Tribological properties of nonasbestos brake pad material by using coconut fiber

A L Craciun¹, C Pinca-Bretotean¹, D Utu² and A Josan¹

¹Politehnica University of Timisoara, Engineering and Management Department, Revolutiei Street, no. 5, 331128 Timisoara, Romania
²Politehnica University of Timisoara, Materials and Manufacturing Department, Mihai Viteazu str., no. 1, Timisoara, 3300222, Romania

E-mail: camelia.bretotean@fih.upt.ro

Abstract. In automotive industry, the brake system is influenced by a large number of variables including geometry of components, materials of brakes, components interaction and many operating condition. Organic fiber reinforced metallic friction composites are increasingly being used in automotive brake shoes, disc and pads, linings, blocks, clutch facings, primarily because of awareness of health hazards of asbestos. Current trend in the research field of automotive industry is to utilization of different wastes as a source of raw materials for composite materials. This will provide more economical benefit and also environmental preservation by utilize the waste of natural fibre In this paper it has performed a tribological study to determine the characteristics of the friction product by using coconut natural fibred reinforced in aluminium composite. In this sense, two different laboratory formulation were prepared with 5% and 10% coconut fibre and other constitutes like binder, friction modifiers, abrasive material and solid lubricant using powder mettallurgy. These drew materials for brake pads are tested for tribological behaviour in a standard pin on disc tribometer. To know the wear behavior of composite materials will determine the parameters that characterize there tribological properties.

1. Introduction

The most important element of braking system is friction material, which is expected to continue its functioning, reliably and efficiently for a prolonged time, in adverse operating conditions, [1]. Nowadays, factors such as road development and road traffic demand more efficient braking system which requires improved brake friction materials, [1].

In automotive industry, the brake system is influenced by a large number of variables including geometry of components, materials of brakes, components interaction and many operating condition. Friction behavior is the most critical factor in brake system design and performance. In specialty literature have been reported a great number of ingredients for being used to tailor the friction composites. These are classified into four major categories: binder, structural modifiers, friction modifiers and fillers. They contribute to controlling friction and wear performance. Nonasbestos organic fibre reinforced metallic friction composites are increasingly being used in automotive brake shoes, disc and pads, linings, blocks, clutch facings, and so forth, primarily because of awareness of health hazards of asbestos, [1].

The use of asbesastos fibre as reinforcement in the friction materials started at the beginning of the 20th century. After that, this material became popular all over the world. Later on, medical reports
regarding asbestos exposure to humans proved that asbestos is carcinogenic and can cause deadly diseases. This motivated researchers all over the world to find safe substitute for asbestos fibers. In paper [2], the authors list the following replacement materials for asbestos: calcium silicate, vermiculite (hydrated calcium aluminum silicate), aluminum silicate, basalt fiber, blast furnace slag, ceramic fiber, polycrylonitrile, polyester, chopped glass fiber and aramid fibers. These components are used solely or in cocktail in friction formulations and research is continuing for more improved these materials, [3–5]. Current trend in the research field of automotive industry is to utilization of different wastes as a source of raw materials for composite development, [6]. This will provide more economical benefit and also environmental preservation by utilize the waste of natural fibre, [7]. In this paper it has performed a tribological study to determine the characteristics of the friction product by using coconut natural fibred reinforced in aluminium composite.

2. Making samples for tribological experiments
In order to conduct this study were achieved iron discs and pin composite for disc - pad brake assembly. Iron discs play the role of brake discs of all real vehicle braking system and the pin’s play brake pad role. Tribological tests will be performed on a pin on disc tribometer, under dry friction.

2.1. The iron disc samples product
The iron discs sample were produced in "Molten Metal Laboratory" placed in the Faculty of Engineering Hunedoara. For this, it is use an oven of 10 kg capacity shown in Figure 1.

![Figure 1. Oven for produced the disc sample](image1)

![Figure 2. Metal load placed in the oven](image2)

![Figure 3. Metal batch out of the oven](image3)

In the oven was placed brake discs, out of use and other constituents, like: 35 g coke, 25g FeSi and 15g FeMn, Figure 2. Melting duration was 90 min and after that the metal bath is discharge into a shape, Figure 3.

![Figure 4. Cylindrical shape](image4)

![Figure 5. Iron disc sample results](image5)

![Figure 6. Disc sample size](image6)

The metal bath was dispensed into a cylindrical shape, shown in Figure 4 and results a disc sample which is shows in Figure 5. The iron disc sample size shows in Figure 6.

2.2. The composite pin product
In order to achieve the tribological experiments were performed composite pin’s. These samples together with disc samples will be mounted in the pin on disc tribometer. The composite pin will take cylindrical form. In this sense, it was designed and executed a mold shown in Figure 7. The pin’s size are presented in Figure 8.
The recipes of composites containing seven ingredients which maintaining five ingredients (around 75%) constant and varying two ingredients, aluminium and coconut fibre (around 25%) in complementary manner as shown in Table 1.

### Table 1. The recipes used in the product of the pin composites

| Pattern composite | Aluminium (%) | Graphite (%) | Zirconia oxide (%) | Silicon carbide (%) | Titanium oxide (%) | Phenolic resin (%) | Coconut fibre (%) |
|-------------------|--------------|--------------|--------------------|--------------------|--------------------|-------------------|------------------|
| Composite 1       | 20           | 10           | 2                  | 10                 | 13                 | 40                | 5                |
| Composite 2       | 15           | 10           | 2                  | 10                 | 13                 | 40                | 10               |

The ingredients were mixed in a drum mixing machine to ensure the macroscopic homogeneity using a speed of 200 rot/min for 5 minutes. It was found that the mixing sequence and time of mixing of ingredients represents factors which influencing the fabrication of composites. If mixing time is low, proper homogeneity cannot be achieved. If it is too high, it does not improve the homogeneity further. The mixture was then placed into a mold and compress under a force of 10 N for 3 min. The mold with the sample was inserted into an oven and heat at 200°C. The time for keeping the sample in the oven was 150 min, after which cooling was carried out in air for 12 hours. Extracting the samples from the mold was done without sticking problems. Then the surfaces of the pin were polished to obtained a smooth surface. The finished pin is shown in Figure 9.

3. **Tribological test by pin on disc tribometer**

In order to determine the tribological characteristics, the iron disc and composite pin were mounted in pin on disc tribometer, Figure 10. Tribological experiments consists on pressing the composite pin on the surface of a rotating iron disc. Disk speed depends on sliding speed and range of work. The time of each test depends on the speed of sliding.

### Table 2. Testing parameters

| Iron disc speed (rot min⁻¹) | Range of work (mm) | Sliding speed (m s⁻¹) | Angular speed (rad s⁻¹) |
|-----------------------------|--------------------|-----------------------|------------------------|
| 1500                        | 25                 | 3.92                  | 157                    |

Table 2 shows the values of parameters used in the tribological experiments.

For each pin composite were performed tests for four different lengths. Trial time for each experiment was determined by the sliding speed and the length of work. The experimental measurements are carried out with two forces of 5 N and 10 N. The weight and thickness of the samples were noted before and after the friction test. These are used to calculate the total wear of
each sample. A thermography camera Thermo CAM Quick View was used to record the temperature of the contact interface during the test and readings were recorded every second. Captured images can provide information about the evolution of the temperature of the parts in contact. Figure 11 shows the disc – pin assembly and Figure 12 shows the auxiliary support for mounted the composite pin.

4. Discussion and results
4.1. Characterization of iron disc sample

The chemical composition of cast iron used in this study is shown in Table 3. Thus, the carbon equivalent (CE) and the degree of saturation of carbon (SC) according to [8], have been determined by the relations (1) and (2). The calculated values for the two parameters are shows in Table 3.

\[
CE = C + 0.3(Si + P) - 0.03Mn + 0.4S + 0.07Ni + 0.05Cr + 0.074Cu + 0.25Al \tag{1}
\]

\[
SC = C/[4.26 - 0.3(Si + P)] \tag{2}
\]

Table 3. The chemical composition, carbon equivalent and the degree of saturation of carbon of iron disc sample used in the study

| Chemical composition (%) |       |       |       |       |       |       |       |       |       |       |       |
|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| C                        | 2.82  | 0.81  | 1.96  | 0.093 | 0.250 | 0.07  | 0.07  | 0.09  | 0.02  | 0.009 | 3.50  |
| Mn                       |       |       |       |       |       |       |       |       |       |       | 0.78  |
| Si                       |       |       |       |       |       |       |       |       |       |       | 0.02  |
| Si                        |       |       |       |       |       |       |       |       |       |       | 0.009 |
| S                        |       |       |       |       |       |       |       |       |       |       | 550   |
| P                        |       |       |       |       |       |       |       |       |       |       |       |
| Cr                       |       |       |       |       |       |       |       |       |       |       |       |
| Ni                       |       |       |       |       |       |       |       |       |       |       |       |
| Co                       |       |       |       |       |       |       |       |       |       |       |       |
| Ti                       |       |       |       |       |       |       |       |       |       |       |       |
| V                        |       |       |       |       |       |       |       |       |       |       |       |
| CE                       |       |       |       |       |       |       |       |       |       |       |       |
| SC                       |       |       |       |       |       |       |       |       |       |       |       |
| HV<sub>10</sub>          |       |       |       |       |       |       |       |       |       |       |       |

The low saturation level of carbon (SC) increase the proportion of perlite, the only constituent that can provide high strength for cast iron, [9]. The chemical composition of iron must ensure a small amount of graphite which is why it contains a low carbon. After modification, the iron structure is perlitic, because of the effect of the graphitized, [9].

Figure 13. SEM imagine of iron disc sample - 100 x magnification
The microstructures of the produced disc samples were investigated using light microscope with magnification of 100x and is shown in Figure 13. The microstructure shows mainly type D flake graphite in a matrix of ferrite-perlite base, [8-10]. Graphite is smaller due to the phosphorus content (0.25%), [10].

4.2. Characterization of composite pin

A density measurement test has been carried out on a laboratory scale to examine the density of the new material obtained. The true density was determined by weighing each sample on a digital weighing machine and calculated their volume. The results shown in Table 4.

Porosity has an important role in automotive brake pad materials, [11]. The function of porosity is to absorb energy and heat, which is very important for effectiveness of the brake system. Theoretically, lower porosity conduct to higher friction coefficient and wear rate due to higher contact areas between the surfaces in contact. The samples was cut to a dimension of 25x25x7 mm. The structure should be preserved during sample grinding and polishing, Figure 14. Then, the samples were left for 24 hours in a desiccator at room temperature, Figure 15. For the porosity test, the samples were weighed, placed in a container with oil and keep at 90°C for 8 hours, Figure 16. After that, the samples were left in an oil container for 12 hours, until the oil cools to the room temperature. Finally, the sample was rolled on a piece of cloth for remove oil from the sample. The sample was weighed again and the value is presented in Table 4.

![Figure 14](image1.png) The samples for the porosity test
![Figure 15](image2.png) The sample placed in a desiccator
![Figure 16](image3.png) Sample placed in a container with oil

The compressive strength test was done using a universal testing machine type Zwich Roell Z005. The sample has the dimensions 25x25x7mm and was subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded. Table 4 shows the results obtained after the experimental determinations for both composites.

| Height (mm) | Diameter (mm) | Density (g cm$^{-3}$) | Porosity (%) | Compressive strength (MPa) |
|------------|--------------|-----------------------|--------------|---------------------------|
| 5% coconut  | 10% coconut  | 5% coconut            | 10% coconut  | 5% coconut                | 10% coconut |
| 21.4       | 14           | 1.82                  | 1.34         | 11.31                     | 13.12        | 405.11      | 398.77      |

It is seen from Table 4 that the density of the 10% coconut fibre composite shows lower than 5% coconut fibre.

The brake pads must have a certain porosity to minimize the effect of water and oil on the friction coefficient. The paper [12] found that increasing porosity by more than 10% could reduce the brake noise. From the porosity results as shown in Table 4 it can be seen that two brake pad formulations shows percentage more than 10%.
The compressive strength value for 5% coconut fibre composite shows higher compared with 10% coconut fibre composite.

4.3. Tribological results

Tribological test has the next objectives: influence of material factors, parameters influence of the operating mode (pressing force, sliding speed, time trial, the regime of friction) on the tribological characteristics of the sample tested, process analysis that occur in the superficial layers of the composite material testing. In this regard we will notice: the evolution of a parameter of wear and the evolution of the temperature in the contact area [13]. Finding the behavior of materials samples is by gravimetric method. During experiments disc sample and composite pin was weighted. For the iron disc will determine the weight loss and weight loss/route for each forces test. The results are presented in Table 5.

Table 5. Experimental results for the cast disc sample

| Test force (N) | Initial mass (g) | Final mass (g) | Total road length (km) | Weight loss (g) | Weight loss / route (g km⁻¹) |
|----------------|------------------|----------------|-----------------------|----------------|-----------------------------|
| 5              | 866.7119         | 866.5577       | 4                     | 0.1542         | 0.03855                     |
| 10             | 866.5577         | 866.4145       | 4                     | 0.1432         | 0.03580                     |

Table 5 shows that weight loss and weight loss/route for iron disc sample decreases with increasing workload. Table 6 shows test parameters and temperature values on the contact area.

Table 6. Experimental results for the composite pin

| Test force (N) | Specific pressure (MPa) | Temperature (°C) | Length test (m) | Trial time t = L v⁻¹(min) |
|----------------|-------------------------|------------------|----------------|--------------------------|
| Test force (N) | Specific pressure (MPa) | Temperature (°C) | Length test (m) | Trial time t = L v⁻¹(min) |
| 5              | 0.032                   | 5% coconut       | 40.1            | 60.4                     | 500             | 2.12             |
|                |                         | 10% coconut      | 43.8            | 74.3                     | 1000            | 4.25             |
|                |                         | 5% coconut       | 44.0            | 74.8                     | 1500            | 6.37             |
|                |                         | 10% coconut      | 32.5            | 61.1                     | 2000            | 8.50             |
| 10             | 0.064                   | 5% coconut       | 47.3            | 74.8                     | 500             | 2.12             |
|                |                         | 10% coconut      | 55.2            | 75.8                     | 1000            | 4.25             |
|                |                         | 5% coconut       | 56.1            | 61.1                     | 1500            | 6.37             |
|                |                         | 10% coconut      | 56.0            | 60.4                     | 2000            | 8.50             |

Also, were determined the variation in height of composite pin according to the trial time, with test force of 5N, Figure 17 and with force of 10 N, Figure 18. It can see that height loss is less for composite 2, with 10% coconut fiber.

**Figure 17.** Variation in height of pin according to the trial time, F = 5N

**Figure 18.** Variation in height of pin according to the trial time, F = 10 N
Figure 19 and Figure 20 shown the loos mass of composite pin according to the trial time for both force applied. It is observed that the mass loss increases with the trial time. For composite with 10% coconut fiber, the mass loss is higher.

Figure 21 and Figure 22 presents the linear wear test parameters with sliding distance using the normal force of 5N, respectively 10 N. The best wear reaction has the composite pin with 10% coconut fibre.

Figure 23 and Figure 24 shows the temperature in the contact area for composite pin with 5 % coconut fiber at the end of wear experiments with 5 N force, respectively 10 N.

Figure 25 and Figure 26 shows the temperature in the contact area for pin with 10 % coconut fiber at the end of wear experiments with 5 N force, respectively 10 N.

In the contact zones the temperature rises rapidly in the first part of the test, this period finishing asperities being treated with the composite structure.
Between 500-1000 m, temperature rises less and in the end of the tests, the temperature drops. At the end of the test period, the iron disc has bigger temperature than pin composite which shows a better distribution of temperature on the composite material.

5. Conclusions
From the results and discussion of this study it can be observed:

- the cooling rate influences the mechanical properties of cast iron, increases resistance and hardness of cast iron, due to the increase in the percentage of pearlite structure and finishing of graphite separation. It must thus preheating the mold before casting, in order to reduce the cooling rate and preventing the occurrence of interdendritic graphite;
- the fabrication of the composite material depends on mixing sequences and time of mixing;
- following the study you can observe that the iron disc wears faster than the composite material and wear resistance does not depend greatly on the amount of metal parts by mass of the sample;
- iron disc wears faster than the composite material, which justifies the importance of tribological studies;
- the study led that natural coconut fibre can be used for the automotive brake pads;
- it can be concluded that both composite showed almost similar properties, hence coir could be a candidate fibre for the mass-scale fabrication of asbestos-free brake pad without any harmful effect.

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