Experimental Analysis of Tribological Behaviour of Organic Composites Materials

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Abstract. The friction material plays an important role in ensuring the quality of the brake pads. Friction and wear characteristics of friction material are the decision makers in new formulations of composites materials developed for the brake systems. In this work, it was developed four recipes of frictional materials using coconut fibres reinforcement in aluminium matrix, using powder metallurgy technique. For these new materials developed are presented the physico-mechanical characteristics in accordance with various relevant international standards. These materials for brake pads are tested to determine their tribological behaviour in a standard pin on disc equipment. In this sense, the wear resistance and the evolution of friction coefficient of these composites materials were determined. The comparative study reveals that proposed composites have acceptable level of physic-mechanical and tribological characteristics. The study allows selecting the best formulation of frictional materials for use in manufacturing of brake pads for vehicles.

1. Introduction
Brake pads play an important role in braking system. These are of different types, and their choice is based on: vehicle type, engine type and general characteristics of the standards in effect [1]. The main components of the brake pads are: friction material, intermediate layer, adhesive, main frame and damping layer. Of all these components, the friction material plays an important role in ensuring the quality of the brake pads in the braking system assembly [1]. This is a mix of materials in which each component has a certain concentration for each type of vehicle. The ideal brake friction material should have constant coefficient of friction under various operating conditions and it should also have various desirable properties such as: resistance to heat, water and oil, low wear rate, high thermal stability, low level of noise, and does not damage the brake disc [2].

In general, each formulation of friction material has its own frictional behaviours and wear-resistance characteristics. Friction material is a heterogeneous material and is composed of a few elements and each element has its own function. Changes in element types or weight percentage of the elements in the formulation may change the physical, mechanical and tribological properties of the brake friction materials [1], [2], [3]. Increasing braking performance can be achieved by improving the physical, mechanical and tribological characteristics of the friction material used in the manufacture of the brake pads [1], [3].
Earlier researchers have concluded that there is no simple correlation between friction and wear properties of a friction material with the physical and mechanical properties [4], [5], [6]. Therefore, each new formulation developed needs to be subjected to a series of tests to evaluate its friction and wear properties. Friction and wear characteristics of friction material play an important role in deciding which new formulations developed are suitable for the brake system. Composition and formulation of brake pads also play a big role on the friction behaviour, and since composition-property relationship are not known well enough [7]. Typical values for friction coefficient are 0.3 to 0.6 taking into account the operating conditions. Studies release that the friction coefficient fluctuate between 0.3 and 0.5 through a pressure range 1 to 2 MPa [1], [2], [8].

Friction materials have also been produced in the literature consisting of organic materials, for example: eggs shells, bananas peels, palm fibres, periwinkle shells, cocoa beans shells [6],[8],[9],[10]. Current trend in the research field of automotive industry is to utilization of different wastes as a source of raw materials for composite development due to the carcinogenic effects of asbestos [5], [6]. The papers in the field has also shown composite materials made with coconut fibre, especially in tropical countries [8],[9]. Coconut fiber composite materials have a wide range of applicability in these countries, such as: building materials, marine ropes, fishing gear, furniture, household appliances [8].Regarding coconut fiber in the literature, it has been shown that it has properties that approve its application in the manufacture of friction materials [4], [7], [9].

In this work, were developed four recipes of frictional materials using coconut fibres reinforcement in aluminium matrix using power metallurgy technique. Each sample was subjected to determine the physical, mechanical, friction and wear characteristics, in accordance with various relevant international standards. Pin-on disc equipment TR-20 is used to evaluate the friction and wear characteristics of the organic composite materials used for brake pad applications. The comparative study reveals that proposed composites has acceptable level of physic-mechanical and tribological character. The study allows selecting the best formulation of composite for use in manufacturing of brake pads for vehicles. Considering that in our country coconut is an exotic fruit, its price is relatively high, this being an initial disadvantage for the friction materials produced in this paper.

2. Experimental Methodology
In this work, it has been made four recipes of composite materials using coconut fibres reinforcement in aluminium matrix using power metallurgy technique. Their purpose is to make brake pads for small and medium vehicles. The choice of constituents was made following the study of the literature in the field and according to their role in meeting the requirements for the brake pads [4], [5], [7], [8], [9], [10]. The recipes of every composite contain eight ingredients; six ingredients were maintained constant and two ingredients were varied, aluminium and coconut fibre in complementary manner as shown in Table 1, and 2.

| Table 1. Composite recipes for Sample 1 and Sample 2 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| No. of sample   | Aluminium (%)   | Graphite (%)    | Zirconia oxide (%) | Silicon carbide (%) | Titanium oxide (%) | Phenolic resin (%) |
| Sample 1        | 20              | 5               | 2                | 11              | 11              | 40              |
| Sample 2        | 15              | 5               | 2                | 11              | 11              | 40              |

| Table 2. Composite recipes for Sample 3 and Sample 4 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| No. of sample   | Aluminium (%)   | Graphite (%)    | Zirconia oxide (%) | Silicon carbide (%) | Aluminium oxide (%) | Phenolic resin (%) |
| Sample 3        | 20              | 5               | 2                | 11              | 11              | 40              |
| Sample 4        | 15              | 5               | 2                | 11              | 11              | 40              |
In order to produce the composite materials in the laboratory, the following steps are taken: weighing, blending, cold pressing, oven storing, hot pressing, hot and cold cooling. After producing the samples according to the four recipes, these will be characterized and tested. All laboratory equipment used take placed at Engineering and Management Department, Faculty of Engineering Hunedoara.

The constituent elements of the recipes were mixed with a mechanical stirrer at 3000 rpm, respecting a certain order of introduction of the elements into the mixture. Thus, for the first time, aluminium and silicon carbide were mixed for 10 minutes. Separately was mixed, for 5 minutes, zirconium oxide and titanium oxide (for Sample1 and Sample2), respectively zirconium oxide and aluminium oxide (for Sample3 and Sample4). This mixture was added over the first one, after which stirring was continued for 4 min at a speed of 1500 rpm. Graphite and coconut fibre was added and mixed at the same speed for another 10 min. The phenolic resin and hexamethyltetramine were mixed separately. The solid mixture was introduced over the liquid mixture, the entire composition being mixed for 10 minutes at a speed of 1000 rpm to obtain the homogeneity of the composition. At the end of the mixing process, the composition, having the appearance of a viscous paste, was introduced into the mold for sintering. The mold allows making samples of 95 mm diameter. The mold base and its piston have been protected with aluminium foil. Before to the introduction of the composition into the mold, a thin graphite layer was sprinkled on, for easy extraction of the sample at the end of the sintering process. After insertion of the mixture into the mold, the screws are tightened and a cold pressing was performed, at a pressure of 20 MPa for 5 minutes. The sample mold assembly was introduced into the heated oven at 200°C, where the sample was held for one hour. After this time a hot pressing was performed with a pressure of 50 MPa, after which the sample was reintroduced into the furnace at 180°C where it was held for 4 hours. It is mentioned that the pressing was intermittent, taking pauses at equal intervals in order to eliminate the gases into sample. Cooling was done in two steps, in the first step in the oven at 100 °C for 8 hours, for convert the resin from thermoplastic to thermosetting and in the second step, in ambient air for 48 hours [4], [5], [6], [7], [8]. The stages and parameters of the sintering technology of composite materials have been established as a result of several experimental tests that allowed critical analyses to be performed and successive improvements.

Figure 1 shows the samples obtained from the four recipes proposed at the end of the sintering process.

![Sample 1](image1.png) ![Sample 2](image2.png) ![Sample 3](image3.png) ![Sample 4](image4.png)

**Figure 1.** Samples obtained from the four recipes proposed at the end of the sintering process.

The samples for each test were carried out by cutting in concordance with actual standards, in order to determine the physico-mechanical and tribological characteristics.

### 3. Discussion and results

Table 3 presents the results of physical and mechanical characteristics of the produced composites. The density values for the obtained composite materials are relatively low compared to the metal densities. The highest densities are obtained by the specimens manufactured with 5% coconut fibre recipes (Sample 1 and Sample 3), due to the fact that these recipes contain the largest amount of metal. Density depends on the percentage of ingredients included in recipes, given that a metallic element has
a density greater than an organic element [2], [4] this justifying the values obtained for density according to the percentage of metal introduced into the recipe.

In Table 1, it can be seen that all composite materials have higher porosity in water than porosity in oil. Similar results were obtained in works [6]. The smallest porosity has Sample 2, followed by Sample 4, both of them are made with 10% coconut fibre. Specialty literature states that the brake pads must have a certain porosity to minimize the effect of water and oil on the friction coefficient and to reduce the noise during braking [4], [5]. The obtained values were compared with those obtained by other researchers who studied the behaviour of composite materials with coconut fibre and similar destination and [4], [6].

### Table 3. Physico-mechanical characteristics for the samples

| Samples   | Density (g cm⁻³) | Porosity in water (%) | Porosity in oil (%) | Hardness HBS | Breaking force (N) | Compressive strength (N mm⁻²) | Modulus of longitudinal elasticity (N mm⁻²) |
|-----------|-------------------|-----------------------|---------------------|--------------|-------------------|-------------------------------|----------------------------------|
| Sample 1  | 1.54              | 0.75                  | 0.29                | 128          | 11886             | (-)27.6141                    | 262999.142                       |
| Sample 2  | 1.37              | 0.55                  | 0.14                | 176          | 14577             | (-)35.7912                    | 32537.454                       |
| Sample 3  | 1.46              | 0.88                  | 0.32                | 109          | 8280              | (-)25.6162                    | 19406.212                       |
| Sample 4  | 1.29              | 0.62                  | 0.17                | 150          | 12992             | (-)33.0730                    | 26248.412                       |

The lowest hardness has Sample 3 (109 HBS), followed by Sample 1 (128 HBS) both having the same amount of aluminium and coconut fibre. Different values of hardness are explained by the fact that Sample 1 contains titanium oxide, and in Sample 2 aluminium oxide. The hardness values are higher than those of other materials used for brake pad applications produced from other researchers [4], [6], [9].

In order to perform a qualitative analysis of the recipes produced on the basis of the established sintering technology and considering the destination of these materials, the compressive strength for each sample Sample1-4 was determined. Compression test was performed with universal testing machine. The compressive strength has increased with an increase in coconut fibre content, due to the correct dispersion of the filler particles with the binder, which has led to an appropriate interaction between these elements. Proper particle dispersion has improved the interaction between coconut fibres and binder. Table 1 shows the average values of mechanical characteristics of composite materials produced after four recipes. The highest compressive resistance has Sample 2, followed by Sample 4. The ultimate strength of the Sample 2 corresponds to 35.7912 N/mm². The breaking of the Sample 4 composite corresponds to a stress of 33.0730 N / mm², and breaking force of 12992N / mm². The highest value of the longitudinal elastic modulus was recorded for Sample 2.

The friction coefficient was determined at the University Politehnica Timișoara, Department of Materials and Manufacturing Engineering. Tribological researches of composite material developed have the following objectives: to study the evolution of wear and the friction coefficient. A pin-on-disc equipment, TR-20 was used to investigate the dry sliding wear characteristics of organic composite materials as per ASTM G99-95 standards. The equipment has four adjustable bays that allow the fitting of various shapes and sizes. The pin of equipment is a steel ball of 6 mm diameter. The pin on disc equipment is programmable to study friction against speed, load and wear. The specimens for the tribological tests are rectangular with the dimensions (25x7x7mm) and they were polished for friction and wear tests. The tests were conducted for five hours at load of 15N. Wearing diameter was 15 mm, speed is 150 rpm and test distance is 2200 m. Figure 2 shows a sample mounted in the pin on disc equipment prepared to determine wear and friction coefficient.

The initial weight of the specimen was measured with an electronic weighing machine, model Sortorius CP2202S-OCE with a least count of 0.0001mg. After running through a fixed time period, the specimen were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear, [4], [5], [10].
The difference in the weight measured before and after the test, gives the wear of the samples [5]. The wear rates were determined using the weight loss method and the results are presented in Table 4. Figure 3 shows the specimens at the end of the tribological tests, with highlighting the friction trace.

| Composites | Initial weight (g) | Final weight (g) | Wear mass (g) | Wear mass relative (%) | Mass wear on the rest distance (g m⁻¹) | Max. friction coefficient (μ) |
|------------|--------------------|------------------|---------------|------------------------|----------------------------------------|-------------------------------|
| Sample 1   | 7.7657             | 7.6057           | 0.16          | 2.06                   | 0.00007272                             | 0.358                         |
| Sample 2   | 7.5917             | 7.5517           | 0.04          | 0.52                   | 0.0001818                              | 0.415                         |
| Sample 3   | 8.2419             | 8.1119           | 0.13          | 1.57                   | 0.0005909                              | 0.331                         |
| Sample 4   | 8.7389             | 8.6789           | 0.06          | 0.68                   | 0.0002727                              | 0.452                         |

Figure 4 presents the variation of mass wear for the organic composite materials and figure 5 presents the evolution of the coefficient of friction during the test. The wear resistance of the material is the inverse of the specific wear rate [5]. In this context, Sample 2 has the highest wear resistance. The wear resistance of Sample 4 is close to the wear resistance of Sample 2.

**Figure 2.** A sample prepared to determine wear and friction coefficient

**Figure 3.** The specimens at the end of the tribological tests, with highlighting the friction trace

**Figure 4.** Variation of mass wear for the organic composite materials

**Figure 5.** Evolution of the coefficient of friction during the test
The initial running of each sample is associated with a slow increase of the friction coefficient. The friction coefficient touches the value of 0.3 for all samples. After a certain trial, the friction coefficient became stable. With increased friction coefficient, the mass wear was lower.

4. Conclusions
From the results and discussion of this study it can be observed:
- the fabrication of organic composites materials depends on mixing sequences, speed and time of mixing;
- the density of composite materials produced by own recipes, depends on the percentage of metallic component introduced in the recipe, which confirms the data from the technical literature;
- the smallest porosity both in water and oil have Sample 2 and Sample 4 that are made with 10% coconut fibre;
- the compressive strength has increased with an increase in the coconut fibre content;
- the higher coconut fibre content, led to the better friction performance in the pin on disc procedure;
- for all samples after a certain trial time, the friction coefficient became stable;
- Sample 2 and Sample 4 is more efficient than other compositions, since it has a good coefficient of friction with less wear rate;
- Sample 2 and Sample 4 made with 10% coconut fibre content have the best physico-mechanical and tribological characteristics;
- Sample 2 and Sample 4 showed similar properties and could be used in fabrication of non-asbestos friction materials for brake pad application;
- the disadvantages that exist with newly created composites consist in: coconut fibre has a relatively high price, the fruit being an exotic one and the organic fibre has non uniform filler size.

5. References
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