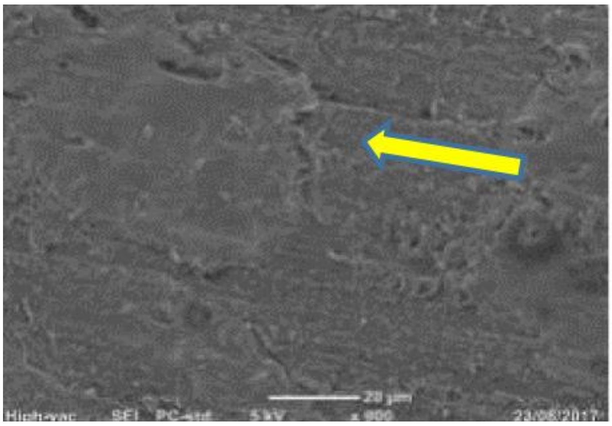
a) debondin



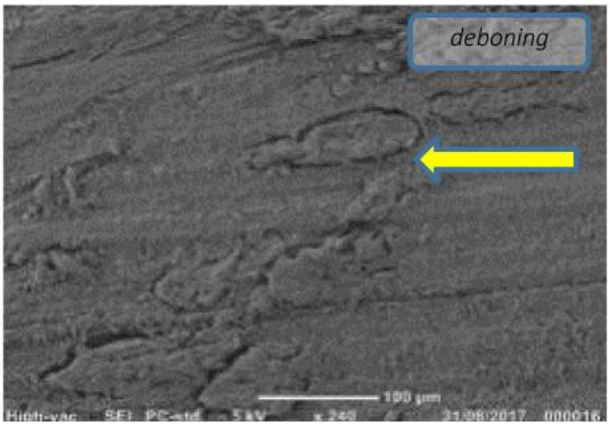
b) debondin



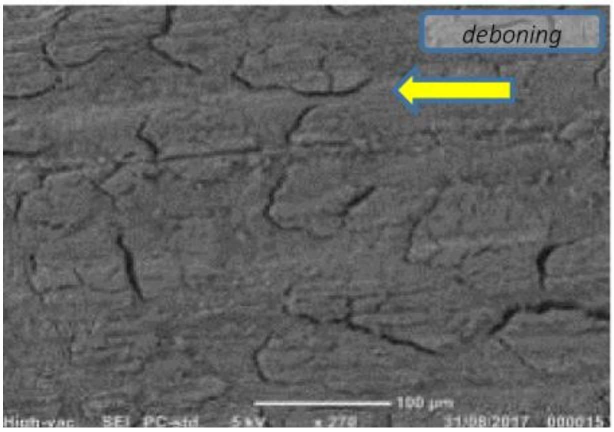
c) abrasion



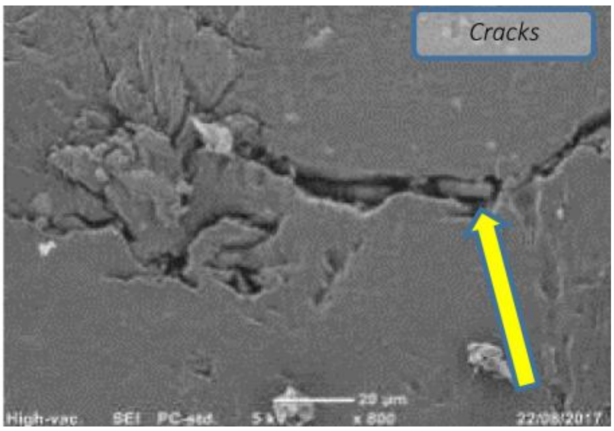
d) end of fibre



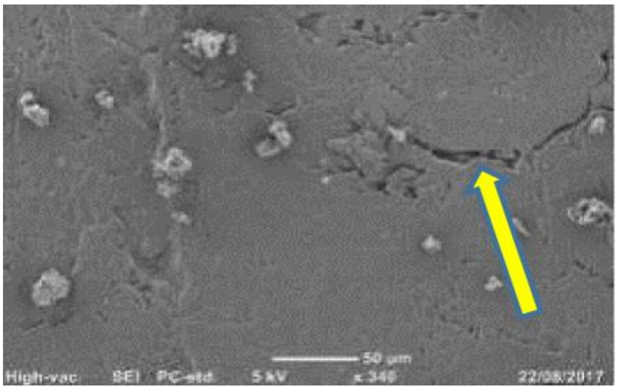
e) debonding



f) debonding

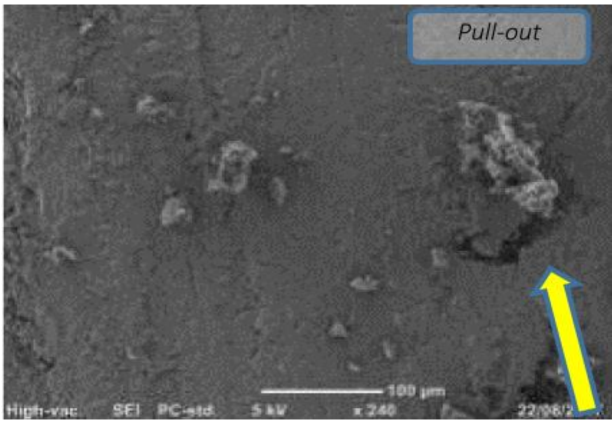


g) cracks

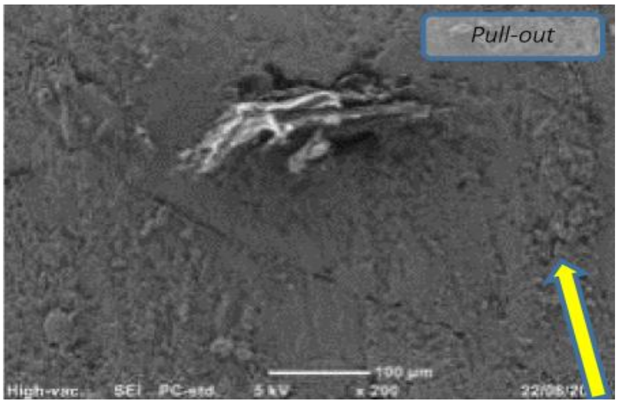


h) cracks

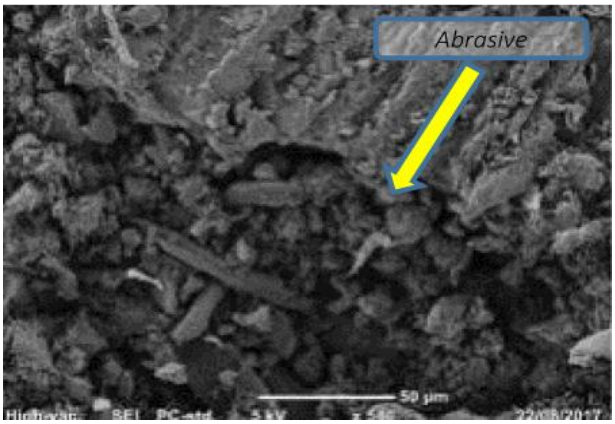
Fig. 10. Micrographs of JFRE Surface After the Testing At Anti-Parallel Orientation.



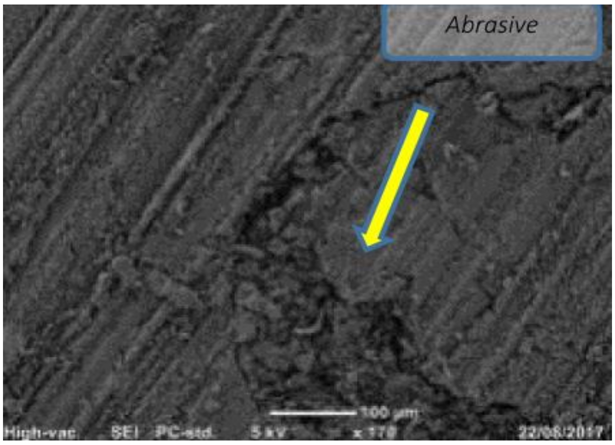
a) pull out



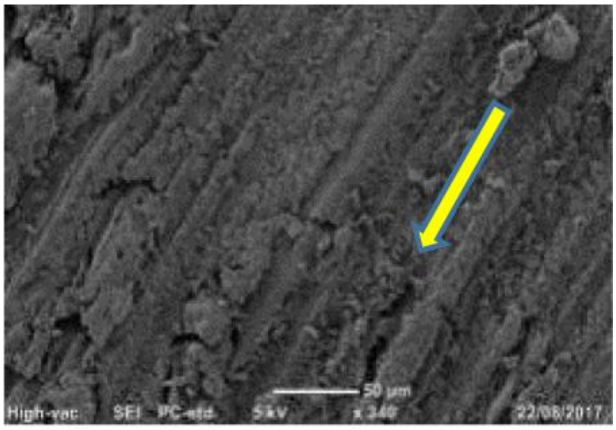
b) pull out



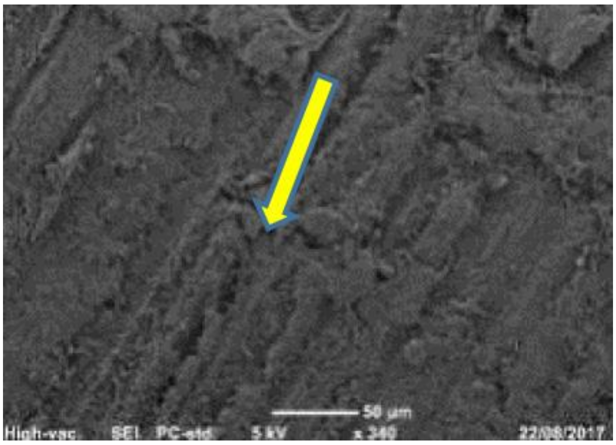
c) abrasion



d) abrasion



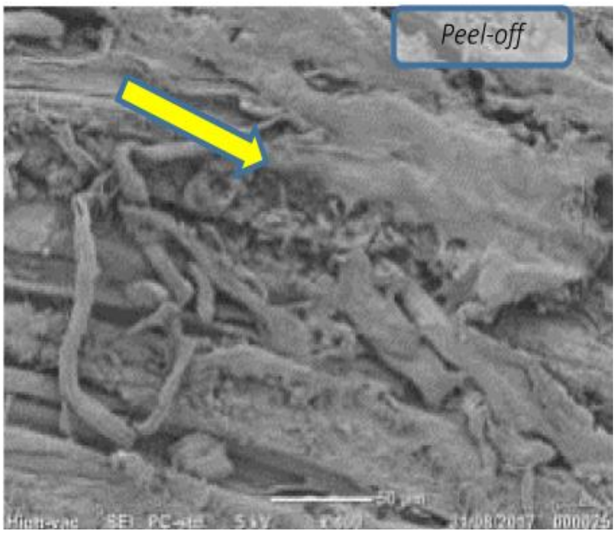
e) breakage



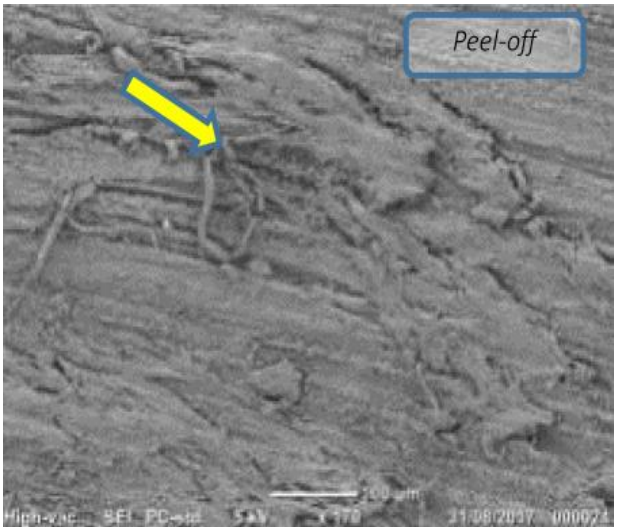
f) micro-cracks

Fig. 11. Micrographs of JFRE Surface after the Testing At Parallel Orientation.

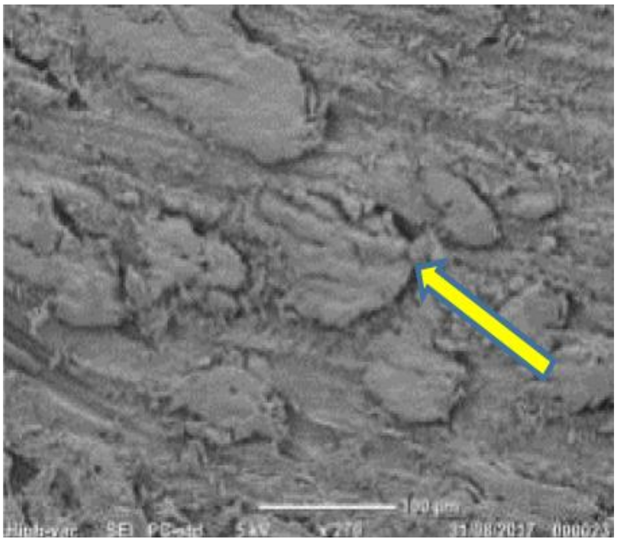
The expose of the epoxy layer or the jute mat layer on the interface in the case of the Normal orientation causes high damages on the composite surface as can be seen in Figs. 12a-12f. The composite surface in normal orientation severely damages since there is pull-put, peel-off and detachments of fibres took place during the sliding. These generate a lot of material removal from the surface which results in high specific wear rate as indicated in Fig. 6. Also, the ease of the material removal of the composites proves the low resistance in the interface which led to the low friction coefficient as reported in Fig. 7.



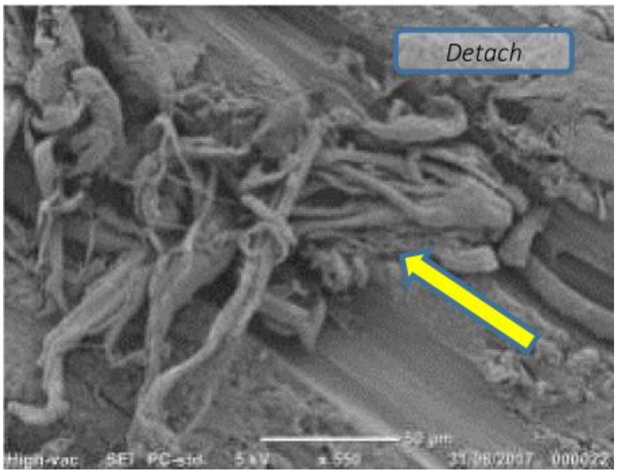
a) peel-off



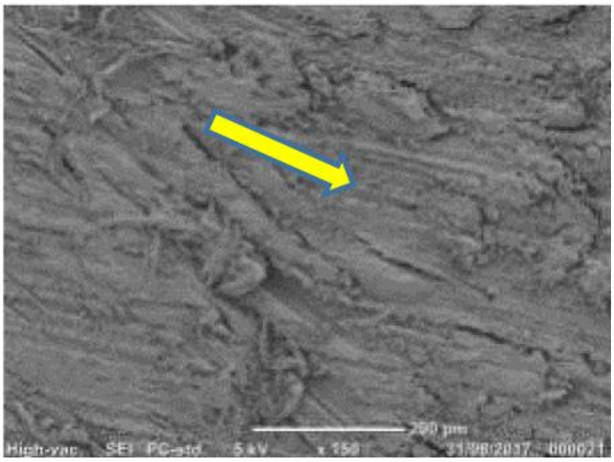
b) peel-off



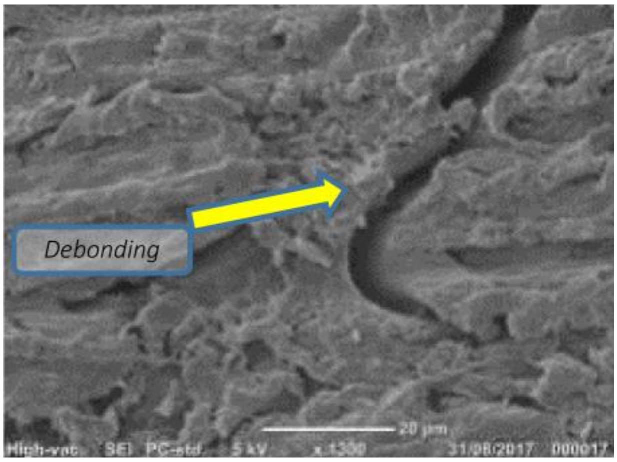
c) debonding



d) detachment



e) peel-off



f) debonding

Fig. 12. Micrographs of JFRE Surface after the Testing At Normal Orientation.

According to the results and the surface observations, the wear behaviour of the composites various according to the orientation of the fibre mat. Figure 13 illustrates the wear behaviour of the JFRE in a different orientation. In the case of the normal orientation it is proposed that high material removal will take place and weak surface exposed to the shear. In the case of the parallel orientation, an individual layer of the composite will carry the load separately which will result in high removal of material in the resin region and the fibres will be damaged as well.

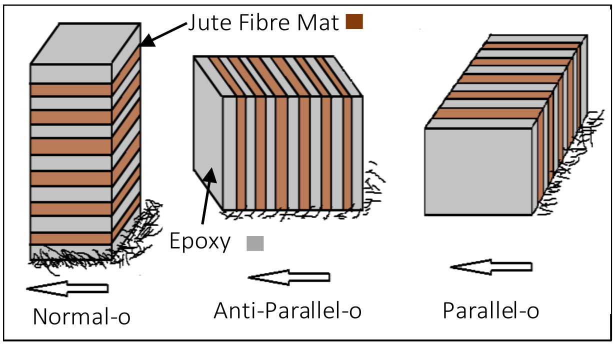


Fig. 13. Illustration Showing the Wear Mechanism of the JFRE at Different Orientations.

Better wear performance of the composite can be achieved when the mats are in the perpendicular direction to the sliding direct and parallel to the applied force. In this orientation, the film can be generated on the composite surface which protects the composite and generates high resistance to the shear. The only issue with this orientation is the high friction coefficient which required some solid lubricant in the composite to overcome it.

6. COMPARISON WITH PREVIOUS PUBLISH WORKS

The current results of jute fibre reinforced epoxy composites are compared with the previously published work in term of the specific wear rate. The high performance of the JFRE in Anti-parallel orientation is selected for the comparison. Previous results of different natural and syntactic fibre reinforced composite were extracted and plotted in Fig. 14 associated with the current results.

The figure shows that the current results of the JFRE are very competitive with other natural fibres such as kenaf and sisal. Also, jute fibres can replace glass fibres for epoxy composite from the tribological aspect. Bamboo fibres showed very bad results due to the poor interfacial of the bamboo fibres with the epoxy since in that work there is no treatment has been done on the fibres.

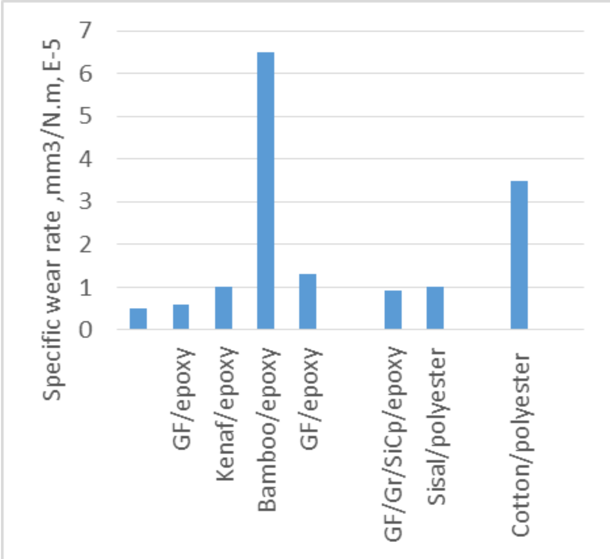


Fig. 14. Current And Previous Specific Wear Rate For Different Fibre Composites Arhaim, Shalwan [36], Nirmal, Hashim [37], Basavarajappa and Ellangovan [38], Xin, Xu [39], Hashmi, Dwivedi [40].

Cotton fibre/polyester composite has very poor wear results since the heat generated by the friction was very high, the temperature reached above the T_g of the polyester and led to decomposers of the material.

7. CONCLUSIONS

In this report, the fabrication of the jute fibre reinforced epoxy composites was explained. The tribological experimental data was reported for different orientations of the JFRE. The surface observation was conducted on the worn surfaces of the composites. The main findings of the works can be listed as follows:

- Fibre orientation has the very significant influence on the wear and frictional performance of jute fibre reinforced epoxy composites
- Sliding distance control, the running in and steady-state wear behaviour of the composites especially when the composite was tested in parallel and antiparallel orientations.
- Wear resistance of the composites found to be better in the antiparallel orientation followed by parallel and then normal.
- Jute fibres gave very promising results to replace glass fibres for the same composites at the same operating conditions

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