Study on tribological properties of palm kernel fiber for brake pad applications

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Abstract
The need of the natural fibers as an alternative for existing synthetic fibers is in great demand for automotive applications. The primary objective of this work is to examine the effect of palm kernel fibers as the replacement of existing synthetic fibers. In this work the palm kernel shell fiber is added in three different weight percentages such as 0%, 5% and 10% and developed in the form of the standard brake pad as per industrial standards by keeping the Barites were used as an space filling ingredient. The various Physical, Chemical and mechanical properties were examined as per industrial standards. Chase Test Rig was used to examine the Tribological properties. Based on the evaluated Results it can be concluded that the coefficient of friction shows a decreasing value on increasing the fiber content. The Brake pad Composites containing 5 wt% of palm kernel fibers possessed high frictional value 0.454 and fade percentage was low with minimal undulations. Palm kernel fibers with 10 weight percentages showed some undulations. It can be concluded Palm Kernel Fiber with 5 weight percentage can be used as a replacement of the synthetic fibers. Scanning Electron Microscopy was used to determine the wear mechanism of the developed brake pad composites.

1. Introduction

The purpose of brake is to stop the vehicle or slow down the vehicle at the required period. The starting or stopping of vehicles takes place due to the frictional surfaces between two mating services. Frictional and wear resistances are the important parameters of the brake pad for better operation. It is used to convert one form of energy into another form. The brake pad generally consists of 13–15 ingredients which are used to satisfy the required frictional properties [1, 2]. They are generally classified as Binders, Fillers, Friction Modifiers (Abrasives and Lubricants) and Reinforcements. Two types of fillers are used such as inert and functional fillers. Initially the era of brake pad started by using the asbestos as the predominant material. Later it has identified as carcinogenic, so replacement of asbestos came into existence. After getting asbestos banned many metallic materials and semi metallic materials came into effect [3–5]. Though these fibers were used it has been found to have some problems such as unsteady performance eco friendliness and high in cost. Now the major area of research is on using natural fibers as the key ingredient [6–8]. The synthetic fibers were replaced by the natural fibers because of the bio degradability, Cost effectiveness etc Many natural fibers have been used as a key ingredients in the brake pad applications and various findings were obtained. Fibers such as Hemp, Areca Fiber, Sisal Fibers and Banana fibers were already explored. Sai Krishnan et al analysed the influence of using areca fiber as an alternative for existing aramid fiber and concluded that increasing the fiber content of areca fiber enhanced the frictional performance of the brake pads [9]. The various natural fibers were selected based on their location and geographical findings. Liu et al analysed the effects of abaca fibers and he concluded that the increasing the abaca fiber content enhanced the wear performance and fade [10]. Pridhar et al investigated the effects of palm kernel fibers as an reinforcement and he analysed the performance in 3 different weight percentages and concluded that...
the increasing the volume has the best Tribological properties [11]. Singh et al analysed the frictional performance by using banana fiber and he concluded that the banana fiber having 5 weight percentage exhibited less wear and 20 weight percentage had the best recovery [12]. Manoharan et al developed a new hybrid composites by using the aramid fibers. He used the recycled aramid fibers and observed that the coefficient of friction was well within the industrial range [13]. Surya Rajan et al used the Prosopis Juliforia fiber with some surface treatment and concluded the Silane treated fibers improved the adhesive property which in turn enhanced the wear resistance [14–18].

Palm kernel shell is one of the natural fibers which is available abundantly and can grow in all sorts of environment. It is an agricultural waste which can be acted as a potential bi product as an reinforcements. Various other fibers were already explored but the palm kernel fibers with phenolic resins for brake pad applications were not done. Based on the literature it can be concluded it has the best mechanical properties compared to existing products and can be used as an alternative for various fibers. Owing to its various beneficial attributes it can be used in automotive applications. Based on the literature it can be concluded that the palm kernel fibers can be effectively used as an alternative in brake pad applications. Palm kernel shell as fiber in brake pad has not explored so far. Therefore the aim of this work is to develop a novel palm kernel brake pad and to assess the Tribological properties by using chase test rig.

2. Materials and methods

Palm kernel fiber was collected from Chennai in a local market and the palm fibers were cleaned thoroughly. The excess moisture content is removed by drying in the Sunlight. After that it is dispersed in a sodium hydroxide solution for one day and it is extracted as a short fiber. It is cut into small pieces in the form of short fibers of 2 mm. The detailed composition used in given in the table 1. The formulation possessed 15 parental ingredients fibers with additives: 20 weight% such as acrylic fiber, rockwool fiber, steel fiber, hydrated lime, binders with additives 20 weight% phenolic resin, NBR, crumb rubber, CaCO3 and frictional modifiers 20 weight% graphite, silicon carbide, and fillers of 40 weight%). The barites and palm kernel fibers varied based on the composition. The conventional method was used to develop the brake pad [19]. The same procedure followed by us in the fabrication of areca sheath brake pad is followed here [20].

2.1. Characterization of the developed composites

The physical and mechanical properties of the developed brake pad composites were assessed by using universal measurand standards. The various properties and standards of measuring are given in the table 2.

2.2. Estimation of the tribological performance by using chase test rig

The Chase test rig was used to determine the Tribological properties of the developed composites. The standard IS2742 was followed for evaluating the performances. Initially the burnishing was carried out. In order to make a good contact between the samples and drum burnishing was done. It was done at the standard 308 RPM for 20 min time until the saturation temperature reaches 93 degree Celsius. After completing Burnishing process the baseline cycle was initiated. A temperature between 82 to 104 degree Celsius was maintained. It is done as per the procedure at 411 RPM and at a load of 660 N. After that the Speed and the load were kept constant and fade and recovery were calculated. The Detailed procedure were presented in table 3 and table 4 and the same testing

| S. No. | Broad categories | Ingredients | PKB1 | PKB2 | PKB3 |
|--------|------------------|-------------|------|------|------|
| 1.     | Fibers inclusive of additives | Acrylic fiber | 4    | 4    | 4    |
| 2.     |                    | Rockwool fiber | 6    | 6    | 6    |
| 3.     |                    | Steel fiber | 5    | 5    | 5    |
| 4.     |                    | Hydrated Lime | 3    | 3    | 3    |
| 5.     | Binders (primary, secondary with additives) | Straight Phenolic Resin | 9    | 9    | 9    |
| 6.     |                    | NBR | 3    | 3    | 3    |
| 7.     |                    | Crumb rubber | 2    | 2    | 2    |
| 8.     |                    | Calcium oxide | 2    | 2    | 2    |
| 9.     | Friction Modifier (Abrasives and Lubricants) | Silicon carbide | 3    | 3    | 3    |
| 10.     |                    | Artificial graphite | 9    | 9    | 9    |
| 11.     |                    | MoS2 | 14    | 14    | 6    |
| 12.     | Fillers (Inert and Functional) | Palm Kernel Fiber | 0    | 5    | 10    |
| 13.     |                    | Barites | 40    | 35    | 38    | Table 1. Designation of brake pad composites and its weight percentage.
procedure were followed as per the literature previously done by us. Finally the wear loss is calculated as per the change in weight observed.

3. Results and discussion

The various mechanical, physical and tribological properties of the developed composites were evaluated based on the test results the values are presented in table 5. The density of the developed composites started decreasing on increasing the palm kernel fiber content. Though there is not a huge difference decrease in the density value is observed. Density values slightly got decreased. The main reason may be attributed due to the increase in the palm kernel fiber content which is more dense. The other reason is also may be due to the addition of space fillers in the composition. Since the space filler occupied more space decrease trend in the density is observed. There is an increasing trend in the porosity value. It can be observed that increase in the density decreased the porosity value which is mainly due to the particle size of palm kernel fibers which is higher than that of the space filler use.
Uniform dispersion with the matrix is also reason for high porosity value. Since uniform curing is happened there is not a high deviation in the acetone extraction. It is very minimal. Hardness decreased on increasing the content of the palm fiber which is due to the porous behaviour of the composites. Compressability of the developed composites found increasing but for PKB3 (Palm kernel having 10 weight percentage) shown some increasing trend which is due to the influence of compressibility witnessed in the literature. All the obtained values where within the industrial range [23-25].

3.1. Chase test analysis by using fade-recovery cycles
The Coefficient of friction values are calculated based on the fade and recovery cycles and it is given in the figure 1 below. Until the temperature was maintained at 149 degree Celsius the friction values showed the increasing values. After crossing the 149 degree Celsius the coefficient of friction exhibited different friction values. The composites having 0 weight percentage of palm kernel fiber content shows the slow decreasing in the frictional value. It decreased gradually whereas the composites with 10 weight percentage of palm kernel content possessed less frictional value with more undulations. The Brake pad Composites containing 5 wt% of palm kernel fibers possessed high frictional value when compared to other composites. This may be due to the

| Properties          | Unit | Standard       | PKB1 | PKB2 | PKB3 |
|---------------------|------|----------------|------|------|------|
| Brake Pad Density   | g cc$^{-1}$ | IS 2742 Part-3 | 2.21 | 2.18 | 2.16 |
| Hardness            | No Unit |              | 102  | 97   | 94   |
| Acetone Extraction  | %    |                | 1.183| 1.195| 1.204|
| Compressibility     | mm   |                | 1.12 | 1.15 | 1.13 |
| Porosity            | %    | JIS D 4418     | 4.25 | 5.26 | 5.95 |
| Shear Strength      | N mm$^{-2}$ | ISO 6312      | 441.3| 441.8|

Figure 1. Chase Test analysis by using Fade-Recovery Cycles.
ruination of the organic content at the higher temperatures. This is also due to formation of friction films in the composites. At the next level temperature variations in friction performances were observed. Above 180 degree Celsius the PKB1 increased and later it got decreased. For the composites PKB2 having 5 weight percentage of fibers had the stable coefficient of friction till 260 degree Celsius and it got reduced, but less undulations were observed. But for composites with 10 weight percentage the frictional values showed decreasing trend from the beginning. It was not stable. For all the three composites after attaining a temperature of 150 degree Celsius the frictional values started decreasing. The frictional values were better for 5 weight percentage when compared to 10 weight percentage. The same trend was followed for all the composites in the second fade cycle. The coefficient of friction during the various cycles in terms of performance, Recovery and average coefficient were discussed in the upcoming sections.

3.2. Fluctuation of $\mu_P$, $\mu_F$, $\mu_R$
Frictional behaviour of all the developed composites was observed and it is given in the figure 1 and 2 below. All the developed composites were well within the industrial range. The Coefficient of performance $\mu_P$ and coefficient of friction $\mu_F$ were in between 0.401–0.495 and 0.325–0.365 respectively and it shown decreasing trend on increasing the pal kernel fiber content and it is presented in the figure below. This is mainly due to degradation of organic contents at higher temperatures [26].

3.3. Performance and worn surface morphology of the composites
The Performance of wear is calculated and it is given in the figure below. The wear rate is attributed due to the presence of the composites present in the brake pad. In this work Increasing the content of the palm kernel fiber increased the wear rate. Based on the results it can be concluded that the increasing the content of the palm kernel fiber increased the wear rate. All the composites had a wear rate in the range of 1.84 to 1.46. The wear for 5 weight percentage of PKB has a nominal wear rate of 1.54 which is well within the industrial range. The wear rate followed an increasing trend. From this it can be concluded that the inclusion of palm kernel fiber in 5 weight percentage has nominal wear percentage and it has beneficial effects on wear performance. The wear of the composites is increased with the content of the palm kernel shell fiber this is due to the influence of phenolic resin at the higher temperature. Phenolic resin will be decomposed at the higher temperature this is the reason for increase in wear with increase in content of the palm kernel fibre. Due to this a decrease in the adhesive property is observed between the resin matrix and ingredients. The composites with 5 weight percentage and zero weight percentage of the palm kernel fiber composites has the better compatibility in nature which decreased the wear. After reaching 10 weight percentage the palm kernel shell fibers were depleted and peeled due to the resin and matrix which resulted in high wear of the composites.

3.4. Surface morphology analysis of developed composites
The surface morphology of the developed 3 composites is analysed in this section. It is presented in the figures 3(a)–(c). The contact plateaus that includes primary and secondary plateaus is discussed below. The

![Figure 2. Fluctuation of $\mu_P$, $\mu_F$, $\mu_R$.](image)
important surface morphology analysis includes cracks, Plateaus, palling pits and wear debris. Higher extend of contact plateaus is observed in the composites. The proper mixing of fibrous ingredient in the developed composites. Small pits and wear debris have been observed in the developed composites [25]. The composites with 5 weight percentages showed some less contact plateaus. The wear debris and pits were observed higher for the composite PKB2 compared to PKB1 which is due to the present of high wear rate in 5 weight percentage than the 10 weight percentage. Due to high fiber content in the composite PKB3 more irregularities have been observed. The 10 weight percentage composites had the relatively rougher exposed surfaces than the other 2 composites. Out of all the three more surface irregularities and damage has been observed in the composite 3 which is due to severe stress. High pulled out is also observed due to the poor bonding between matrix and the fibers. The highest weight percentage of palm kernel fibers is present in 10 weight percentage which leads to exposed tribo surface causing highest wear.

4. Conclusion

The Brake Pads were fabricated by compression moulding technique and the following conclusions were drawn.

Palm kernel with different weight percentages have been fabricated and various mechanical, Tribological and chemical analysis were done. Chase Test IS2741 was used to examine the Tribological properties. Based on the mechanical and morphological analysis it is concluded that the density of the developed composites started decreasing on increasing the palm kernel fiber content. There is an increasing trend in the porosity value. Since uniform curing is happened there is not a high deviation in the acetone extraction. It is very minimal. Hardness decreased on increasing the content of the palm fiber which is due to the porous behaviour of the composites. Compressibility of the developed composites found increasing but for PKB3 Based on the obtained results it can be concluded that the 5 weight percentage of the palm kernel fibers is the best among the all developed composites. It increased the frictional performances with decreased wear rate.
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