Friction and wear characteristic of organic brake pads material

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Abstract. Many parts of motor vehicles contribute actively or passively to increasing operation performance. The safety is closely related to the effectiveness of the braking system. Due to the fact that the automotive industry is a branch of economics that uses products obtained in almost all other industries, the current concerns are directed towards the application of the latest research in the field of modern materials and technologies in all fields involved in the manufacture of motor vehicles. The proposed and carried of this paper aimed to presented, obtained, characterize and test some organic composite materials, designed to make brake pads for the braking systems of small cars with medium performances. The experimental research strategy included the determination of the functional characteristics of organic composite materials developed. In this respect, experimental laboratory determinations were carried out on the friction and wear of composite materials produced, using standardized test methods. The knowledge of these elements provides the possibility of pertinent assessments on the durability in operation of the composite material used for the manufacture of brake pads.

1. Introduction

Brake friction materials are needed for aircrafts, helicopters and passagers cars [1-3]. They can be classified into semi-metalic, metallic, organic and ceramic types [3].

Over the time, the most used brake pads were those based on asbestos fibres [4]. Studies shown that asbestos fibres have harmful effects both on the environment and on human health [4], [5]. For this reason, it has been decided to ban this reinforcement fibre in the friction materials intended to make the brake pads. This created a scientific and technical problem that has caused by replacement of asbestos with other eco-friendly materials [6-9]. Paper [10] lists several materials that can replace asbestos, but none has the same properties as this one, but it offers some features with similar performance. The current trend in scientific research in the field of motor vehicles is to use composite materials with natural fibres because they offer numerous economic and environmental benefits [7].

The organic friction material for brake pads is a heterogeneous material and is composed of several elements. Each of these contributes to improving the friction properties at high temperatures, to increasing strength and stiffness, to prolong life, reduced porosity and noise. Ideally, the friction material for making the brake pads must have stable friction coefficient under different operating conditions such as: applied loads, temperature, speeds, braking mode in dry or wet conditions, so as to maintain the braking characteristics of the vehicles [4]. Also, besides the previously mentioned properties, the friction material must have: low wear rate, high thermal stability, low noise and not damaging the brake disc. From a practical point of view it is impossible for all these properties to be
met. Therefore, some requirements need to be mitigated to meet others. In general, each recipe of friction material has its own unique friction behaviour and wear-resistant features [4], [11].

At present, different types of fibers are used in making brake pads, such as: calcium silicate, mineral fiber, ceramic, carbon, cellulose, fiberglass, vermiculite (aluminum silicate hydrated calcium), aluminum silicate, basalt fiber, steel or copper fibers polyacrylonitrile polyester fibers, etc., [4], [7], [10], [11]. Each of them has advantages and disadvantages, such as: braking capacity and dissipation of heat, braking behavior, noise and vibration, but the final properties of each type of brake pad depend on the abrasive used in their composition [6], [11].

A good number of studies has been done on the organic composites materials, [2-11]. Organic fibers used to reinforce composite materials can be obtained from a wide variety of plants: strains of cereals (cane, barley, rice), textile plants (flax, hemp, raffia, cotton), other plants with industrial uses (sugar cane, reed, sisal, etc. [6]. A big disadvantage of organic fibres is the differences in anatomical and chemical structure, which determines physico-chemical properties with large variations from one species to another, sometimes even within the same species due to vegetation and microclimate conditions [6]. On the other side, technical literature showed that there is no simple correlation between the frictional physical-mechanical properties of the friction material [9], [12]. Therefore, each newly developed composite material recipe developed must be subjected to a series of tests to assess the friction and wear properties [9], [12].

The proposed and carried of this paper aimed to presented, obtained, characterize and test some organic composite materials, designed to make brake pads for small cars with medium performances. The experimental research strategy included the determination of the functional characteristics of organic material developed. In this respect, experimental laboratory determinations were carried out on the friction and wear of composite materials produced, using standardized test methods. The knowledge of these elements provides the possibility of pertinent assessments on the durability in operation of the composite materials used for the manufacture of brake pads.

2. Developed and production in laboratory stage of composites materials

In order to establish the recipes was taken a mixture of raw materials, comprising eight components. Their choice was made in according to the destination of the brake pads (for small vehicles and average performance) and to the scientific literature. In order to establish prescriptions was started from a mixture of raw materials, including: aluminium, graphite, zirconium oxide, silicon carbide, titanium oxide, phenolic resin and coconut fibre. The recipes for composites materials produced in laboratory stage are shown in Table 1.

Table 1. Chemical composition of composite materials

| Sample | Aluminium (%) | Graphite (%) | Zirconia oxide (%) | Silicon carbide (%) | Titan oxide (%) | Phenolic resin (%) | Hexamethyl tetramine (%) | Coconut fibre (%) |
|--------|---------------|--------------|--------------------|--------------------|-----------------|--------------------|-------------------------|----------------|
| C1     | 20            | 5            | 2                  | 11                 | 11              | 40                 | 6                       | 5              |
| C2     | 15            | 5            | 2                  | 11                 | 11              | 40                 | 6                       | 10             |

The production of organic composite materials for brake pads is based on powder metallurgy [3], [5], [7], [11]. The main reason for using powder metallurgy is to obtain an increased homogeneity of composite materials [4]. The scheme for the production, characterization and testing of composite materials produced in the laboratory is shown in Figure 1.
Parameters of sintering technology have been established as a result of several experimental tests, which allowed for critical analysis and successive improvements. Parameters of the sintering process are presented in Table 2.

| Heating temperature (°C) | Time in oven (min) | Pressing force (KN) | In oven | Cooling In air | Temperature (°C) | Time (min) | Temperature (°C) | Time (min) |
|--------------------------|--------------------|---------------------|---------|----------------|------------------|------------|------------------|------------|
| 200                      | 60                 | 20                  | 100     | 480            | 25               | 2880       |                  |            |

In order to characterize and test composite materials produced in laboratory stage, were made samples to determine physical-mechanical and functional characteristics of these friction materials.
3. Discussion and results
For composite materials developed and produced in laboratory stage were determined density, oil and water porosity, hardness HRS, Young modulus and compressive strength. The results are presented in Table 3.

Table 3. Physico-mechanical characteristics of organic friction material

| Samples | Density (g cm\(^{-3}\)) | Porosity (%) | Hardness HRS | Breaking force (N) | Young modulus (N mm\(^2\)) | Compressive strength (N mm\(^2\)) |
|---------|--------------------------|---------------|--------------|-------------------|---------------------------|-------------------------------|
| C1      | 1.57                     | 0.29          | 0.75         | 59                | 12887                     | 26299.142                    | -27.6141                     |
| C2      | 1.35                     | 0.16          | 0.55         | 61                | 15766                     | 32537.454                    | -38.7788                     |

Table 3 shown that density values for composite materials are relatively low compared to metal densities. On the other hand, the density of the samples decreased with the increase in the amount of coconut fibre. In the literature there have also been produced friction materials with coconut fibre [7], [13], and the conclusions obtained are similar.

As for the water and oil absorption capacity, they decrease with the increase in the amount of coconut fibre. The reduced water and oil absorption capacity can be attributed to the increase in the bond between the binder and the filler, due to proper homogenization of the constituents. The variable content of coconut and aluminium fibres determines different hardness values of sample. Thus, it is observed that the highest value of the hardness was obtained for C2. This sample being made with 10% coconut fibre [13]. Table 3 shows that the compressive strength of composite C1 is lower than C2 sample.

The sample with the largest amount of coconut fibre (10%) has the highest compressive strength, respectively the highest value of the request effort. This is explained by the fact that the coconut fibre particles were evenly distributed over the aluminium matrix, making a corresponding interference between them [8], [9]. The compressive strength and the Young modulus of the composite materials increase with an increase in the amount of coconut fibre. Similar conclusions being reached also in paper [3].

In order to test composite materials, were performed experimental determinations which had the objective to study the influence of some parameters of the working regime (pushing force, slip speed, test time, friction mode) on the functional characteristics of composite materials and study the evolution of friction coefficient according to the pressing force. The knowledge of these elements provides the possibility of pertinent assessments on the durability in operation of the composite materials used for the manufacture of brake pads.

The study of the influence of some parameters of the working regime will be carried out on an experimental plant. The principle of this consists in pressing a pin made of composite materials (C1, C2) on a rotary disc made of cast iron, in order to determine wear characteristics [5], [13]. The applied load simulates the contact pressure between the friction couplers.

For the experiments, were made cylindrical samples (pins) from composite materials (C1-C2) and a cast iron disc made in laboratory assimilated to the G 2500, according to ASTM A 159 norms.

The disk and pins used in the experiments are shown in Figure 2.

![Figure 2. Iron disc and pins using in experimental determination](image)
The main parameters used in these experiments are presented in Table 4.

**Table 4. Parameters of experimental determination**

| Sliding speed (m s⁻¹) | Test range (mm) | Length of test (m) | Test time (min) |
|----------------------|-----------------|--------------------|-----------------|
| 3.92                 | 25              | 2000               | 8.5             |

The mass and dimensional characteristics of cast iron discs and composite pins at the beginning and to the end of experiments are presented in Table 5.

**Table 5. Dimensional characteristics of samples**

| No. | Samples  | Initial weight of samples (g) | Final weight of samples (g) | Initial height of samples (mm) | Final height of samples (mm) |
|-----|----------|-------------------------------|-----------------------------|--------------------------------|-----------------------------|
| 1   | Cast iron S1 | 50.8934                      | 50.6214                     | -                              | -                           |
| 2   | C1       | 7.8657                       | 6.3243                      | 27.5                           | 18.4                        |
| 3   | C2       | 7.2317                       | 6.7532                      | 26.4                           | 17.8                        |

The wear parameters for cast iron samples and composite samples are shown in Table 6.

**Table 6. Wear parameters for cast iron and composite pins**

| No. | Samples  | Wear mass (g) | Wear intensity (g m⁻¹) | Relative durability to wear |
|-----|----------|---------------|------------------------|-----------------------------|
| 1   | Cast iron S1 | 0.272         | 0.000136               | -                           |
| 2   | C1       | 1.5414        | 0.0007707              | 0.1764                      |
| 3   | C2       | 0.4785        | 0.0002394              | 0.1839                      |

Table 6, shown that the highest wear intensity was obtained for the composite C1, and the smallest for C2 composite. Also, the highest relative durability of wear was obtained for the composite containing 10% coconut fibre (C2).

During experiments, sample C2 was timed and weighed at intervals and lengths the results obtained are in Table 7, [13].

**Table 7. Experimental results on variation in mass and height of sample C2**

| Time (min) | Length route (m) | Mass (g) | Absolute weight reduction (g) | Relative weight reduction (%) | Heigh (mm) | Absolute heigh reduction | Absolute heigh reduction |
|------------|------------------|----------|-------------------------------|-----------------------------|------------|--------------------------|--------------------------|
| 0          | 0                | 7.2317   | 0                             | 0                           | 26.4       | 0                        | 0                        |
| 2.12       | 500              | 6.7323   | 0.4994                        | 6.9057                      | 23.1       | 3.30                     | 12.5                     |
| 4.25       | 1000             | 6.0819   | 1.1498                        | 15.8994                     | 21.0       | 5.40                     | 20.45                    |
| 6.37       | 1500             | 5.9122   | 1.3195                        | 18.2460                     | 19.4       | 7.04                     | 26.66                    |
| 8.5        | 2000             | 5.7532   | 1.4785                        | 20.4447                     | 17.8       | 8.60                     | 32.57                    |

In order to establish simple correlation equations, the results presented in Table 7 were processed in Excel program and the graphs being presented in Figures 3, 4 and 5.
Figure 3. Wear mass for C2 sample

Figure 4. Relative weight reduction for C2 sample

Figure 5. Relative heigh reduction for C2 sample
Analyzing the graphs presented in Figures 3, 4 and 5 it is observed that significant results were obtained from the correlation of coefficients [13].

The determination of the evolution of friction coefficient was performed on TR-20 test equipment, whose principle of operation is based on the “pin-on-disc” method. The pin equipment is a steel ball with 6 mm diameter and the experimentation regime is dry friction. For experiments the friction material was made of parallelepipeds with dimensions 45x45x50 mm. Each test was performed at a radius of 25 mm from the symmetry axis of the equipment. They were subjected to alcohol purging, then dried and weighed with a digital balance accurate to \( \pm 0.01 \) mg. In the test, measurements were made for three different pressing forces (5N, 10N, and 15N) at each test weighing the samples before and after the test to determine the wear mass. Test parameters use in tests are presented in Table 8.

Table 8. Parameters for determining the friction coefficient

| Wear trace diameter (mm) | Speed (rot min\(^{-1}\)) | Test time (h) | Test distance (m) |
|--------------------------|--------------------------|---------------|-------------------|
| 25                       | 150                      | 5             | 2200              |

The experimental data for the three values of the test results obtained in the text file in the tribome computer software are presented in Table 9.

Table 9. The wear and friction coefficient obtained in experiments

| Samples | Friction coefficient \( F_1 = 5N \) | Friction coefficient \( F_2 = 10N \) | Friction coefficient \( F_3 = 15N \) | Wear (g) \( F_1 = 5N \) | Wear (g) \( F_2 = 10N \) | Wear (g) \( F_3 = 15N \) |
|---------|-----------------------------------|-----------------------------------|-----------------------------------|-------------------|-------------------|-------------------|
| C1      | 0.43                              | 0.33                              | 0.30                              | 0.19              | 0.15              | 0.13              |
| C2      | 0.50                              | 0.45                              | 0.39                              | 0.07              | 0.05              | 0.03              |

At low pressing loads, friction coefficients have high values and as the workload increases, friction coefficient values decrease. Their values during the experiments are kept between 0.3 and 0.5. Technical literature states values of friction coefficients for friction materials from 0.15 to 0.6. Practically, for most vehicles the nominal values of friction coefficients range between 0.3-0.6 [4]. The values obtained for the coefficients of friction in the experiments are confirmed by specialized literature.

In Figure 6 was studied the effect of the pressing force on the friction coefficient and Figure 7 illustrates the influence of the pressing force on sample wear.

**Figure 6.** The influence of the pressing force on the friction coefficient

**Figure 7.** The influence of the pressing force on sample wear
Figure 6 shows that the friction coefficients decrease with the increase of the pressing force and Figure 7 shows that wear decreases with increased the pressing force. Also for sample C2 is observed the most pronounced decrease of the friction coefficient with the increase of the applied.

4. Conclusions

From the results and discussions it can be observed:

- organic composite materials are heterogeneous materials, composed of several components with different properties, therefore choosing the constituents and their percentage in recipes will significantly affect the behaviour in operation;
- physical-mechanical properties of composite materials with natural fibres depend on: behaviour, concentration, distribution and orientation of natural fibres;
- density, porosity, hardness, compressive strength, and Young modulus increase with the increase in coconut fibre;
- structural integrity of composite materials offers superior physical-mechanical characteristics of frictional materials;
- the highest wear resistance is obtained with 10% coconut fiber;
- cast iron disc wear is much less than the wear of composite materials, which shows that the wear resistance does not depend much on the amount of metal [13], this is very important for the practical situation because the brake pads are easier to replace than the disc;
- the best functional characteristics has C2 sample made with 10% organic fiber.

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