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Adhesive wear and frictional behavior of Bamboo /Epoxy composites under dry contact conditions

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Abstract

The reduction of harmful materials is became an interesting field for many researchers. In addition, the low cost of reinforced composite materials and the production of environments were the main reasons to improve the mechanical and tribological properties of thermoset composite materials, in this study a tribological test was conducted on selected materials (neat epoxy and bamboo reinforced epoxy). The adhesive wear and frictional performance of both materials are studied. The wear performance and the friction coefficient of bamboo reinforced epoxy have been decreased as the neat epoxy. Furthermore, the roughness profile and microscope results were mentioned that the natural fiber has high mechanical and tribological behavior.

Keywords: Composites, friction & wear behavior, tribological properties, reinforcement.

1. Introduction

The global demand on conventional materials consumption such as iron, copper, silver and steel is gradually decreasing due to their high manufacturing costs, high density, non-renewability, low properties, etc. In the last decade, researchers and scientists were working out to develop a new material which may has better properties if compared with conventional materials [1]. The tribological behavior of materials is one of the most important properties that should be considered for many mechanical designs. Tribology studies friction and wear behavior of any components. [2,7]. Nowadays, there is huge demand on low wear resistance and good friction coefficient materials. This led many researchers and scientists to conducted many studies in various materials. One of the most common materials has been found is the composite material which has good mechanical and tribological properties [3]. On the other hand, in the last few years there is a big awareness towards the environment of using non-renewable, polluting, non-recycled, and synthetic materials, this have forced the engineering to select a renewable, non-polluted, and recycled materials [4]. One of the most common martials have been used to make a composites is fiber such as natural/synthetic fibers because fiber has high mechanical and tribological behavior [5]. Moreover, fiber has low density, low manufacturing cost, flexibility, easy to deal with, light-weight, etc. Natural fibers such bamboo, jute, banana, kenaf, linen, oil palm and sugarcane have been used as a fillers (reinforcement) in different materials such polymers to meet the requirements for many applications. For this interest many studies were done trying to understand the potential properties of reinforcing fiber into polymers [6]. Furthermore, natural fibers have become highly attractive to the industries over the synthetic fibers due to their better mechanical properties, renewability, environmentally friendly, low density, low manufacturing costs, flexible, light-weight, etc., [7]. The tribological behavior of the selected materials was studied in term of adhesive and abrasive wear mode. Recently, bamboo fiber was attracted to manufactures due to its low cost, availability, renewability and flexibility [8]. Furthermore, bamboo reinforced epoxy has high tribological behavior and good mechanical properties. The adhesive wear and frictional performance of bamboo fibers reinforced epoxy were studied by many researchers as bamboo has big interest in the industry [9, 12].

2. MATERIAL PREPARATION AND EXPERIMENTAL PROCEDURE

2.1. PREPARATON OF THE FIBRES

For this study, manually method been attempted to extract the bamboo fiber, because some researchers proved that, manually extracted fibers show improved fiber density properties if this compared with chemical method to extract the node parts and thin layers of bamboo's bark been cleaned manually, only the cylinder culm has been left which contains the bamboo fibers [10]. Later, the cylinder culm was peeled down to gain the strips with different lengths and different diameters as shown in figure 2.1, [11]. After that, the strips were soaked in the water for three days at room temperature to make the strips soft then the strips were soaked again in solution of NaOH 6% for 24 hours to clean the tissues and dusts from the fibers as shown in figure.2.3-(b),[12,22]. Then, the strips taken out of the water and quietly beaten by hand on solid slab to separate the bamboo strips and loose some of the unwanted tissues as illustrated in figure.2.1, [11,13, 19].

Fig. 2.1 Illustrate the bamboo strips

2.2. PREPARATION OF THE COMPOSITE

In the recent years, there is incorporation of materials that have been used to meet high technical purposes [14]. Natural fiber presents high mechanical properties that will contribute to improve the polymers properties if they reinforced to make a composite [15]. For this study the resin was used is the liquid Dow Epoxy Resin (DER) 331 with density 1120 kg/m3 and dynamic viscosity is 13.5 cp. A 70 mm length, 10 mm width and 10 mm depth steel mould was used for fabrication of the composites and the neat epoxy samples; the mould was manufactured and it was taken out of the water and quietly beaten by hand on solid slab to separate the bamboo strips and loose some of the unwanted tissues as illustrated in figure.(2.1-a-) and (2.2-b-), [15, 20].

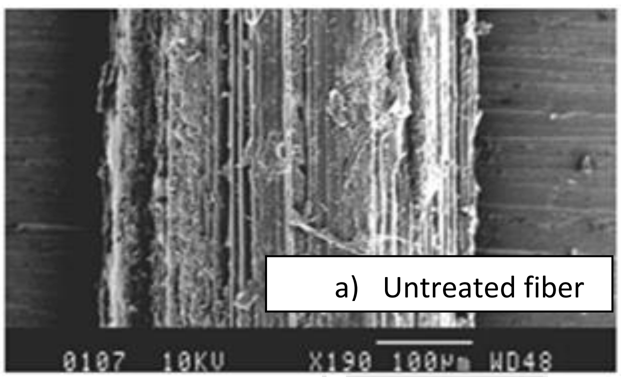

Fig2. 2: Shows untreated fiber strips.

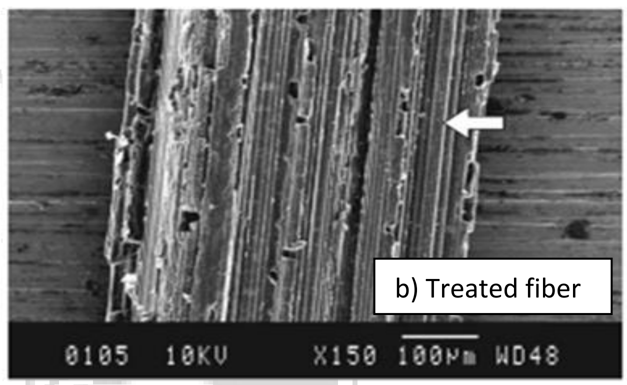

Fig2. 3: Shows treated fiber strips.

In addition, epoxy liquid mixed with a hardener with 1:3 respectively. Then the liquid gently melted down into the mould. Prior to this, a wax liquid has been rubbed on the inner surfaces of the mould, in order it will be easy to pull off the epoxy block out of the mould. As the mould was completely filled with the liquid then it was placed into a vacuum room (MCP 004 PLC) for 24 hours at room temperature (25°C) [16,19] Later, the epoxy block have been removed from the mould and cut into three equal specimens that are ready for the experiment.[17].

2.3. OPERATIONAL PARAMETERS

There are many studies which have been conducted to study natural fibers in term of tribological behavior [18, 20]. The parameters such speed, load and time were used in this study were adopted for various papers that recommended these parameters for the tribology of natural fiber. The neat epoxy specimens and bamboo/ epoxy specimens were subjected to the same parameters to figure out the different for both specimens.

2.4. EXPEREINETAL PROCESDURE

Tribological test for neat epoxy and bamboo/epoxy composite were conducted using a tribology machine. Basically this machine can generate two different experiments; block on desk or block on ring, for this study will use block on desk configuration as it has been recommended by the researchers. The load cell was used to measure frictional forces and digital mixed with hardener by 1:3 respectively. Prior to this, fiber strips were gently fitted into the mould at 40 % of the cavity. Then it is slowly poured the mixture over the fibers on the mould. A small needle was used to push the liquid down (i.e. using a small needle to ensure the resin filled the area underneath the fiber). Once the mould was completely filled then was left in the vacuum room (MCP 004PLC) for 24 hours at room temperature (25°C), in which the air bubbles between fibers will be recovered and also to cure the mixture parameters is illustrated below (Table.2.1).

NO	LOAD N	SPEED m/s	TIME min
1	10	1	45
2	15	1	45
3	17	2	45
4	20	2	45
5	27	3	45

Table.2.1: presents the operational parameters

Friction sensor is combined with the load cell capture the frictional readings every second. To start the test, first, the specimen was fixed in the specimen holder tightly to ensure it has full contact with the counter-face, and then the desired speed and load were set up using the control panel. On the tribology software a new folder was opened to save the frictional reading for each test. A timer was used to measure the time for each test (45 minutes). Once the machine was run a thermo image camera was used to measure the interfacial temperature between the specimen and the counter-face during the test. Prior to this, the counter-face (stainless steel) must be polished by using smooth silica carbide abrasive paper or smooth sand paper (i.e. any dust or scrap from pervious works will have big change on the current results). Adhesive dry sliding tests were done at room temperature (25 c) and under different loads and different velocity too. A measurement of all specimens' weight before and after each test was done using very sensitive scale. The specific wear rate was calculated using the equation (1). $\boldsymbol{Ws} = \frac{\Delta V}{FnD}$ (1).

Where:

Ws = Specific wear rate (mm^3/N m),
ΔV = Volume difference (mm3),
Fn = Normal applied load;
D = Sliding distance (m).

The friction coefficient was determined using the equation (2) below. The same procedure was conducted for each specimen and takes the same measurements.

$$\mu = \frac{measured\ firctional\ force}{normal\ applied\ load} \quad (2).$$

2.5 Wear performance.

2.5.1 Weight Lost.

The wear performance of neat epoxy (NE) and bamboo epoxy as a function of weight lost vs. sliding distance at different counter-face sliding velocities subjected to different applied normal load is shown in Fig.2.4. It can be observed from the figure that, the weight lost is significantly is sensitive to different sliding speed as well to different applied load (i.e. the weight lost increased as the speed increased or the load increased). In details, the increase in weight lost for the neat epoxy is entirely more as a result of increasing speed, load or sliding distance. This shows how the reinforcement the epoxy with the bamboo fibers can improved the weight lost performance of the polymers composite.

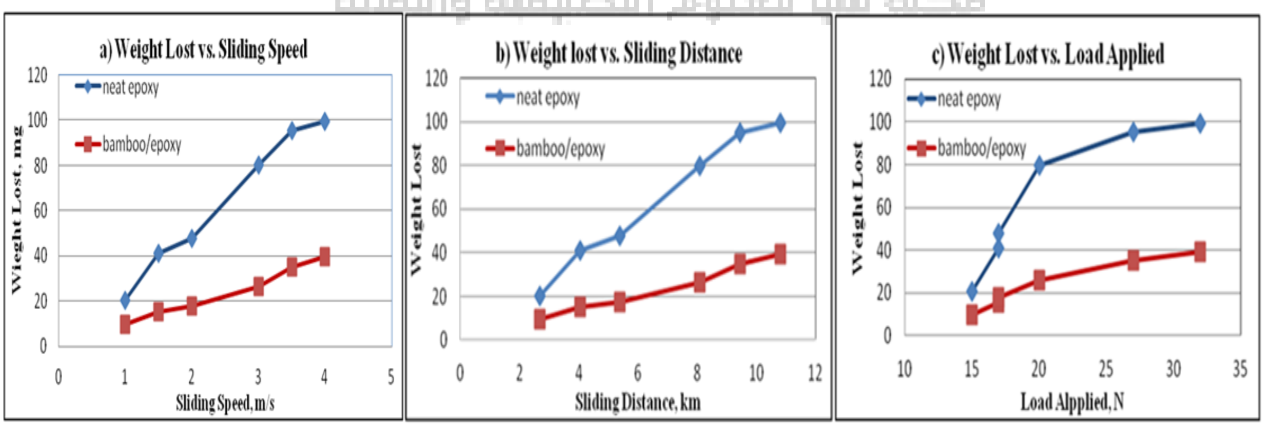

Fig2.4: The relationship between weight lost and sliding distance, sliding speed and applied load(NE).

2.5.2 SPECIFIC WEAR RATE.

On the other hand, the specific wear rate (SWR) was studies for both neat epoxy (NE) and bamboo epoxy with sliding distance at different counter-face sliding velocities subjected to different applied normal load is shown in Fig. 2.5. From the figure it can be seen that, the relationship between the SWR and sliding distance, sliding velocity and applied load is inverse relationship (i.e. as the sliding speed was increased the SWR decreased and the same with applied load and the sliding distance). In details, the increase in sliding distance, applied load and sliding velocity for BFRE composite gives lower SWR if compared with the SWR of NE results, as shown in figure.2.5. This entirely shows the improvement in SWR of the polymers (epoxy) as it has been reinforced with natural fiber (bamboo).

2.6 FRICTION PERFORMANCE.

The frictional performance of neat epoxy and bamboo fiber composite as a function of sliding distances, normal applied load and sliding velocity is plotted in figures below. The figures indicate that there is an improvement in friction coefficient for the bamboo fiber composite while was tested to different sliding velocity, normal applied load and different sliding.

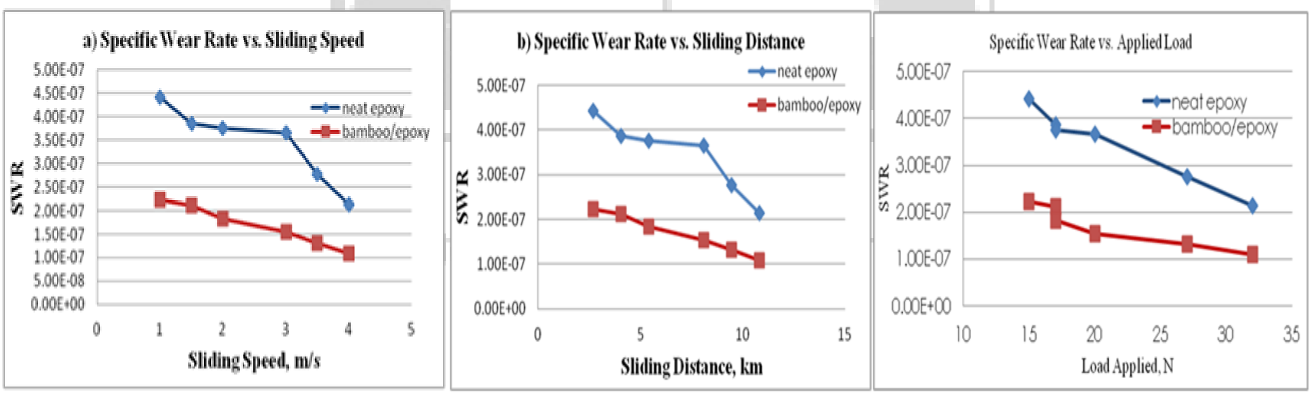

Fig.2.5. The relationship between specific wear rate (SWR) and sliding distance, sliding speed and applied load (BFRE).

2.6.1. FRICTION PERFORMANCE OF NEAT EPOXY.

In details, the neat epoxy tests show a gradual increase in frictional values as results of increasing the sliding distances and sliding velocities too. This is as a result of material lost from the specimen (weight lost) that becomes higher at high sliding speed. This has led to possibility to exist a new material between the specimen surface and the counter-face, this material calls the adhesive wear; also this phenomenon is known as "cold welding’ or ‘rupture’ that caused by an uneven specimen surface. This a new body “material” has led to coarse contact condition between the counter-face and

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the specimen that result in an increased in the friction coefficient between neat epoxy and the counter-face as shown in Fig.2.6. On the other hand, the contact conditions in this test are considered to be dry conditions as there is no lubrication been used for this test.

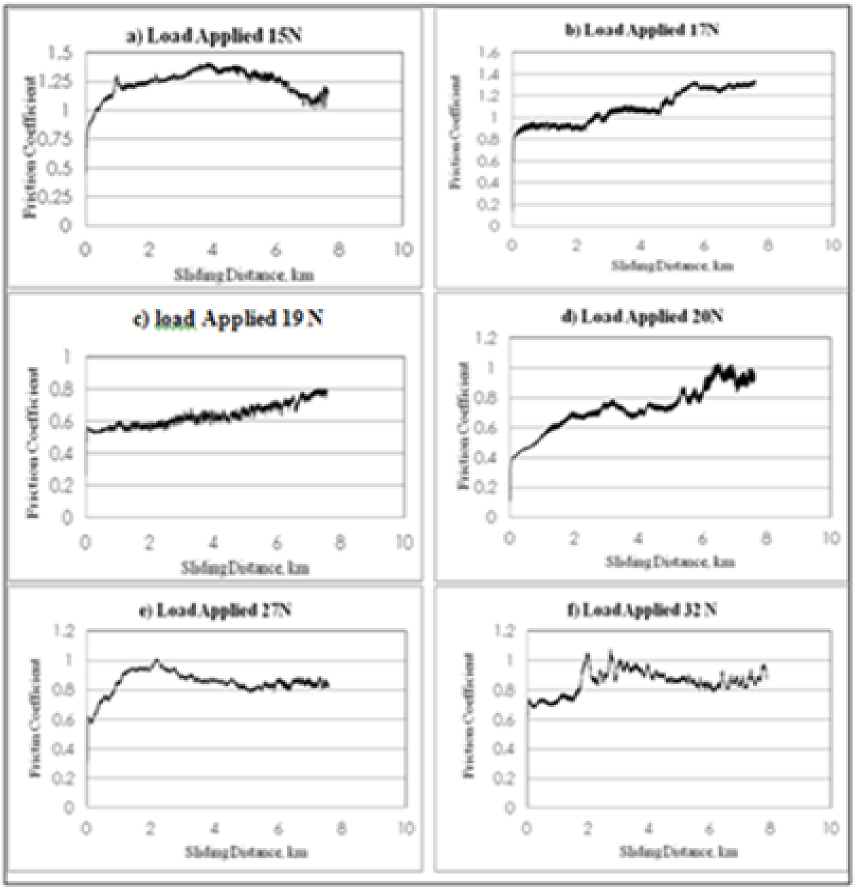

Fig.2.6. The frictional coefficient of neat epoxy

2.6.2. FRICTION PERFORMANCE OF BAMBOO RIANFORCED EPOXY

For the bamboo epoxy tests, despite of increasing the load applied, sliding speed and sliding distance, there was slightly decreased or either steady level of the frictional values. This because in this case the material lost or the third body “adhesive wear” is mixed between bamboo fiber and epoxy resin, that has an effect on the contact condition and let to not fully dry conditions (i.e. the adhesive wear contains some of bamboo which worked as a self-lubrication and led to steady level of friction values). So that helps to keep the frictional values at steady level or either have slightly decrease as it can been seen in Fig.2.7 below.

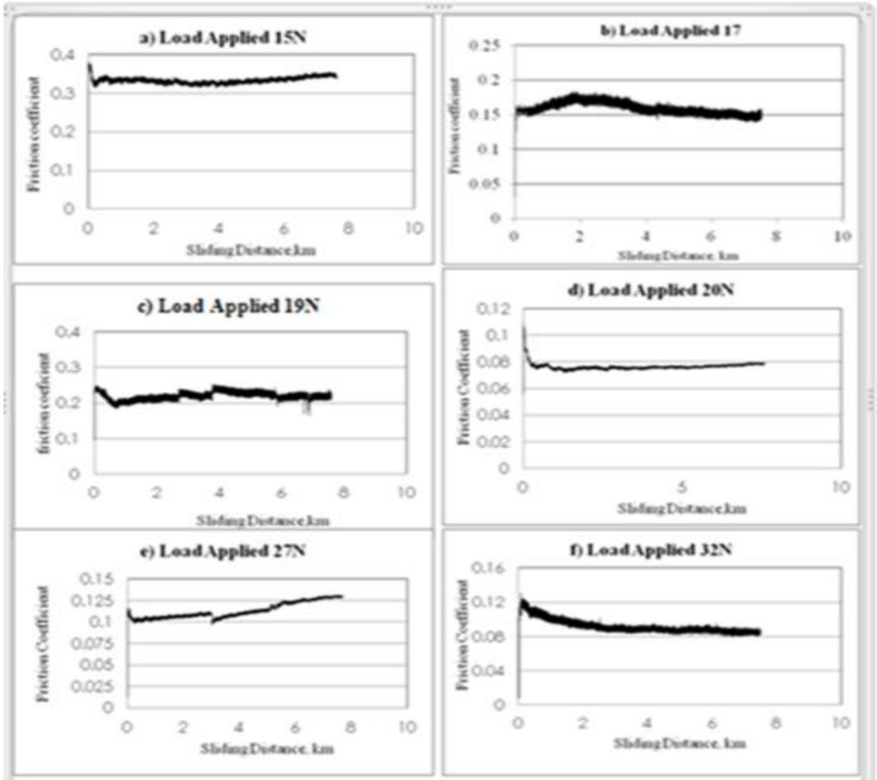

Fig.2.7. The frictional coefficient of bamboo reinforced epoxy.

3. MIRCOSCOPE IMAGES.

The microscope images of the worn surfaces' morphology that have been subjected to different operational parameters will be explained in several figures. From Fig.3.1 can be seen the way that the bamboo fibers were arranged in the epoxy matrix. In addition, a close visual view indicates that, the bamboo fire has a full contact with the interfacial surface which will help to obtain accurate outcomes.

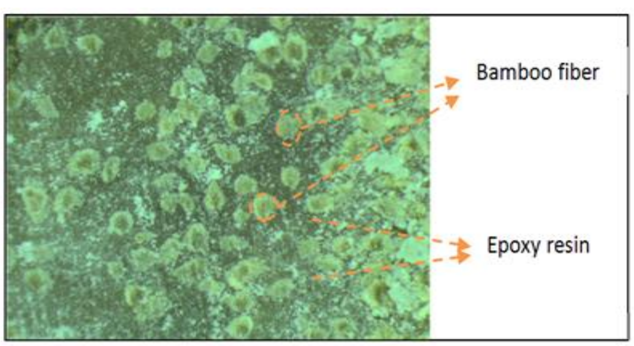

Fig.3.1 The distribution of fiber through the epoxy resin

A close visual examination of Fig.3.2 indicates that, at 1 m/s sliding velocity and 15N load there was a very small deformation occurred to the BFRE composite surface that associated to the low operational parameter. However, as the sliding velocity was increased to 2 m/s as well as the normal applied load to 17 N there was adhesive wear associated with wear debris scattered on the resin region, as it can be seen in Fig.3.3. Moreover, there seems no damage associated with the fibers region.

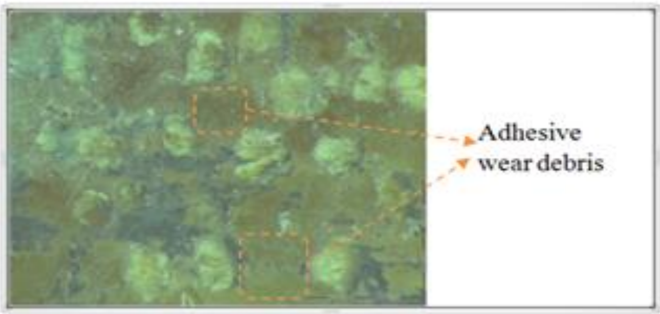

Fig.3.2 Show the effect of low sliding distance operational and low applied load

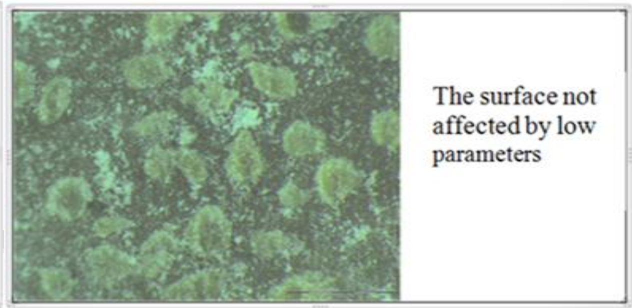

Fig.3.3. The effect of increasing the parameters.

On the other hand, as the sliding speed was increased into 3 m/s and the normal applied load to 20 N, there was clear sight by microscope of adhesive wear on the tested specimen associated with wear debris appeared on the resin region, as it can be noticed in Fig.3.4.

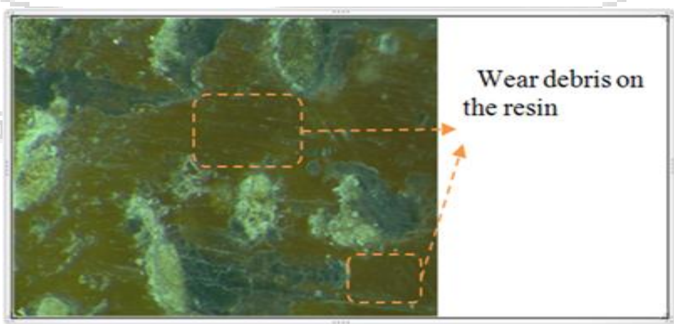

Fig.3.4. The effect of high sliding velocity and high applied load.

Moreover, the load, there was evidence that, there was still adhesive wear appeared on the specimen surface and on the fibers region too, as in Fig.3.5.

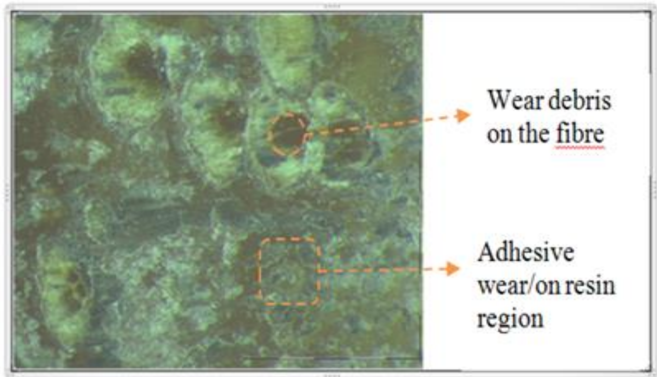

Fig.3.5. Illustrated the effect of high operational parameters.

When the test was performed at 4 m/s sliding velocity and 32 N normal applied load the effect is illustrated in Fig.3.6. As it can be noticed in the microscope image, there is a torn and loose in bamboo and a small breakage at the specimen edge. Furthermore, the wear debris scattered on the resin region as a burned lyre. This shows the effect of high operational parameters on the BFRE composite.

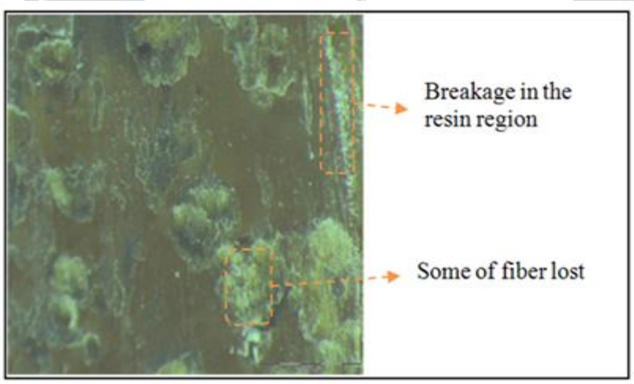

Fig.3.6. The effect of high operational parameters.

4. ROUGHNESS PROFILE.

4.1. ROUGHNESS PROFILE OF NEAT EPOXY.

It can be seen from figure.4.1 that, the roughness values of selected NE samples are quite similar. As the speed, applied load and sliding distance were changed, the roughness values of NE are changed too, for example, in Fig.4.1. a. The sliding distance was 1 m/s and the load applied was 15 N in return the roughness value was 1.763 µm, however, in Fig.4.1. e. The sliding speed was 3.5 m/s and the load applied was 27 N and the roughness is 2.734 µm. This can be explained as, there was a small deformation in the NE surfaces associated to the low in sliding velocity or applied load "different operating parameters", however, as there was an increase in the sliding velocity and the applied load the deformation become more and more that gives different roughness values.

Fig.4.1: The roughness values of NE samples.

4.2. THE ROUGHNESS PROFILE OF BAMOOB EPOXY COMPOSITE.

The roughness profile of BFRE composite is presented in Fig.4.2. In detail, it was noticed that, the roughness values of the BFRE composite were significantly high if they compared to the NE ones. In detail, in Fig.4.2 a the sliding speed was 1 m/s and the applied load was 15 N in return the roughness is 2.942 µm , in contrast, at the same parameters for the NE the roughness value is 1.763 µm. Moreover, the sliding speed was increased to 3.5 m/s as in Fig.4.2.e with an increased in the load applied to 27 N this parameters gave a roughness value of 8.257 µm, but for the same operational parameters applied on the NE gave roughness 2.734 µm only. For this significant change in the roughness values, there are two potential reasons. First, as the BFRE samples were subjected to high temperature before the tests that may lead to increase the rigidity of the samples surface, in order, when the composite surface jostles with counter-face, that caused higher deformation in the contacted surface then gives higher roughness values if compared with NE values. On the other hand, the increase in sliding velocities or the normal applied loads has significant effect on the roughness values (i.e. as the operational parameters increased the roughness values increased too). This can be highlighted; factors such as sliding speed, applied load and sliding distance have an important effect on the roughness profile.

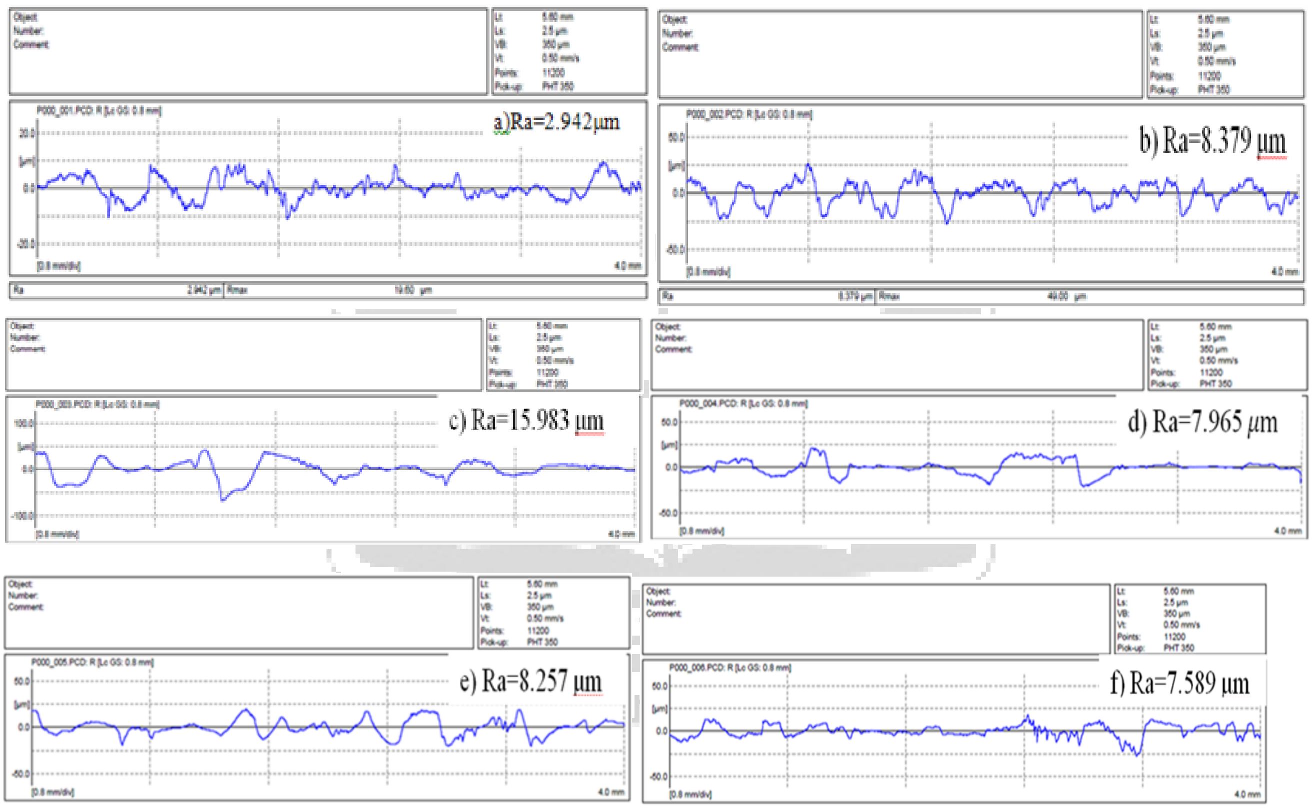

Fig.4.2: The roughness profile of bamboo fibre reinforced epoxy.

From the above it can be concluded that, the roughness values of BFRE were higher than the NE one. This was related to, first the BFRE composite had particular treatment before the tests, second the reinforced the bamboo into polymer has improved the strength of the polymer that gives higher roughness values. Furthermore, different operational parameters have entirely impact on the roughness profile of the materials.

5. CONCLUSTION.

Some points are concluded as following:

1- The mechanical properties of the composite has been improved as it was reinforced with bamboo fibre, in return, the composite can withstand heavier loads.

2- The adhesive wear of polymer has been improved due to reinforcement the neural fibre into the polymer matrix (i.e. the wear lost has decreased as well as the specific wear rate).

3- There was significant reduction in friction coefficient as the epoxy reinforced by the bamboo fibres. This is because the distribution of the natural fibre (bamboo) in the polymer matrix, that helps to reduce the friction between the counter-face and the specimen surface (i.e. the bamboo worked as self-lubrication.

4- Plastic deformation was sighted for the worn surface of the composite at low sliding velocity and low applied load. However, for BFRE composite, a breakage in the resin region was indicated as the specimen was subjected to higher operational parameters which have significant effect on the wear resistance behavior.

5- The roughness values of the BFRE composite were affected by the operational parameters (i.e. the roughness profile were varied as the sliding velocities changed as well as the applied loads.

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