Physico-mechanical and tribological characteristics of composites used for brake pads

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Abstract. Brake pads are a crucial component of the braking system in an automotive vehicle. It is a primary factor in ensuring the normal driving of motor vehicles and the safety of passengers. Therefore, the research and study of the brake pads are extremely important. The materials which used in the manufacturing of brake pads should be environmentally friendly as harmful substances releases during operations by asbestos containing brake pads, which pollute the environment and thus harmful for human so becomes a primary reason of acceleration for research and development of new materials for brake pads. Composite materials have required excellent properties, so it is gaining an important position in this field. In this research, composite materials with coconut fibre are produced in the laboratory which can be used to produce brake pads for braking systems of the medium-performance small car. This research aims primarily towards producing the composite material which consists of the best proportion of organic fibre to have superior physical-mechanical and tribological characteristics. To achieve these goals, the following steps have been taken, the laboratory manufacturing of organic composite materials, technological analysis of the samples, improving the qualitative characteristics of friction materials, determination of the physical-mechanical and tribological characteristics of the materials according to the standards in force. This paper provides a detailed investigation on the characteristics of composite materials made with coconut fibre for brake pads.

1. Introduction

At the beginning of the automotive construction, the expectations of buyers were relatively low and the vehicle being made up of 80% of metallic material. The technical performances of the vehicles depend on the characteristics of their components. Competition in this area require knowledge the properties of the materials, developing advanced materials and modern technologies in order to increase performance and safety in operation, in conditions of accessible prices, adapted to the requirements imposed on the market.

The study for effect of emerging technology and advancement of materials that can be used for automotive parts is of crucial importance. Researchers are actively developing new braking materials, often in the context of possible future regulations. The steady development of the competitive characteristics of automobiles has over the past several years demonstrated the significance of the braking mechanism. The brake pads are the most critical components of automotive safety and performance [1], [2].
Most automotive repair outlets and parts shops have only brake pads which are either organic or semi metallic because each have different braking characteristics, wear rate and noise levels. Nonetheless, in deciding the degree of replacement of brake pads, driving style is typically more critical than brake pad composition. The scientific literature indicates that organic friction materials in the production of brake pads are being established as substitutes to asbestos, automotive sector now emphasis on organic composite materials [3], [4].

In the scientific literature have also been mentioned papers in which have been studied brake pads with organic fibres: coconut shell, candlenuts shell, cocoa shell, palm kernel shell, maize husks, periwinkle shell and other agro-wastes [5-11].

Sapuan et al. performed tensile and bending tests for composites with coconut shell as filler material, considering three different concentrations. The results revealed that the tensile and bending characteristics of the new composites enhanced with the increase of the content of filler material [5].

Onyeneke et al. shows that the coconut shells have high strength and resistant to wear, they are easily reducible to granular form and can be compounded with many other additives to make brake pads [6].

M.A. Maleque et al. studied created a new aluminium based composite reinforced by natural fibre for the application of brake pad in automobiles. Four different samples with different coconut fibre material (0, 5, 10 and 15 volume fractions) were prepared together with binders, solid lubricants, abrasive materials and friction modifiers using powder metallurgy method for the production of new natural fibre reinforced aluminium composites. Results reveals that coconut fibre of 5 and 10% demonstrated enhanced physico-mechanical properties in comparison to other formulations [7].

J. R. Simamora et al. done a research work which focus on investigated of properties of the composite material for brake pad composites produced by the candlenuts shell and coconut shell. Results shows that the common rate of wear increases with the improvement in sliding speed and applied load for all compositions. Overall test results shows that the brake pad developed by newly composite material have with longer wear life, fewer noise, better stopping strength and protection [8].

M. Afolabi et al. investigated the development of polymer composite which reinforced by cow bone (CB) and the Palm Kernel Shell (PKS) and used for production of brake pad. In various sieve grading, the PKS and the CB is applied to an epoxy resin. Based on the brake pad specifications, the designed brake pads were examined and were found to meet with the appropriate brake pad feature criteria. In the hardness test for PKS and CB, 55.7 HRB and 46.0 HRB are recorded polymer matrix composite reinforced by PKS and CB particles may be a substitute to asbestos-based reinforced material in manufacturing of brake pad with PKS and CB reinforced material. The brake pad manufactured was found to be thermally stable enough. The hardness values for the PKS and the CB is positive in contrast with the existing value [9].

O. Adeyemi et al. conducted an investigation which was focused on developed of automotive brake pads produced from intermixed agro-waste materials which contains palm kernel shells (PKS), coabens shells (CBS) and maize husks (MH) by powder metallurgy technique. In results abrasion resistance, friction coefficient and water soaking capacity decreased, although strength (tensile, compressive) improved with matrix wt % in the composition [10].

S. Yawas et al. investigated properties of non-asbestos automobile brake pads which produced with periwinkle shell particles used as friction filler material to replace asbestos, which was discovered to be carcinogenic. The findings showed that the compressive strength of samples, hardness and density improved when particle size decreased, a decrement in wear rate observed with the reduction in particles size of filler material. The findings of this research show that news composite can be successfully used in the brake pads manufacturing [11].

In this work, fifteen composites samples are produced using coconut fibre, developed for brake pads for motor vehicles. The main objective of the paper is to choose the best formulations of the composite which ensure for the brake pads superior physico-mechanical and tribological characteristics.
2. Materials and methods
In this paper were obtained in laboratory organic composites materials after fifteen recipes, with the chemical composition illustrate in Table 1.

Table 1. The chemical composition of composite materials

| The elements        | The raw of composite materials |
|---------------------|--------------------------------|
|                     | R1   | R2   | R3   | R4   | R5   | R6   | R7   | R8   | R9   | R10  | R11  | R12  | R13  | R14  | R15  |
| Al                  | 25    | 24    | 23    | 22    | 20    | 18    | 17    | 16    | 15    | 13    | 11    | 10    | 8    | 6    |
| Graphite            | 5     | 5     | 5     | 5     | 5     | 5     | 5     | 5     | 5     | 5     | 5     | 5     | 5     | 5     |
| ZrO₂                | 4     | 4     | 4     | 4     | 4     | 4     | 4     | 4     | 4     | 4     | 4     | 4     | 4     | 4     |
| Si₃C                | 10    | 10    | 10    | 10    | 10    | 10    | 10    | 10    | 10    | 10    | 10    | 10    | 10    | 10    |
| Al₂O₃               | 15    | 15    | 15    | 15    | 15    | 15    | 15    | 15    | 15    | 15    | 15    | 15    | 15    | 15    |
| Phenolic resin      | 40    | 40    | 40    | 40    | 40    | 40    | 40    | 40    | 40    | 40    | 40    | 40    | 40    | 40    |
| Hexametiltetramaine | 6     | 6     | 6     | 6     | 6     | 6     | 6     | 6     | 6     | 6     | 6     | 6     | 6     | 6     |
| Coconut fibre       | 0     | 1     | 2     | 3     | 5     | 7     | 8     | 9     | 10    | 12    | 14    | 15    | 17    | 19    |
| Total (%)           | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   | 100   |

Table 1 shows that in the formulation of the recipes, the proportion of aluminium varied between 6 and 25%, and the proportion of coconut fibre between 0 and 19%. The quantities for the other constituents were kept constant. The fifteen samples of different composition were manufactured in a mold. This mold allows to obtain disk samples with a diameter of 150 mm. To obtain samples, all components were milled, grinding and mixing, to obtain a proper homogeneity.

The composition appeared as viscous paste at the completion of the mixing process and was pressed with a force of 20 N and then placed in the mold for sintering. In order to sintering, the mold-sample assembly is introduced into a resistance oven. Parameters of the sintering process are: heating temperature 210°C, time in oven 50 min, cooling in oven at 100°C for 480 min and in air for 2880 min.

The compression strength of the samples was determined to make a qualitative analysis of the samples produced. The compression test was conducted on universal testing equipment, which works with the testXpert II software. The test was carried out on parallelepiped samples with the dimensions of 50x50x15 mm made from each recipe. The compression test was conducted on a sample of five parallelepiped samples made from each recipe. In the paper will be taken into account the average values of this samples. The sample were subjected to a compressive force, applied continuously until the burst was produced. The results are shown in the Table 2.

Table 2. Average values of compressive strength

| No. of recipes | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| Compressive strength (N mm⁻²) | 6.39 | 6.93 | 7.13 | 7.33 | 8.92 | 7.41 | 8.55 | 9.18 | 12.15 | 11.96 | 12.96 | 13.43 | 10.25 | 11.45 | 13.20 |

Table 2 shows that there is a tendency to increase the compressive strength with increasing amount of coconut fiber and decreasing the amount of aluminium up to a certain limit. The results obtained in Table 2 were processed in Matlab computational programs in order to obtain correlations between the compressive strength and the proportion of components in the recipe. In the processing of experimental data in Matlab, a statistical-mathematical calculation was performed to analyse the influence of the constituent elements of the recipes on the compressive strength [12], [13]. Thus, equations of double correlation between technological factors and compressive strength were established, the results being presented in analytical and in graphical form. The equation of the regression surface has the form:

$$z = 0.024 \cdot x^2 + (-0.116) \cdot y^2 + (-0.072) \cdot x \cdot y + (-0.358) \cdot x + 3.313 \cdot y$$  (1)
where: $z$ is the compressive strength; $x$ is the amount of aluminium in the recipe, and $y$ is the amount of coconut fibre. For this equation, the correlation coefficient obtained is $R^2 = 0.87$.

Figure 1a, b shows the variation of the compressive strength versus the amount of aluminium and coconut fibre.

Taking into account the influence of the elements aluminium and coconut fiber on the compressive strength, it can be stated that: the maximum value of the compressive strength is obtained for an amount of approximately 12 g of coconut fiber and 7 g of aluminum. For quantities less than 5 g of coconut and more than 20 g of aluminum, the compressive strength decreases. Similar situation is for over 10g coconut fiber and less than 15 g of aluminum. From the fifteen recipes were selected R5, R6, R7, R8, R9, R10. After the statistical-mathematical calculation for these recipes were obtained the highest compressive strength depending on the concentration of aluminum and coconut fiber. Based on these recipes were obtained the samples presented in Figure 2.

![Sample images](image_url)

**Figure 2.** The sample obtained after R5-R10 recipes

For the R5-R10 recipes, the physical-mechanical and tribological characteristics were studied.

Obtaining samples from composite materials in the laboratory encountered a number of difficulties such as: proper homogenization of components in recipes, correlation of the powder/phenolic resin/hexamethylenetetramine ratio, obtaining a completely circular geometric shape and a smooth surface. In order to characterize the composite materials, from all fifteen recipes, were made samples according to the characteristics of the experimental installations. The literature shows that the assessment of the quality of composite parts is made by: material homogeneity assessed by the lack of porous inclusions, surface condition, dimensional stability and accuracy, mechanical and thermal resistance of the material. For this reason all samples obtained were analyzed for geometric shape, integrity, structure, compactness and mechanical strength [14], [15].
3. Results. Discussions
The physical-mechanical characteristics of the materials decisively influence the technical performances of the systems. From the disc samples made from each composite material recipe were made samples to determine the physico-mechanical and tribological characteristics, in accordance with the standards in force. Thus, the density, porosity in water and hardness of the composite materials produced according to the six recipes were determined. The analysis of the density of the samples is presented in Figure 3.

![Figure 3. Density of samples obtained according to recipes R5-R10](image)

The densities for all composites are relatively low compared to metal densities. Density depends upon the weight percentage of ingredients which included in recipes. Considering that a metallic material has a higher density in comparison to an organic element, this justifies the lowest densities obtained for recipes R9 and R10. These recipes contain 10g of coconut fiber and close amounts of aluminum [16]. Figure 4 shows the porosities in water for recipes R5-R10.

![Figure 4. Porosity in water of samples according to recipes R5-R10](image)
Porosity is a characteristic of pore structure and provides information on fractions of the total volume of material that is not filled. The lowest porosity values were obtained for recipes R9 and R10. These samples have the highest amount of organic fibre. The results are equivalent to the literature reports [17].

The variable coconut and aluminium fibre content ascertains different sample hardness values. Figure 5 shows the hardness for recipes R5-R10. It is therefore identified that for R10 made with 10% coconut fibre, the highest hardness value is obtained. The sample R9 with 10% coconut fibre also have the high hardness. The literature shows that in order to increase braking stability, the hardness must be relatively low. If the porosity is too high, the hardness will be decreased, resulting in an increase in frictional wear of the material. This requires studies of the friction and wear parameters for the friction materials produced in order to make a decision on their use in the production of brake pads [18].

![Figure 5. Hardness of samples according to recipes R5-R10](image)

The tribological research had the following objectives: determination of the friction coefficient and material loss as a result of the wear process. The experimental equipment used is a TR -20 tribometer and the test parameters are shown in Table 3.

**Table 3. Parameters of tribological tests**

| Samples | Pressure (MPa) | Test range (mm) | Speed (rot min⁻¹) | Test time (s) |
|---------|----------------|-----------------|-------------------|--------------|
| R5-R10  | 1              | 7.5             | 145               | 20000        |

The experimental determinations of friction and wear are presented in Table 4.

**Table 4. Experimental determinations of friction and wear**

| Characteristics | R5  | R6  | R7  | R8  | R9  | R10 |
|-----------------|-----|-----|-----|-----|-----|-----|
| Friction coefficient | 0.25 | 0.31 | 0.36 | 0.39 | 0.44 | 0.45 |
| Loss of material     | 0.18 | 0.15 | 0.12 | 0.10 | 0.08 | 0.07 |

The highest values of the coefficient of friction and the lowest material loss were obtained for R9 and R10. The literature indicates the values of the coefficients of friction for brake pads ranging from 0.15 to 0.6 in practice, for majority of vehicles the nominal values of the coefficients of friction vary between the limits 0.3-0.6. More amount of coconut fibres in the composite brake (R4 and R5) led to a high coefficient of friction in the samples R9 and R10. For the tested composite materials the friction
coefficients range of 0.25-0.45. The friction coefficients obtained according to recipes R9 and R10, qualify these materials in the category of those that may be useful in making of brake pad for small and medium performance vehicles, intended for urban traffic. Coconut fibre can be used in friction materials because of its high strength, light weight and excellent properties [19], [20].

4. Conclusions
The conclusions can be drawn on the basis of the results obtained in this paper are:

- Obtaining composite materials with superior characteristics can be achieved by changes in the concentration of constituents in the recipe;
- The physical-mechanical properties of friction materials can not be assessed only based on the type of components used in recipes, they depend on the parameters of the sintering process (mixing time, pressure and compaction time, cooling time until further hardening, temperature from the oven, holding time in the oven);
- The correlations made between the compressive strength and the proportion of components in the recipes, by statistical-mathematical calculation, allow the establishment of recipes with the best physical-mechanical and tribological characteristics for composite materials with coconut fibre;
- Improving the characteristics of composite materials can be obtained by changes in the concentration of components in the recipes;
- The physical-mechanical characteristics of composite materials can be used to control the quality of recipes developed in the sintering process;
- The choice of the most suitable friction material for the brake pads cannot be made only on the basis of physical-mechanical characteristics, but it is also necessary an evaluation of the friction and wear properties;
- The important factors on the obtaining of higher physical-mechanical and tribological characteristics of produced composite materials are: types of ingredient, optimization of proportion of ingredient, and sintering technology parameters; for the composite materials tested, the friction coefficients were stabilized over the time, at the values indicated by the literature;
- The best friction and wear behaviour had the samples made according to recipes R9 and R10, which have 10% coconut fibre.

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