

## Tribological and mechanical properties of biobased reinforcement in a friction composite material

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### ABSTRACT

This work presents the function of biobased ingredients (palm fiber) as reinforcement in brake pad materials. Reinforcement in brake lining improvise wear stability, wear resistance and friction optimization under a dynamic set of operating variables such as braking force, sliding speed, braking duration and braking temperature. The effect of palm fiber on physical, mechanical and tribological properties of brake pad composite is evaluated. The percentage of palm fiber is gradually increased from 2% to 12% at an interval of 2% as an alternate of rockwool fiber by varying the pressure and speed in a pin on disc tribometer. By increasing the pressure, 8% and 10% shows high friction stability at all speeds. The results show that the raise in the palm fiber quantity increases the hardness, specific gravity and heat swell and the properties, loss on ignition and porosity decreases. The SEM descriptions of the composite indicated that the smaller micro voids occurred in the sample having low palm fiber. Weight gain in the composites were also observed by exposing them in salt water, water and oil.

**Keywords:** Palm Fiber, Wear, Friction Stability, Brakes, SEM.

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### 1. INTRODUCTION

The Intelligent product systems (IPS) suggests that commodities of service consist of substances that can be endlessly reused in technical cycles and commodities of consumption consist of substances that can be securely introduced into biological cycles [1,2]. Most parts of a car can potentially be reused as technical cycle. The brake pads are true commodities of consumption and the constituents used in brake pad must be selected positively to reduce their effect on health and environment [3-8]. Because of this, the entire world is concentrating on developing bio materials with equivalent mechanical and tribological properties, which is the main interest for this work.

Brake operates in hot and cold environments, on and off paved roads, both wet and dry conditions, with frequent stops and with different kinds of control system. The feature of friction materials is it can may perform good under one set of conditions but inadequately under another. Therefore, the development of commercial brake pad with acceptable performance is challenging [9,10]. A brake system must provide steep and stable friction, vibration free performance, low wear and noise. These properties can be obtained by using more than 10 ingredients in a single brake pad. Each constituent significantly contributes towards effective tribological properties [11].

Brake pad materials are essentially constructed by four components: a binder, filler, friction modifier and reinforcement. The main task of the binder, holds the components of a brake pad together and to prevent its constituents from crumbling apart [13-15]. Fillers are essentially used to reduce the overall cost of the material and partly to alter the brake pad properties. The role of abrasive in the brake pad is to control the friction level during braking and cleaning the glaze on the disc at the friction interface. Solid lubricant in brake pad plays the role of developing the friction film on the brake drum surface which influence the brake performance such as brake drum wear, torque variation, stopping distance and noise propensity [16].

Palm fiber have attractive performance to cost ratio has stimulated the idea of exploring their possible incorporation

into brake pad composite materials. Palm fiber have high compressive strength, they are important determining factor in brake pad to withstand the sudden cracks. It possess good thermal conductivity, low density and improved ductility [30]. In south Asia enormous amount of Palm fibers are obtainable and clarity about the frictional properties of palm fibers are not available. Palm fiber is enriched with Potassium, Selenium, Silica, Copper, Iron, Sodium, Calcium and Manganese equally like asbestos [23-25]. Consequently, it is a viable alternate for asbestos in friction material. Its low wear rate and high hardness along with low ash content made it is a suitable alternate for friction pad material. Hardness, thermal stability and dielectric constant of the composite materials can be augmented. It is the muse behind this work to examine the impact of palm fiber on the frictional properties.

The brake pads in use now are having environmental and toxicological uncertainties which are slowly started to be recognized by the industries. This work provides substantial evidence to use bio-based composites in brake pads.

## 2. PREPARATION OF FRICTION MATERIALS

Six different composition were prepared for friction test is shown in table 1. The specimen's various parameters like friction stability, hardness, heat swell, specific gravity, porosity, loss on ignition are analyzed by pressing by using two moulds of dimensions 150 X 150 X 3 mm and 8 X 32 mm. Analytical balance instrument is used to measure the constituents to an accuracy of 0.1 g. The constituents are blended at the temperature of 30°C at the speed of 4000 rpm for a time lapse of sixteen minutes in electron EBR 100. A uniform mixture is prepared by a chronological mixing procedure. The procedure is stated as follows :

The fibers were initially added to a blender to make it as a large quantity to improve the mixture volume. The fibers were blended for 10 minutes then the filler and friction modifiers. For another 3 minutes the blender was made to run at the same speed by adding the filler materials. Hence the total mixing time for each composite is 16 minutes [26-29]. 500 grams of the blend is placed in a preheated die to temperature of 180°C and pressed with a load of 160 kgf/cm<sup>2</sup> using a hydraulic press of 120-ton capacity for 6 minutes. During this process to remove the volatile materials five “breathing” time was allowed. The prepared mold was cured for 2 hours each at 140°C, 160°C and 180°C respectively, thus the porosity and thermal expansion of the blend reduces.

**Table 1:** Formulation of friction material by varying palm fiber content

Raw Materials (% in Weight )	2 PF	4 PF	6 PF	8 PF	10 PF	12 PF
Cardanol Resin	15	15	15	15	15	15
Phenolic Resin	5	5	5	5	5	5
<b>Palm fiber</b>	<b>2</b>	<b>4</b>	<b>6</b>	<b>8</b>	<b>10</b>	<b>12</b>
<b>Rockwool fiber</b>	<b>10</b>	<b>8</b>	<b>6</b>	<b>4</b>	<b>2</b>	<b>0</b>
Steel fiber	8	8	8	8	8	8
CaCO <sub>3</sub>	20	20	20	20	20	20
Alumina, Cashew dust, <sup>3</sup> Calcium Silicate, Vermiculate, Silicon	32	32	32	32	32	32
Antimony trisulfide, Graphite	8	8	8	8	8	8

### 2.1 Testing

DUCOM W and F monitor was used to conduct the test and WINDUCOM data acquisition system is used for the all testing at ASTM G-99 standards. With 0.12 m dia grey CI as the counterpart.

The machine is an orthodox tribometer with a planar rotating disc and a pin with dead weight used for testing. The test was conducted by changing the load and sliding velocity continuously. The output parameters from the test are the friction coefficient and the specific wear rate.

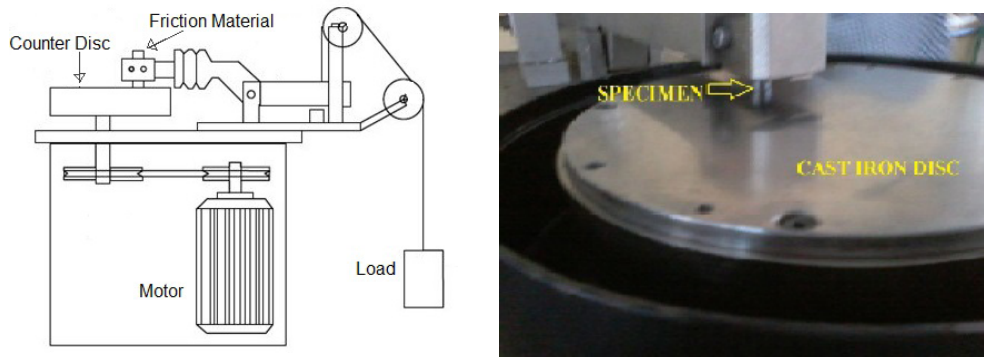


Figure 1: (a). Win Ducom wear and friction tester (b) Closed view of composite friction

A single composite material measures dia 8 mm and 32 mm length. The disc was conditioned for every test by grinding to obtain smooth surface. The testing conditions are

Parameter	Range
Load	20 N to 40 N
Velocity	2 – 4 m/s
Distance	6 – 31 km
Time	2100 sec
Speed	300 – 700 rpm

SEM analysis was carried out using the model EVO MA15 to find the blending of friction materials. At standard atmospheric condition the impact of the friction material on the ecosystem is measured at ASTM D 570-77 standard with distilled water, brine solution and Society of Automotive engineers 20W – 40 lubrication oil.

Specific wear rate depends on applied on to cause wear, it is volume loss per unit meter per unit load. Its unit is (m<sup>3</sup>/Nm). The specific wear rate is calculated by equation 1.

$$\text{Specific Wear Rate} = \frac{V_i}{F * s} \tag{1}$$

Where, V<sub>i</sub> is the wear volume, F is the normal load and s is the sliding distance.

The friction force (F) was observed and calculated for each pass and a average was considered for the total number of passes for each wear test, in order to determine the friction coefficient (μ).

The average value of coefficient of friction (μ) of composites was calculated from the following expression equation (2).

$$\mu = \frac{F_f}{F_n} \tag{2}$$

Where, F<sub>f</sub> is the average friction force and F<sub>n</sub> is the applied load.

Friction Stability is measured as a function of braking pressure and sliding speed by equation (3).

$$\text{Friction Stability} = \frac{\mu_{avg}}{\mu_{max}} \times 100 \tag{3}$$

Where, μ<sub>avg</sub> is the average friction coefficient and μ<sub>max</sub> is the maximum friction coefficient. Magnitude of percentage friction stability should be as high as possible and near to 100.

Hardness is calculated in ‘S’ Scale using a Rockwell testing machine. SAE J417 standard is used to measure hardness.

Specific gravity of the friction material was measured by the standard SAE J380. Heat Swelling was measured by SAE J160 standard. The process was repeated after heating the sample in oven at  $200 \pm 2^\circ\text{C}$  for 2 Hrs. The increase in thickness was noted as heat swell and percentage was determined.

For determining the mixing of friction materials, the composite friction surface of the samples were characterized and inspected using scanning electron microscope (SEM) model EVO MA15. With the intention of introspecting the atmospheric effect of the friction material, they were determined at room temperature and measured by ASTM D 570-77 standard with salt water and water and SAE 20w-40 oil.

### 3. RESULTS AND DISCUSSION

#### 3.1 Physical, mechanical and absorption properties

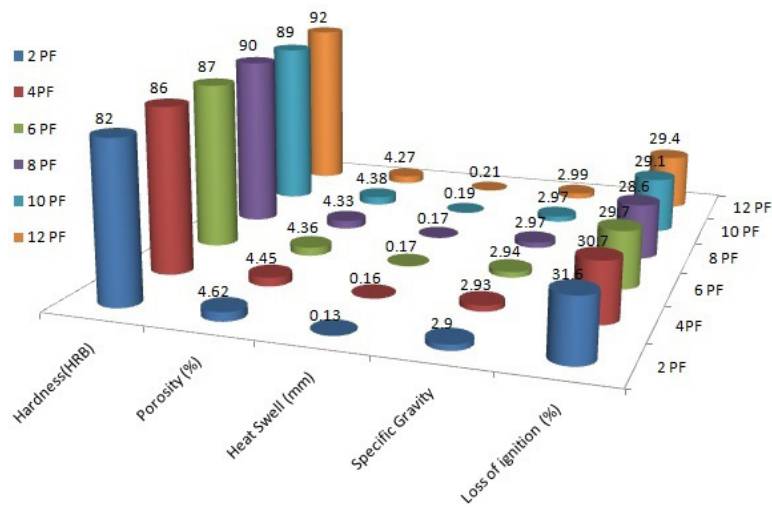


Figure 2: Properties of palm fiber material as a brake pad

Table 2: Physical, Mechanical and Absorption properties for palm fiber composite

SPECIMEN	2 PF	4 PF	6 PF	8 PF	10 PF	12 PF
Hardness (HRB)	82	86	87	90	89	92
Porosity (%)	4.62	4.45	4.36	4.33	4.38	4.27
Heat swell (mm)	0.13	0.16	0.17	0.17	0.19	0.21
Specific Gravity	2.9	2.93	2.94	2.97	2.97	2.99
Loss of Ignition (%)	31.6	30.7	29.7	28.6	29.1	29.4
Water Absorption (%)	0.212	0.21	0.209	0.205	0.2	0.204
Salt Water Absorption (%)	0.196	0.162	0.161	0.171	0.162	0.162
SAE 20w-40 Absorption (%)	0.182	0.194	0.204	0.18	0.181	0.19

The physical and mechanical properties of palm fiber loaded friction composite are presented in figure 2. Property such as porosity and loss of ignition (2 PF > 4 PF > 6 PF > 10 PF > 8 PF > 12 PF) decreased slightly and then increased, which is in tune to the literature range. In 8 PF and 12 PF due to higher content of palm fiber porosity decreases to 6.2% and 9.1% respectively. High porosity may cause premature wear and low porosity may lead to squeal [6]. The porosity must be lower than 5% for high friction composite material. If porosity decreases, specific gravity and hardness increases. Hardness increases as palm fiber content increases in the composite material. In 2PF loss of ignition (LoI) is high which indicates the pyroprocessing of friction material was incomplete. Materials having high LoI will have high porosity which leads to absorption of moisture content from the surrounding in turn it reduces the strength of the material.

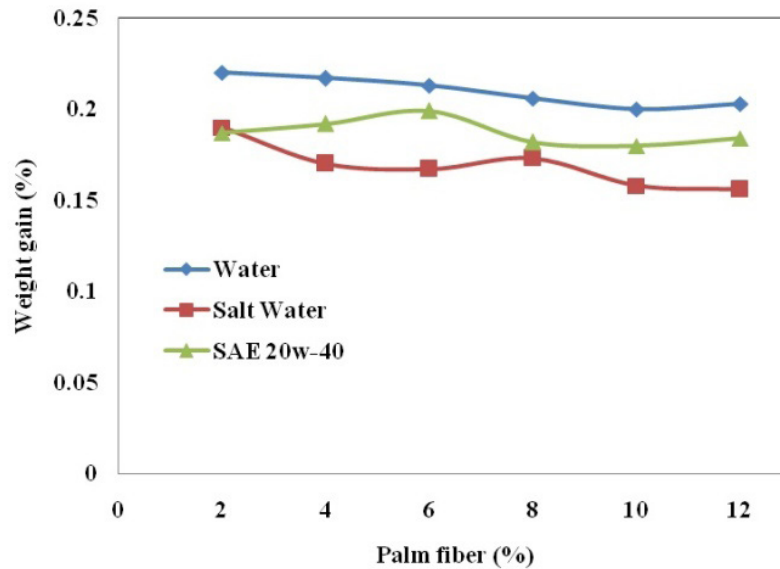


Figure 3: Absorption of palm fiber on water, salt water and lubricating oil

High content of palm fiber reduces loss of ignition. This may be due to low ash formation of palm fiber during heating. From the hardness, porosity, loss on ignition and specific gravity values none of the friction material was best in all properties. The water, salt water and SAE oil absorption tests for all compositions are presented in figure 3. 10 PF and 12 PF shows low absorption for water and salt water. For all composites absorption was in the range of 0.16 - 0.22 % which is in tune to the literature range[16,19].

### 3.2 Friction performance

Friction coefficient value should ranges between 0.35 - 0.45 for good performance of brake pad. Here performance is also considered by effect of varying speed at each pressure on friction coefficient. The graphical representation of the time dependency of coefficient of friction is portrayed in figure 4. The addition of palm fiber increases the value of friction coefficient. Increase in COF value for the composition of palm fiber higher than 8% relates to the particulate structure of palm fiber which reduces the binding strength [17, 31]. 6 PF and 8 PF revealed a stable friction coefficient throughout the test. This signifies that a stable friction layer was developed after a short period.

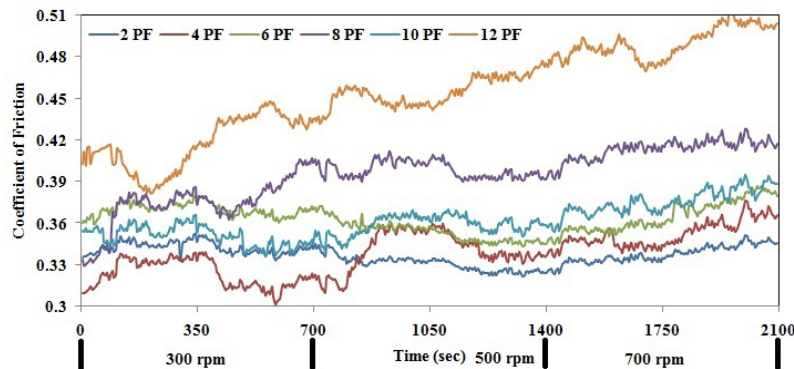
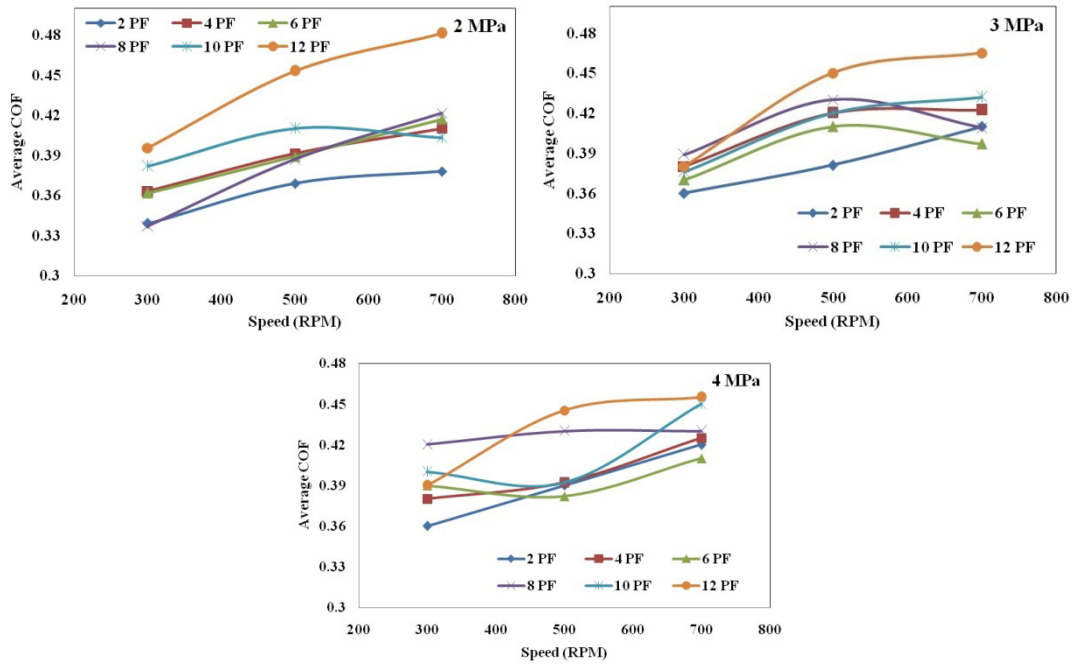


Figure 4: Effect of varying palm fiber composite for COF (2 MPa)

At the beginning sudden decrease of COF is observed for 12 PF which may be because the test was conducted under a unstable friction layer. The fluctuation of COF was higher in this time. On subjecting the 12 PF specimen for continuous run the COF values exceeds beyond 0.45, which tends to increase the wear rate. Similarly at high speed also the COF increases above the optimum range. For 2 PF and 4 PF, the COF fluctuates approximately 6% when the counter disc speed is increased by 200 rpm. This implies that the increase in rotational speed of the counter disc has a direct impact on the friction level for the similar composition of the reinforcement [26]. In 1000 – 1300 rpm range 6 PF shows sudden drop in friction coefficient. The sudden decrease of friction coefficient shows that the palm fiber separated from the binder resin while sliding at more rotational speed.



**Figure 5:** Friction performance of palm fiber composites under various speed and pressure (a) 2MPa (b) 3MPa (c) 4MPa

From figure 5, the performance of composite material based on COF is in the following order

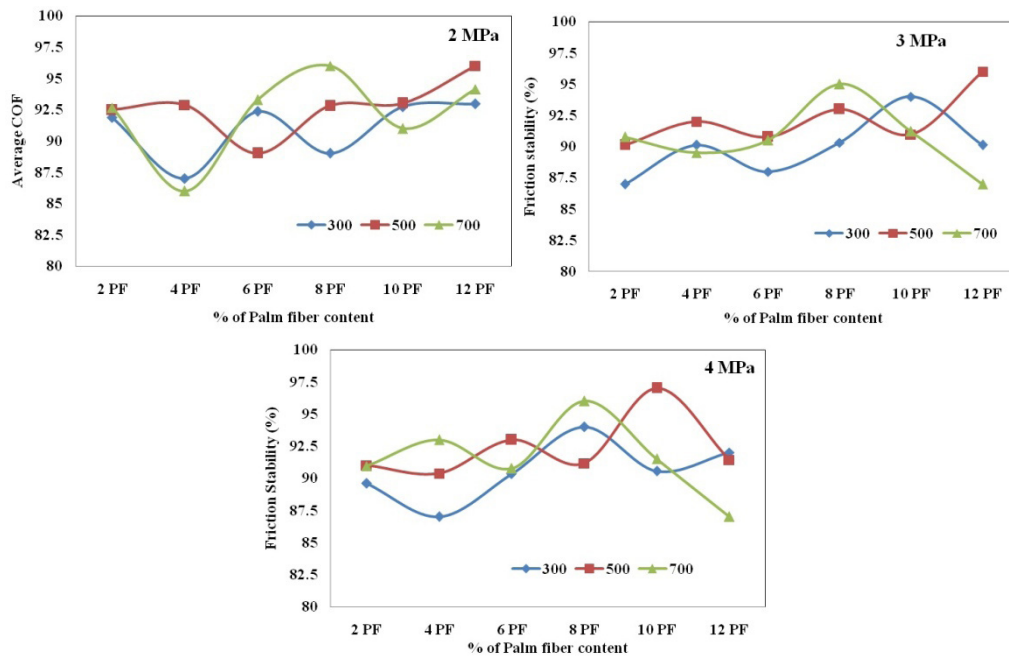
$$6 \text{ PF} \approx 4 \text{ PF} > 10 \text{ PF} > 8 \text{ PF} > 2 \text{ PF} > 12 \text{ PF} \quad \text{for } 2 \text{ MPa}$$

$$10 \text{ PF} > 4 \text{ PF} > 8 \text{ PF} > 6 \text{ PF} > 2 \text{ PF} > 12 \text{ PF} \quad \text{for } 3 \text{ MPa}$$

$$8 \text{ PF} > 4 \text{ PF} \approx 6 \text{ PF} > 10 \text{ PF} > 12 \text{ PF} > 2 \text{ PF} \quad \text{for } 4 \text{ MPa}$$

The best coefficient of friction observed for 6 PF, 8 PF and 10 PF may be due to high inclusion of palm fibers with limited quantity of rockwool fibers. This could also be attributed to non-formation of cold welding and rupture of asperities of the composite surfaces [26]. Hence, there were no isolated asperities captured between the sliding surfaces which could have resulted with a raise in the coefficient of friction to a required level. With increase in speed At high pressure (4MPa), up to 6 PF there is no significant increase in COF. It shows that the inclusion of palm fiber at low percentage does not play a role in creating an impact on COF. 2 PF and 12 PF showed excessive increase confirming its high sensitivity of COF for speed. For rest of friction material there was hardly any appreciable difference in the friction coefficient.

### 3.3 Friction Stability



**Figure 6:** Friction stability of palm fiber for various operating pressure and speed (a) 2MPa (b) 3MPa (c) 4MPa

Friction stability (FS) in terms of percentage of palm fiber content was shown in figure 6. For ideal material, FS should be as close to 100 as possible and friction coefficient range should be as small as possible. Generally, in such relations strictly regular trends are not observed and overall trends are to be considered. At all speed, FS of 4 PF was awfully poor and varied from 86 % to 92.5% for 2 MPa. But it shows better result when the pressure increased for all the speed. It shows that palm fiber reduces the friction fluctuation at higher pressure. It gives comfort to the driver, when the level of friction force is same at various conditions.

Composite with lower palm fiber content shows moderate performance towards FS and it is increased by increasing the fiber content. 10 PF showed better performance and FS was in the range of 91% to 98%. At high pressure and high speed (4MPa and 700 RPM) friction stability of 12 PF is 87.5 which is low compared to other samples. The reason for low friction stability of 12 PF is at high pressure and speed, it started to disintegrate which reduces the friction between the disc and the sample. For all composites, at lower rpm and pressure the performance was poor. This may be since under mild conditions, initially full contact cannot be established.

### 3.4 Wear Analysis

For automotive brake systems in friction materials, natural fiber plays a vital role in the wear of the friction material. This is because the heat generated during brake control raises the temperature of the friction material beyond the degradation temperature of the organic constituents [13].

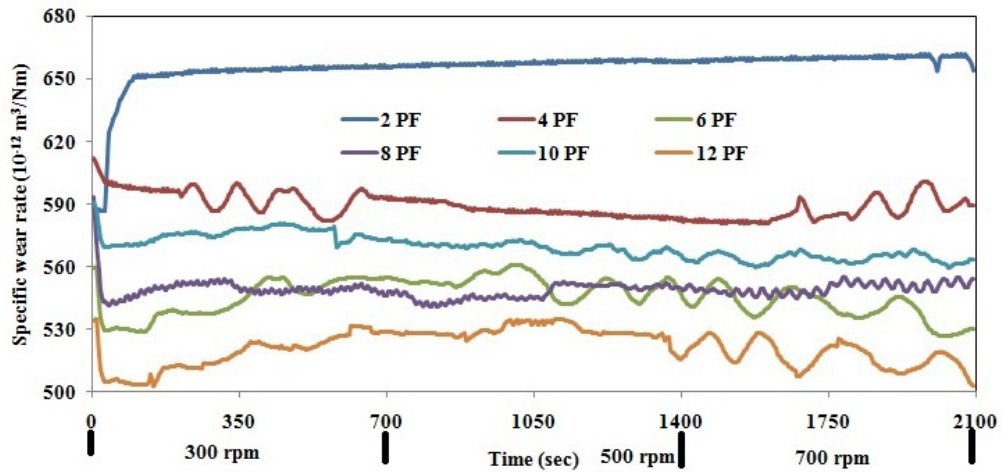


Figure 7: Effect of varying palm fiber for specific wear rate (2MPa)

The specific wear rate of the composite as a function of time is shown in figure 7. It was observed that increase in palm fiber content, reduces the weight loss and thickness loss of the composite indicating that presence of palm fiber was responsible for wear reduction in the composite material. For instance, highest wear rate were observed for 2 PF with higher rockwool content. Initially there is sudden decrease of specific wear rate is observed for all specimen which may be due to the test was conducted under a sudden impact of load on specimen.

In case of 6 PF and 12 PF lowest wear rate were observed. Although this is a good result in terms of wear resistance, this condition results in higher friction coefficient values which scratch the brake drum along the sliding direction. 8 PF and 10 PF showed the best wear performance suggesting a longer life. This may be since palm fiber is nearly equal in proportion to that of the steel and rock wool fiber which enhance frictional performance and suppresses the wear [26]. The improvement in the wear resistance of the material is results due to the characteristic wear resistance of palm along with rockwool fiber.

### 3.5 Sem analysis

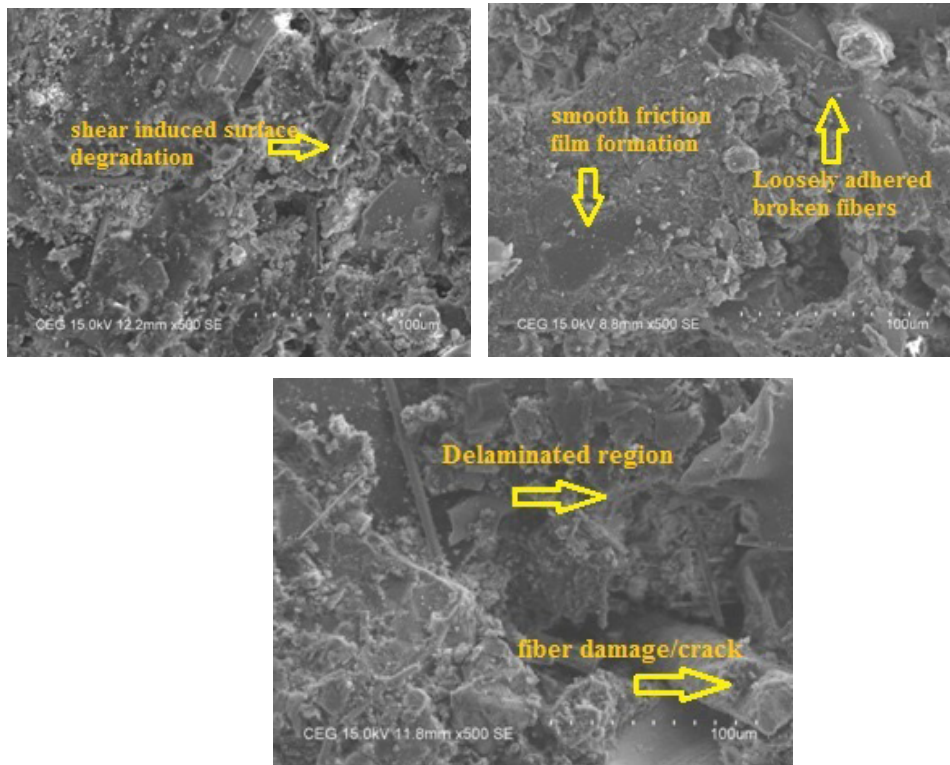


Figure 8: Worn surface showing morphology of the friction film on the brake lining after friction test (a) 6 PF (b) 8 PF (c) 10 PF



The SEM images of the sample's worn surface after the friction test are shown in figure 8. The SEM images of the specimens having higher content of palm fiber show that the composite containing higher palm fiber content, loosen up the fiber whereas when the palm fiber content is fewer, the fibers were tightly held up to the resin. Because of this the wear on the surface gets reduced. On 8 PF's surface we can notice the formation well leveled friction layer. It shows that the abrasive effect of the glassy phase is reduced by eliminating the sharpness of the composite [21].

In 10 PF severe pitting action and delaminated region, similar to three-body abrasive wear, clearly identified on the layer of the pad. These damaged fiber were detached by abrasion and sliding action caused by the contact with the counter steel disc at different sliding speeds and pressure. On comparing the 8 PF specimen with the 10 PF, it shows more amount of fiber damage. But in 8 PF freely clung broken fibers are noticed. Whereas in 6 PF specimen the changes in the surface is noticed as a thin film of solid. Friction between the surface and the CI disc results in high fiber disintegration. Small cavities were formed in the specimens having lesser palm fiber content. But, in the specimens having more amount of palm fiber content the size of cavities is larger. The reason behind this is that the palm fiber particles tends to loosen up. It shows the fiber coherence is more, in turn it increases the wear. In 6 PF the particles, which escaped the shear induced surface integration create the friction interface layer. This forms a ablative wear and found in overstrained and heated surfaces on the outer surfaces of brake pad materials.

#### 4. CONCLUSIONS

From the investigation, it was observed that friction stability of Palm fiber composite is high at high pressure, and therefore reduces fluctuation for continuous sliding. 8 PF and 10 PF exhibited the best wear performance compared to other friction material, and these types of reinforced specimen exhibits a longer life. This may be because of the palm fiber is nearly equal in proportion to that of the steel and rock wool fiber.

2 PF and 4 PF shows the lower COF value less than 0.36 throughout the sliding, and hence the contact connecting the pad and rotor was found to be poor. None of the combination presented in this study are not best in all the properties. In a specimen, if hardness, heat swell and specific gravity increases in turn there is a reduce in the properties of loss on ignition and porosity.

8 PF and 10 PF were considered as optimized composition and were subjected to produce brake pad composites to do the further studies.

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