Fabrication and Performance Evaluation of a Composite Material for Wear Resistance Application

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Abstract—Brake lining materials generally are asbestos, metals and ceramics. Asbestos during application releases the hazardous gases, which causes damage to the health. By the application of natural resources the material is made harmless. The main element is used for brake lining from palm kernel shell. The powder metallurgy technique is used in the production of components. It consists of stages as powder making, powder blending, compacting, sintering followed by heat treatment process. The average disk temperature and average stopping time for pass is increased and it has poor dimensional stability. Hence it has lost favor and several alternative materials are being replaced these days. In this work a non-asbestos bio-friction material is enlighten which is developed using an Agro-waste material palm kernel shell (PKS) along with other Ingredients. Among the agro-waste shells investigated the PKS exhibited more favorable properties. Taguchi optimization technique is used to achieve optimal formulation of the friction material. The developed friction material is used to produce automobile disk brake pads. The developed brake pads were tested for functional performance on a specially designed experimental test rig. Physical properties of this new material along with wear properties have been determined and reported in this paper. When compared with premium asbestos based commercial brake pad PKS pads were found to have performed satisfactorily in terms of amount of wear and stopping time. This composite is used in the automobile industry for brake linings.

Index Terms—Brake Pads, Friction Material, Taguchi, Design of Experiments

I. INTRODUCTION

The development of modern friction materials has a history spanning over the past 110 years. Herbert Frood is credited with inventing the first brake lining material in 1897. His invention led to the founding of the Ferodo Company, a firm that still supplies brake lining materials today. In 1901, Herbert patented a block made from layers of textile material impregnated with rubber, if the block was to be used against steel, or wax, if it were to be used against rubber. As the duty of the brakes increased, the cotton tended to char, so in 1908, Herbert replaced it with asbestos. The asbestos was woven into a loose fabric and impregnated with resins and varnishes of high melting point. By 1914, the use of Ferodo brake linings was widespread. In 1920s all friction materials were of the Ferodo type. In 1925, the British Belting and Asbestos (BBA) Limited became known as BBA Group that produced such famous friction material brand names as Mintex, Don, Textar.

In the 1930s, Ferodo turned to thermosetting resins and later introduced molded instead of woven linings. The molded linings were made by mixing fiber and resin together and also, polymerizing the resin under pressure and temperature. Fillers such as mineral and metal particles, which modify the wear properties of the lining, could be introduced in these linings and polymers could be used which were impracticable with woven linings. From the foregoing, asbestos has been used as base material in the manufacture of brake lining materials for close to 100 years. It is still being used by some manufacturers who do not possess the necessary technology or will to change to other materials. Though asbestos has been referred to as a "God given" material for inclusion in friction linings due to its good physical and chemical properties that remain stable over the temperature range experienced by friction materials it has been reported that asbestos has serious health risks. Diseases associated with it include asbestosis, Mesothelioma, lung cancer and other cancers.

Efforts have been geared to replace asbestos fibers in friction linings. This is exemplified by the work of Nakagawa in 1986, used metal fibers for inclusion in brake pads to overcome environmental pollution. They developed semi-metallic pad material using chatter–machined short metal fibers because it exhibited excellent properties in view of brake characteristics and resistance to wear. The brake pad contained about 60% by weight of steel fibers with 60µm in diameter and 3mm long. Blau (2001) reported the additive effects of various non-asbestos materials
on friction linings. Asbestos – free organic, semi-metallic and metallic friction lining materials are now increasingly being used.

Gbadam et al are done extensive investigations on the palm kernel shell to evaluate the properties of the PKS. The cracking of palm nut shell mostly depends on the moisture content in it. The PKS shell is completely dried out, then it is easy to crush into fine powder. Apart from this other physical and mechanical properties are also evaluated [20]. Dagwa, I.M et al developed an experimental set-up for testing the performance of the brake pad material [22]. Sivarao et al designed and developed brake pad wear monitoring system for successful testing and validation. In this the embedding of sensor at the manufacturing level into the brake pad is suggested. A method for manufacturing a brake pad comprised of casting back plate in the mould. The plate is formed with at least one integral projection which overhangs an adjacent surface of the plate [23]. The compositional design of friction materials is a well-known problem of multi criteria optimization which involves not only the complications of handling the different categories of ingredients but also reaching at a suitable and desired level of performance. Thus to reduce or to completely eliminate the health risks posed by the asbestos in friction lining manufacture and to reduce the cost of friction linings, this work presents the development of an asbestos - free friction lining material in which an agro – based (palm kernel shell [PKS]) was used as base material.

II. SELECTION OF INGREDIENTS

A. Introduction

The base material for formulation is palm kernel shell which is an agro – waste. Apart from PKS, the other ingredients are also used. Non-asbestos organic (NAO) based friction materials are essentially multi ingredient systems (containing more than 10 ingredients, in general) in order to achieve the desired amalgam of performance properties. Though the list of ingredients used for formulation of such composites exceeds the number 700, these are classified into four major categories viz. Binder, fibers, friction modifiers and fillers based on the major function they perform apart from controlling friction and wear performance. Binder is the heart of a system which binds the ingredients firmly so that they can perform the desired function in the friction materials. Fibers in combination are added mainly for strength while friction modifiers are used to manipulate the desired range of friction. Fillers are of two types viz. functional fillers (to improve particular characteristic feature of composites such as resistance to fade, etc.) and space/inert fillers (mainly to cut the cost). Phenolic resins (modified and unmodified) are invariably used as binder in friction materials due to low cost along with a good combination of mechanical properties such as high hardness, compressive strength, moderate thermal resistance, creep resistance and very good wetting capability with most of the ingredients. However, these resins are sensitive to heat and humidity and in situ polymerization starts slowly even at ambient temperature leading to its poor shelf life.

B. Materials and Methodology

The base material for formulation was palm kernel shell which is an agro – waste. Apart from PKS, the other materials used are Cashew Nut Shell Liquid, Sulphur, Calcium Carbonate, Quartz, Brass chips, Iron Ore, Carbon Black, and Ceramics. The following tests were performed to determine the physical and mechanical properties of Palm kernel shells. The tests include dimensional properties, moisture content, true density, specific heat capacity, fade and wear, compressibility, hardness, temperature rise. The base raw material, PKS, was collected and cleaned thoroughly to remove impurities. It was crushed and ground to a fine powder, and sieved using 125µm sieve. About eight trial formulations were initially made for preliminary test. After trial formulations, a fairly good composition was arrived at, which was used for determining the manufacturing parameters. Four brake pads based on this formulation were made using four different sets of manufacturing parameters. Then further tests were conducted on them which led to identification of optimum formulation for friction lining.

C. Fabrication of the Brake Pad

1) Materials list

The materials were used to make the Brake pad taking different compositions as shown in figure1.
2) **Formulation using Design of experiments**

Increasing productivity and improving quality are important goals in any business. The methods for determining how to increase productivity and improve quality are evolving. They have changed from costly and time-consuming trial-and-error searches to the powerful, elegant, and cost-effective statistical methods that JMP provides. Designing experiments in JMP is centered on factors, responses, and runs. JMP helps you determine if and how a factor affects a response.

3) **Taguchi method**

The goal of the Taguchi method is to find control factor settings that generate acceptable responses despite natural environmental and process variability. In each experiment, Taguchi’s design approach employs two designs called the inner and outer array. The Taguchi experiment is the cross product of these two arrays. The control factors, used to tweak the process, form the inner array. The noise factors, associated with process or environmental variability, form the outer array. Taguchi’s signal-to-noise ratios are functions of the observed responses over an outer array. The Taguchi designer supports all these features of the Taguchi method. You choose from inner and outer array designs, which use the traditional Taguchi orthogonal arrays, such as L4, L8, and L16. Dividing system variables according to their signal and noise factors is a key ingredient in robust engineering. Signal factors are system control inputs. Noise factors are variables that are typically difficult or expensive to control. The inner array is a design in the signal factors and the outer array is a design in the noise factors. A signal-to-noise ratio is a statistic calculated over an entire outer array. Its formula depends on whether the experimental goal is to maximize, minimize or match a target value of the quality characteristic of interest. A Taguchi experiment repeats the outer array design for each run of the inner array. The response variable in the data analysis is not the raw response or quality factors; it is the signal-to-noise ratio. The Taguchi designer in JMP supports signal and noise factors, inner and outer arrays, and signal-to-noise ratios as Taguchi specifies.

4) **Experimental Design using MINITAB**

The Taguchi Method of experimental design was used. The method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments, which could give the full information of all the factors that affect the performance parameter. The orthogonal array experiments are used as they allow the simultaneous variation of several parameters and the investigation of interactions between parameters. The main advantage of the Taguchi method is that the number of experiments conducted in most of the cases is lesser than that of any other experimental design method using a statistical approach.
5) **Methodology**

Ingredients collection as per the requirement standards

- Composition formulation by volume fraction method
- Trial formulations were initially made for preliminary test. After trial formulations, a fairly good composition was arrived at, which was used for determining the manufacturing parameters.
- The pad samples were made as per standard manufacturing process (Powder metallurgy route)
- The Taguchi method uses a statistical measure of performance called signal – to – noise (S/N) ratio. This is a performance measure to choose control levels that best cope with noise.

6) **Performance testing**

The test rig was used to determine the performance of the brake pads produced with the optimum manufacturing parameters and optimum composition. The brake pad wear and braking time under different braking conditions are evaluated. The functional characteristic values of laboratory brake pad and commercial brake pad were evaluated under similar working conditions. When a set of brake pad is fixed into the brake caliper assembly of the test rig, the system is switched-on and the drive shaft begins to rotate, it is then allowed to attain a desired speed. Thereafter, a manual force is applied on the brake pedal which is similar to that of a motor car. Subsequently the stopping time and brake pad material lost are recorded and reported.

### III. **RESULTS AND DISCUSSION**

Brake pad specimens were formulated according to the experimental design layout. Tribological tests like determination of coefficient of friction and wear rate on each specimen were carried out. The optimum level settings for the ingredients were determined. Actual values of ingredients were used for the optimum formulation of the brake pad. Its performance was compared with that of the premium asbestos-based commercial brand of brake pads.

**A. Comparisons between Laboratory Brake Pad & Commercial Brake Pad**

The developed brake pad and commercial pad are tested for comparing the performance of these two pads. The responses like wear, temperature rise and stopping time are recorded by varying weights on rotating disk at constant speed of results are shown in table 1. The comparative performance curves are shown in figure 2. The figure compares the effects of inertia on brake pad wear, brake disk temperature rise and stopping time for developed and commercial brake pads. The average material loss per application of the developed pad (4.2mg) compare well with that of the commercial pad (4.1mg). Blau (2001) reports a value of 3mg for commercial brake pads. The deviations of the developed and the commercial pads tested from the quoted value are within the acceptable limits. The average disk temperature rise for the developed pads tested is 3.4° C. The average stopping times are 1.8s for the developed pad. The above values suggest that the developed brake pad may be able to perform as well as the commercial brake pad.

<table>
<thead>
<tr>
<th>Load (Kg)</th>
<th>Wear (in mg/application)</th>
<th>Disk temperature rise (°C)</th>
<th>Stopping time (in sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Developed</td>
<td>Commercial</td>
<td>Developed</td>
</tr>
<tr>
<td>10</td>
<td>1.9</td>
<td>2.7</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>3.2</td>
<td>2.9</td>
<td>3</td>
</tr>
<tr>
<td>30</td>
<td>4.5</td>
<td>3.4</td>
<td>3.3</td>
</tr>
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<td>4.8</td>
<td>6.2</td>
<td>4.1</td>
</tr>
<tr>
<td>50</td>
<td>5.3</td>
<td>4.6</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Table 1. Performance of developed and commercial pads under different inertia conditions
The developed brake pad and commercial pad are tested for comparing the performance under varying speeds. The responses like wear, temperature rise and stopping time are recorded at different speeds and shown in Table 2. The comparative performance curves are shown in Figure 3. The figure compares the effects of speed on brake pad wear, brake disk temperature rise and stopping time for developed and commercial brake pads. The developed pad had greater wear than the commercial pad at higher speeds. The comparisons for disk temperature rise and stopping time shows that the developed brake pad has about the same performance as the commercial pad. The average disk temperature rise and average stopping time for the developed pad are 10.7°C and 5.3s respectively, while the corresponding values are 13.1°C and 4.2s for the commercial pad.

### Table 2 Performance of developed and commercial pads under different speed conditions

<table>
<thead>
<tr>
<th>Speed (kmph)</th>
<th>Wear (in mg/application)</th>
<th>Disk temperature rise (°C)</th>
<th>Stopping time (in sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Developed</td>
<td>Commercial</td>
<td>Developed</td>
</tr>
<tr>
<td>20</td>
<td>4.1</td>
<td>2.1</td>
<td>3</td>
</tr>
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<td>100</td>
<td>8.6</td>
<td>7.8</td>
<td>12</td>
</tr>
</tbody>
</table>

IV. **CONCLUSION**

A friction lining material based on PKS as a substitute for asbestos has been developed. The mechanical and physical properties compare well with commercial asbestos-based friction lining material. Its performance under static and dynamic conditions compare well with the asbestos-based lining material. However, further refinement of the PKS lining formulation is recommended in order to have a comparable wear rate at higher vehicular speeds. We can improve the properties further by changing the composition of a brake pad material (PKS).
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REFERENCES


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