Composites materials for friction and braking application

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Abstract. The brake pads are an important component in the braking system of automotive. Materials used for brake pads should have stable and reliable frictional and wear properties under varying conditions of load, velocity, temperature and high durability. These factors must be satisfied simultaneously which makes it difficult to select effective brake pads material. The paper presents the results of the study for characterisation of the friction product used for automotive brake pads. In the study it was developed four frictional composites by using different percentages of coconut fibres (0%, 5%, 10%, 15%) reinforcement in aluminium matrix. The new composites tested in the laboratory, modelling appropriate percentage ratio between matrix and reinforcement volume and can be obtained with low density, high hardness properties, good thermal stability, higher ability to hold the compressive force and have a stable friction coefficient. These characteristics make them useful in automotive industry.

1. Introduction
Braking is the process of partially or completely decrease traveling speed of a vehicle. During braking, a part of the kinetic energy gained by the vehicle turns into heat through friction. Other part is consumed for overcoming resistance to rolling and air resistance, which opposing the movement. The large amount of heat that is generated during braking contributes to the worsening of the vehicle braking qualities, hastens wear and friction linings and other brake system components. In recent years, the continued growth of the dynamic qualities of the vehicle and traffic, stressed the importance of braking systems, [1].

A braking system must have the following qualities: effectiveness, stability, fidelity and comfort. The effectiveness of the braking system ensures enhancement of the performance speed of the vehicles. A high efficiency of the braking system leads to obtaining higher speeds, in which case the vehicle's performances are elevated, [2]. Stability of the braking system, involves conservation of braking qualities of the vehicle. This is achieved if the braking force applied is maintained constantly in all operating conditions, [2]. In the case of brakes with friction, this depends on the stability of the friction coefficient of the brake pads. In normal use, the brake thermal regime should not exceed 300°C, to ensure this constant friction. In this scope, the brake pads must ensure evacuation of heat that occurs during braking, because in the event of excessive heating, noises and vibrations, the structure of material is change and the friction coefficient is reduced. All these leading to lower efficiency and decrease traffic safety, [3]. This is the reason why special attention is paid to the design and manufacture of braking systems components. The brake pads are an important component in the braking system of automotive. These are of different types, suitable for different types of automotive and engines. Brake pads are designed for: friction stability, durability, minimization of noise and vibration. The typology of the brake pads depends on the material which they are made. Materials
used for brake pads should have stable and reliable frictional and wear properties under varying conditions of load, velocity, temperature and high durability, [4]. These factors must be satisfied simultaneously which makes it difficult to select effective brake pads material, [5].

Range of materials used in the manufacture of brake pads varies from asbestos formulations to semi metallic, organic and ceramics. In the past, asbestos was a favorite material in the manufacture of brake pads because it has a good ability to dissipate heat, but it has proved to be harmful to human health, [2], [3]. Currently, the brake pads are made from mineral fibers, aramid fibers, cellulose, glass fiber, steel fibers and copper, [6], [7]. Each material has its advantages and disadvantages related to: environmental conditions, wear, noise, braking capacity, but the final properties of each type of brake pads are influenced by the abrasive material. In technical literature are some types of brake pads, depending on the type of material that comes into contact with the brake disc: semi metallic, non-asbestos organic, low-carbon non-asbestos organic and ceramic.

Semi-metallic brake pads have metal content in percentage of 30-65%, organic compounds and resins for connection. They have a high thermal conductivity and high durability, but presents a loud noise and producing a high wear of the brake discs. Non-asbestos organic brake pads are composed of fiberglass, carbon, rubber, Kevlar and high temperature resins. They are quieter, but wear faster and produce more dust. Non-asbestos organic brake pads with a low metal content are made with a low metal content, to provide 10-30%, better heat transfer and better braking. They produce a large amount of dust and high levels of noises. Ceramic brake pads are made of ceramic fibre, non-ferrous materials, bonding agents and sometimes small amounts of metal. They have a high heat transfer capacity, high durability, produce less dust, have low noise and reduced wear of the brake disc. They are only used in light vehicles but not recommended for medium and heavy vehicles. On the other side, their price is higher than other brake pads.

Regarding the manufacture of brake pads, literature indicates that there are government rules that restrict the use of materials in the manufacture of brake pads, [2]. Recently, more research has been focused on the non-asbestos organic fibre reinforced metallic friction composites, [3].

The aim of this paper is to develop new organic material with low metal content for automotive brake pads without any harmful effect. In this sense, were prepared four different laboratory formulations with varying percentage of coconut fiber, friction modifiers, abrasive material and solid lubricant using powder metallurgy technique. The properties examined are density, porosity, hardness, mechanical properties, loss of weight, microstructural analysis and friction coefficient.

2. Technical requirements

2.1. Experimental procedures for formulation the samples

The new composite for brake pads was developed through the process beginning with the selection of raw materials, weighing, mixing, compacting and sintering, [8].

There are four formulations with different composition of coconut fibre content. The fabrication of composites containing seven ingredients was based on keeping the composition of five ingredients (around 75%) constant and varying two ingredients, namely aluminium and coconut fibre (around 25 %), Table 1, [8], [9].

In establish of the recipes it was considered the study realized in paper [2] referring to automotive brake pad formulations. Similar recipes were used by authors in paper [3]. In present paper, the difference lies of: adding hexamethtetramine, various proportions of components and in replacement of aluminium oxide with titanium oxide. We considered this approach because a small change of the composites recipe and manufacturing technology can improve the characteristics of the final product.

All materials were prepared in powder form, [3]. Graphite was added to minimize fracture in the mixing process. In this investigation the coconut fibre was used as a filler material, [3]. The method used in fabrication of new developed composite was powder metallurgy technique. The prime reason for using the powder metallurgy process is the possibility of obtaining uniform parts and reducing tedious and expensive machining processes, [3].
Table 1. The recipes used in the product of composite brake pads material, [8], [9]

| Samples | Aluminium (%) | Hexametil tetramine (%) | Graphite (%) | Zirconium oxide (%) | Silicon carbide (%) | Titanium oxide (%) | Phenolic resin (%) | Coconut fibre (%) |
|---------|---------------|--------------------------|--------------|---------------------|---------------------|-------------------|------------------|------------------|
| C1      | 25            | 6                        | 4            | 2                   | 10                  | 13                | 40               | 0                |
| C2      | 20            | 6                        | 4            | 2                   | 10                  | 13                | 40               | 5                |
| C3      | 15            | 6                        | 4            | 2                   | 10                  | 13                | 40               | 10               |
| C4      | 10            | 6                        | 4            | 2                   | 10                  | 13                | 40               | 15               |

The ingredients were mixed in a drum mixing machine, type PM 100, to ensure the macroscopic homogeneity, using a chopper speed of 1500 rpm. First, aluminium and titanium oxide were churned together for 6 minutes. Zirconium oxide and silicon carbide were switched on at 120 rpm. After this, graphite and coconut fibre were added and mixed for 16 minutes. Then phenolic resin was added and the mixer was run for 5 minutes. The mixing sequence and time of mixing of each component led to proper uniformity in the mixture. If mixing time is low, proper homogeneity cannot be achieved. If it is too high, it does not improve the homogeneity further. Then, the materials were introduced in a mould presented in Figure 1. The settlement order in the mould is: an aluminium foil layer at the bottom of the mould, a layer of graphite on the aluminium foil, introduce the mixture into the mould, the piston is wrapped in aluminium foil, after that the mould with the mixture were pressed at the temperature room, finally the mould is insert in the oven to the temperature of 200°C, [10].

![Figure 1. The mould for making samples, [10]](image1)

![Figure 2. Finished composite samples with variable addition of coconut fibre](image2)

After 15 minutes, a compaction was performed using a hydraulic press machine under a force of 0.5 KN. After that, the material was sintered in an oven at a temperature of 200°C for an hour, after which cooling was carried out in air for 12 hours. Good consistency of the sample is due by heating-cooling regime. Extracting the samples from the mould was done without sticking problems, which is solved by using aluminium foil layer graphite. All samples are appropriate in appearance, shape and consistency. The surfaces of the samples were then polished with a grinding wheel to attain the desired thickness and smooth surface. The finished composite samples were shown in Figure 2.

In order to characterize the new composite material, were achieved tests to determine density, porosity, hardness, thermo-gravimetric analysis, mechanical testing, and microstructure. The samples for each test were carried out by cutting in concordance with actual standards.

2.2. Characterization of the brake pad material
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 measuring their volume by liquid displacement method. The specific gravity formula is, [3]:

\[
\text{Density} = \frac{\text{mass}}{\text{volume}}
\]
\[ \rho = \frac{m}{V} \]  

The results shown in Table 2 and represents the average density of five readings for each formulation.

| Samples | Density (g cm\(^{-3}\)) | Porosity (%) | Hardness HRS |
|---------|-------------------------|--------------|--------------|
| C1      | 2.59                    | 21.23        | 55.7         |
| C2      | 2.42                    | 15.63        | 69.3         |
| C3      | 2.38                    | 16.60        | 62.6         |
| C4      | 2.29                    | 23.43        | 41.7         |

Composite C4 with 15% coconut fibre content shows lower density compared with other three formulations. The density of composites which have more coconut fibre shows lower density than formulation of C1 without coconut fibre. The high density of C1 is explained by the greater amount of aluminium in the recipe. Comparing the densities of the materials obtained in this paper with the paper [3] it was observed higher densities. This is explained by the fact that the chosen recipe consists of titanium oxide which is denser than aluminium oxide. On the other hand, the densities obtained are much lower than in the case of metallic and semi-metallic pads.

The function of porosity is to absorb energy and heat. Theoretically, lower porosity will result in higher friction coefficient and wear rate, [3]. The paper [11] presented that increasing porosity by more than 10% could reduce the brake noise. On the other side, brake pad should have a certain amount of porosity to minimize the effect of water and oil on the friction coefficient, [3]. Porosity test was performed in accordance with Japanese Standard JIS D 4418: 1996, [3]. The specimen was cut to dimensions: 25 mm x 25 mm x 7 mm, then left in a desiccator for 24 hours at room temperature and cooled to room temperature in desiccator, Figure 3. The sample was weighed to the nearest 1 mg before test sample placed in the test oil in the container and keeps at 90 ± 10 °C for 8 hours. The test sample was left in the oil container for 12 hours until the oil cools to the room temperature and then withdrawn from the oil container, [3], Figure 4.

![Figure 3. The test samples left in a desiccator](image)

![Figure 4. The test samples immersed in the oil container](image)

Finally, the sample was rolled on a piece of cloth to remove oil from the test sample. The sample was weighed again to the nearest 1 mg, [3]. Table 2 shows the porosity test results for all formulations of brake pad materials. From the porosity results it can be seen that two brake disc formulations, such as C2 and C3, shown lower percentage of porosity compared to other two formulations. Same conclusions were obtained in the paper [3], the difference consisting on values of porosity. In the present paper were obtained higher values of porosity which is explained by the different manufacturing technology of composite materials.

The hardness test was conducted on a Rockwell unit PH-C-01 /02 in accordance with EN ISO 6508-1 standard: 2002. The hardness measurements were conducted under test load of 980.6 N, the
steel ball diameter is 1.58 mm, using scale B as stipulated in the standard. The measurements were performed at a distance of 13 mm. Drive speed of the load was 0.8 m/s and the holding time was 10 s. The hardness of the sample represented the arithmetic mean of the readings five indentations, [8].

Table 2 shown the hardness of the four formulations brake pads material. It can be seen that the hardness value of C2 is the highest of all and the hardness value of C4 show lower hardness value, which is explaine by the ductile nature of the material. Formulation C2 composite has the highest hardness value of 69.3 HRS because of having more aluminium content used as a matrix. Varying content of aluminium and coconut fibre will exhibit different hardness value of the material. Compared to work [3], hardness achieved are higher due hexametiltatramine, which has the role to transform the phenolic resin which is a thermoplastic material into thermosets.

![Figure 5](image1.png)

**Figure 5.** A complete set of samples for compression test

![Figure 6](image2.png)

**Figure 6.** Sample C3 during compression tests

The compressive strength was done using a universal testing machine type Zwick/Roll Z005 with a corresponding software name Test-Xpert II, that retrieves data from experimental testing machine and process them statistically. The dimensions of the samples are: 25mm x 25mm x 7 mm. Figure 5 shows a complete set of samples to achieve compression test. The samples were subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded, Figure 6. Table 3 shows the compressive strength for new composite materials developed.

| Samples | Mechanical strength | Compression load at tensile strength (N) | Compression strength (MPa) |
|---------|---------------------|-----------------------------------------|---------------------------|
| C1      |                     | 1260                                    | 21.45                     |
| C2      |                     | 2710                                    | 41.56                     |
| C3      |                     | 2610                                    | 39.72                     |
| C4      |                     | 2940                                    | 47.67                     |

The compressive strength showed the formulation of C4 exhibited higher strength to withstand the load application and higher ability to hold the compressive force. The ultimate strength of the formulation C4 is corresponds to the stress of 47.67 MPa. The sample starts to break at stress of 45.21 MPa.

The four formulations for brake pads are subject to thermo-gravimetric analysis. Thermo-gravimetric analysis reveals the weight loss when the composite materials were exposed to 50–300º C, [6]. Thermo-gravimetric analysis of the developed composites is carried out in a TLB 180 series type machine at a heating rate of 15º C/min. The sample is weighed accurately with a balance of fourth decimal. Figure 7 present the procedure of weighing of the samples utilized in thermo-gravimetric
analysis. Each sample was placed in a crucible that is inserted into the furnace maintained at 250 to 300°C and soaked for two hours. Then the crucible shall be removed from the furnace, cooled in a dessicator and weighed, [6].

![Image](image1.png)

**Figure 7.** A complete set of samples for compression test

The weight loss % of composite material during exposure was calculated with relation (2), [6]:

$$\Delta M = \frac{M_2 - M_3}{M_2 - M_1} \times 100$$  \hspace{1cm} (2)

In relation (2) M_1 represents the weight of empty crucible, [g]; M_2 is the weight of crucible and the sample, [g]; and M_3 is weight of crucible and the sample after ignition, [g].

Figure 8 shows thermo-gravimetric analysis results for the developed composites which reveals the weight loss % when the samples were exposed to 50–300°C.

Loss by weight % is as follows: C4 < C3 < C2 < C1. Hence C4 has better thermal stability than the other composites. We can observe that the higher of coconut fibre content offer to composite materials higher thermal stability.

For morphology study scanning electron microscopy SEM was used to observe and investigate the distribution of microstructural features along with elemental constituents of new composite reinforced with various content of coconut fibre, Figures 9.

![Image](image2.png)

**Figure 9.** SEM microstructure for composite samples with variable addition of coconut fibre

The resin binder in dark region along with aluminium distribution in white region can be saw in microstructure for composite C1. This formulation showed that aluminium with graphite and zirconium oxide content more aluminium element. The graphite element in grey regions also can be visualized in Figure 9.

The microstructures of C2 composite showed the homogeneous distribution of abrasive, solid lubricant, binder and friction modifier in the aluminium matrix. Higher amount of aluminium is present in C4 due to more coconut fibre in the formulation. The other three structures showed the
heterogeneously distribution of elements which explain by different weight of elements. Also the sintering process of materials at different temperatures contribute to change the structure.

To determine the friction coefficient of the composites developed was used Tribometer TR-20 Micro, Figure 10. This equipment allows the study of the wear behaviour of materials by pin-on-disk method. This is computerized and programmable to study friction against speed, load, temperature and wear. The device enables mounting of circular or rectangular samples which moves a steel ball with a diameter of 6 mm. In order to achieve tests were used samples with dimensions 25x25x10 mm. Such tests were carried out on four samples of each composite recipe.

The results shown in this paper are the average of four tests per sample. In conducting the experimental determinations, test parameters were: the loading force $F=20N$, test range $R=7.5$ mm, ball speed $n=150$ rot/ min and time test $t=60$ min. The distribution of load will also affect the friction level. The initial running of a new sample is associated with a slow increase of the friction coefficient. The results of various composites named C1-C4 are shown below in Figures 11 to 14.

![Tribometer TR 20 Micro](image)

**Figure 10.** Tribometer TR 20 Micro

![Graph](image)

**Figure 11.** The friction coefficient for composite C1
The initial running of each sample is associated with a slow increase of the friction coefficient. The friction coefficient, touch the value of 0.26 for all samples. For the sample C1 and C2 there is a
fluctuation of friction coefficient, and to the other two, after a certain trial, the friction coefficient is stable. From Figure 13, the friction coefficient for C4, goes as high as 0.26 which is attributed to the good thermal stability caused due to lesser amount of weight loss as found from the loss of ignition test. Larger amount of coconut fibre in brake composite does not only provide high and stable friction coefficient, but also strengthens composite body. More content of coconut fibre in the brake composite C4 causes more fibres to appear on the friction surface. This made the true contact area between the fibres and steel ball, so a higher friction coefficient is achieved.

In general, the brake pads with high coefficient of friction provides better braking with a low effort brake pedal, but tend to lose efficiency at high temperatures, increasing the braking distance. The brake pads with a constant low friction coefficient and do not lose braking efficiency at high temperatures, but they need a force of the brake pedal higher, [2].

3. Conclusions
Based on the results obtained in this paper the following conclusions can be made:

- Composite C4 has lower density, but higher porosity compared to other formulations;
- C2 and C3 composites even have a greater density than C4, but they have less of porosity;
- Formulation C2 has the highest hardness value of 69.3 HRS;
- Composite C4 exhibited higher strength to withstand the load application and higher ability to hold the compressive force;
- Composite C4 is more efficient than other compositions since it has good thermal stability. A good thermal stability have composites C2 and C3;
- From the SEM study it can be see that microstructures of C2 composite showed the homogeneous distribution and this composite modelling appropriate percentage between matrix and reinforcement volume;
- Composites C3 and C4 is more efficient than other compositions since it has stabile friction coefficient. It can be concluded that C3 and C4 showed almost similar properties from the four formulations and it could be utilize in the manufacturing of brake pads.
- The higher coconut fibre content, led to the better friction performance in the pin on disc test procedure.

Future research directions proposed prescription in the recipe to increase the friction coefficient. The study led that natural coconut fibre is a potential candidate filler material for the light and medium weight vehicles brake pads.

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