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Composites Based on Sustainable Biomass Fiber for Automotive Brake Pads

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Abstract: *Biomass fibers are promising materials for applications in modern vehicles. They have great economic and ecological significance, as well as a great potential in the fabrication of composite materials due to the relatively high level of strength and rigidity, low density, availability, recyclability, and biodegradability. In this context, the focus is on the development of automotive brake pad materials from sustainable sources. This work refers to the investigation of the behavior of composite materials made of biomass fibers, phenolic resin, graphite and aluminum oxide. These materials are intended to be used for brake pads on automobiles with moderate efficiency. For this purpose, three recipes of composite materials with different percentages of coconut fiber and wood powder were developed in laboratory. The physical and mechanical as well as functional properties of these composite materials with varying amounts of biomass fibers are examined in this paper. The best performances in this terms was obtained for the composite material containing the highest amount of wood powder and the lowest amount of coconut fiber.*

Keywords*: fiber, brake pad, biomass, coconut, wood powder*

1. Introduction

In the braking process of motor vehicles, brake pads play a particularly role in speed control. Their appearance was a welcome idea in the industry, but the dust, fine and ultrafine particles that they release outside following the braking process represent a great concern currently [1]. Over time, the construction of brake pads has evolved both in terms of the materials and in terms of the impact on the environment [2]. Asbestos-based brake pads are no longer allowed for use in vehicles because of their carcinogenic properties [3]. In this context, environmentally, friendly and non-toxic materials are gaining popularity among researchers in all industries. Introduction of environmentally and friendly natural fibers to replace asbestos in the production of brake pads has become a popular concept among researchers in the automotive industry. The technologies of the future are based on the principles of sustainable design, which means the use of energies from renewable sources, the rational use of natural resources, the development of new materials with superior properties, capable to elimination of waste. The valorization of resources from waste is a current concern of society, so the creation of new materials and technologies based on waste as raw materials, especially vegetable ones, is a field that requires immediate attention [2]. Fibers derived from agricultural waste have great economic and ecological significance, as well as a great potential in making composite materials due to the relatively high level of strength and rigidity, low density, availability, durability, recyclability, biodegradability [4]. In this context, the production of brake pads from sustainable sources is required [5]. European Union strategies try to reproduce the specific objectives and means by which waste management methods can be improved for a better use of natural resources [6]. Composite materials based on biomass fibers are the ones we must focus on in the future, not only because they have proven their reliability over time, but especially because they come from renewable sources. These materials through their properties can successfully replace expensive materials from non-renewable resources. In the specialized literature there are several studies that analyzed different combinations of materials for brake pads asbestos free.

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Thus, many researchers have succeeded in improving the performance of braking systems by introducing composite materials produced from sustainable fibers.

Idris et al. produced brake pads made with banana peel waste and studied the influence of phenolic resin content on their braking performance, [7]. Daut et al. studied brake pads made from coconut powder [8].

The behavior of composites for brake pads using different combinations of biomass fibers has also been analyzed in the specialized literature.

Juan et al. produced brake pads with different compositions of coconut shell, walnut shell, pineapple leaf, carbon and polyurethane resin using powder metallurgy. Experiments shown that the produced friction material has an improved braking performance, and the polluting emissions resulting from braking are low, [9]. Rajmohan et all. tested natural sugar cane fibers and coconut fiber in the manufacture of brake pads. These were combined with epoxy resin, SiC powder. Experiments showed an improvement in tribological parameters with increasing coconut shell content, [10]. Sutikno et al. produced friction material with bamboo fiber, coconut, alumina, magnesium oxide and epoxy resin. The braking performance achieved was superior to commercial brake pads, [11]. Another combination of fibers from agricultural waste used in the production of brake pads was analyzed by Kholil et all. They produced brake pads from natural coconut fiber and waste wood powder used in the braking system of motorcycles, [12].

In this paper is analyzed the behavior of composite materials made of biomass fibers, phenolic resin, graphite and aluminum oxide intended for brake pads used for small vehicles with medium performance, which are harmless to human health. For this purpose, three recipes of composite materials with different percentages of coconut fiber and wood powder were developed. The paper analyzes the physical-mechanical and functional characteristics for these recipes with different proportions of biomass fibers.

2. Materials and methods

Biomass from agricultural production has commercial and environmental value and can be put to use in the fabrication of brake pads, [2]. It can be used as reinforcement in composite materials. In order to obtain the friction material, several materials must be chosen which are mixed with a resin with the role of binder with the property of transforming thermoplastic into thermoset.

In this paper, will be produced and characterized friction materials for brake pads used for small vehicles with medium performance, which are composed of coconut fiber and wood powder. Coconut fiber comes from the shell of the exotic fruit, and wood dust is a waste that comes from factories that use wood in the production process. In order to obtain efficient composite materials with predictable properties, an important role is played by the chemical composition of the fibers in order to achieve strong connections between the fiber and the resin. Table 1 shows the chemical composition of coconut fibers, and Table 2 shows chemical composition of wood powder.

Tabel 1. Chemical composition of coconut fibers

Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	Water (%)
33.07	8.5	39.23	8.12	11.08

Tabel 2. Chemical composition of wood powder

Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pentosan (%)	Ash (%)	Water (%)
40.81	29.12	20.23	5.43	1.01	3.4

By comparing Tables 1 and 2, we can deduce that the main components of biomass fibers are cellulose, hemicellulose, lignin, protein, pectin, and ash. Glycosidic bonds in cellulose play a decisive role in determining the composite's mechanical characteristics. Hemicellulose is a component of the plant cell wall and is made up of several monomers such as: xylose, galactose, mannose, rhamnose and arabinose that lead to the formation of a branched and amorphous polymer. Lignin is a phenolic compound that imparts compressive strength and stiffness to the plant body.

Humidity is a characteristic of vegetable fibers, and its content must be determined precisely, for each type of fiber. An excess of humidity can lead to damage to the material that contains it. The literature shows that for various vegetable fibers the water content varies between 9 and 12%, [13]. Regarding the water content of the wood powder that will be used in the recipe, it is less than 4%.

In order to produce the composite materials in the laboratory, the biomass fibers were chemically treated with a 5% alkaline solution. The role of this surface treatment is to achieve optimal bonding interfaces between the fiber and the organic matrix, by removing deposition materials and activating the fiber surface.

The following materials were used in the development of composite materials: coconut fiber, wood powder, phenolic resin, graphite, aluminum oxide. The coconut fibers and wood powder are used as reinforced material. The binder used in the production of composite materials was phenol formaldehyde resin. Graphite used in this study as friction modifier. The aluminum oxide is used as abrasive. Figure 1 illustrates different forms of the materials that are used in development of a composite materials. An increased level of homogeneity in the recipe's ingredients is essential for producing products with better physical-mechanical and functional. An increased level of homogeneity in the recipe's ingredients is essential for producing products with better physical-mechanical and functional attributes [14-20].

Coconut fiber	Wood powder	Graphite	Phenolic resin	Aluminum oxide

Figure 1. Raw materials used to obtained composite materials

With the raw materials shown in Figure 1, were developed three material recipes with different concentration of coconut fibre and wood powder (Table 3).

Table 3. Chemical composition of composite materials

Samples	Coconut fiber (%)	Wood powder (%)	Graphite (%)	Phenolic resin (%)	Aluminum oxide (%)
A	20	40	5	25	10
B	30	30	5	25	10
C	40	20	5	25	10

The technological flow for the laboratory production of composite materials with biomass fibers includes the following stages: procurement of fibers, grinding, drying, chemical surface treatment with alkaline solutions, resin application, mixing, hot pressing, sintering, product finishing.

The biomass fibers together with the other materials in the recipes were mechanically mixed for 10 min, after which the formaldehyde resin was added together with a small amount of sulfuric acid as a catalyst. In order to homogenize the components of the recipes, they were mixed using a mixer with a power of 500W and a speed of 2800 rpm. This mixture was placed in a circular mold with a diameter of 96 mm in which the mixture was pressed (Figure 2).

Figure 2. Mold with composite material during the pressing process

Sample 1 Sample 2 Sample 3

Figure 3. Disc samples made from developed recipes

Table 4 shows composite fabrications details. Figure 3 shows the samples obtained at the end of the manufacturing process.

Table 4. Composites fabrications details

Sintering conditions	Temperature (ºC)	Pressure (MPa)	Time (min)
Conditions for molding	150	15	10
Conditions for oven curing	200	-	300

The samples obtained after the three recipes were adequate in terms of compactness, integrity, elasticity and appearance when removed from the mold. For the three recipes of composite materials, were determined the physical-mechanical and the functional characteristics.

3. Results and discussions

3.1. Physical and mechanical characteristics

Determination of the density of the new materials was used fluid displacement method. The samples were immersed in a cylinder with distilled water. The mass of the samples, was determined by weighing with a balance that has an accuracy of ±0.01, before and after their immersion in water. The volume of the piece was determined by the difference between the volume of water before and after immersion. For each sample were made three readings, taking into account the average value. The density of the samples was calculated, the results being presented in Table 5.

Water absorption was determined for the three proposed recipes. The samples were measured, then immersed in water for 24 h at ambient temperature before being weighed again. Moisture was removed and samples were reweighed after this period. The difference in mass gave the amount of water absorbed and their percentage.

Vickers hardness according to ASTM 92 was determined for each sample. The average results from three separate trials of each samples were used to determine the final valuation (Table 5).

The compressive strength was determined according to SR EN 1926:200795 and SR EN 1926:200796 standards. The measurements were carried out with a universal machine for the static testing of materials. The results are determined as average values of three separate measurements (Table 5).

Table 5. Physical and mechanical characteristics of composite materials

Samples	Density (g/cm^3)	Water absorption (%)	Hardness VHN	Compression strength (MPa)
A	2.55	5.22	56	176.7
B	2.78	4.99	49	140.3
C	2.95	3.76	45	162.6

The lowest density was obtained for sample A. This is explained by the fact that a porous material was obtained as a result of the combustion of cellulose during the manufacturing process, which reduced the density of the finished product.

The literature also states that in these conditions the braking noise is also reduced, which is an important thing in the operation of the brake pads [3]. As a result of the increased porosity of sample A, it also had the highest percentage of water absorption. On the other hand, sample A has the highest concentration of wood fiber that contains the highest amount of cellulose, which is why it absorbs water better. The creation of hydrogen bonds among hydroxyl groups and water explains how lignocellulosic materials are able to absorb water, [14]. Regarding the hardness of the composite materials, an increase is observed as the concentration of wood powder increases. Sample A has a 56VHN hardness, which is the highest of the samples tested. Hardness decreases with increasing coconut fiber composition and reducing wood dust. Consequently, samples B and C with a higher amount of coconut fibers have a lower hardness. The lowest compressive strength was sample C in which there is an equal amount of coconut fiber and wood powder that resulted in a uniform matrix. The highest compressive strength was recorded for sample A.

The physical and mechanical properties determined experimentally for the types of composite materials presented are influenced by several parameters such as: the proportions of raw materials used, the nature of vegetable fibers, the fiber-matrix interface, alkaline treatments applied, the parameters of the manufacturing technology. In order to choose the composite material with superior characteristics, it is also necessary to evaluate the functional characteristics.

3.2. Tribological characteristics

The coefficient of friction, few wear parameters, and temperature at the friction couplings were all tracked over time to evaluate the tribological performance of the laboratory-made composite materials.

Dry friction conditions were used using a TR-20 tribometer, whose working principle is focused on the "pin on disc" approach, to calculate the friction coefficient over time. The equipment's pin is a steel ball 6 mm in diameter, and each of the three composite material samples is 30 mm by 30 mm by 20 mm. Experiments used a pressing force of 10 N. Table 6 lists the various experimental conditions.

Table 6. The parameters for determining the friction coefficient

The diameter of the wear mark (nm)	Speed (rot/min)	Test time (h)	Test distance (m)
5	150	5	2200

The friction coefficient of the samples has a relatively slow increase over time, and its value stabilizes until the end of the test period.

According to specialized literature, Braking requires a friction coefficient that is consistently greater than normal, hence friction materials must be designed accordingly [15, 16]. The evolution of the friction coefficients for the composite materials tested is presented in Figure 4.

Shortly after the beginning of the trials, in the vicinity of 2000s, the friction coefficient of sample A was reached 0.4. Sample B's friction coefficient reached a maximum of 0.35 after 14,000 s, and its minimum was 0.3 after 18,000 s. A higher percentage of wood powder and a lower percentage of coconut fiber resulted in a higher friction coefficient, as seen in Figure 4.

To determine the wear of the composite materials, they were tested under dry friction conditions, using the pressing force F=10N and two sliding speeds: 3.92 m/s and 4.71 m/s. The test time was 10 min.

The wear of the investigated materials is evaluated using the gravimetric technique. [18, 19].

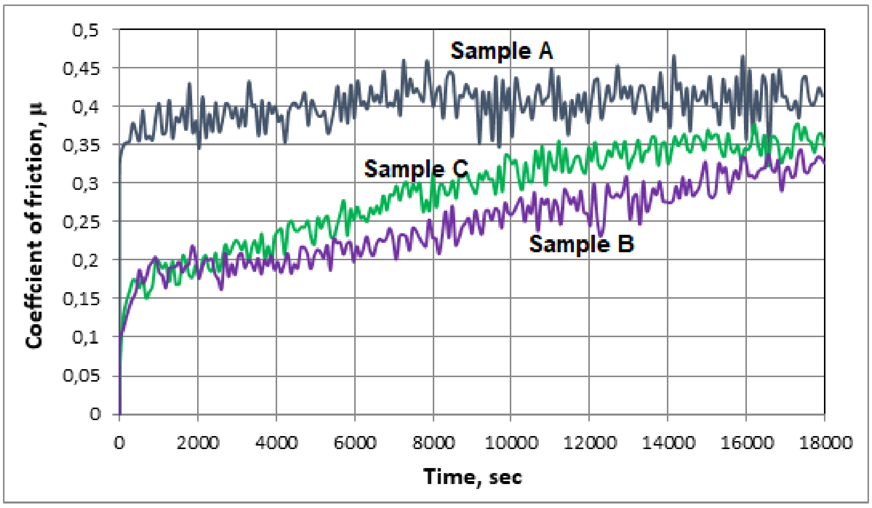

Figure 4. Evolution of friction coefficients for samples A, B and C

In this sense, the mass wear and the linear wear rate are determined, the results being presented in Table 8. The wear rate was determined using the formula: [18-20]:

$$W_e = \frac{\Delta_m}{F \cdot L} \quad (1)$$

In relation (1) Δ_m - the difference between sample mass at the beginning and sample mass at the end [g]; F - the normal force applied to the tribometer, [N]; L - sliding distance, [m].

Table 8. Samples wear rate

Samples	Sliding speed v [m/s]	Initial mass m_i, [g]	Final mass m_f, [g]	Mass wear Δ_m, [g]	Wear rate [g/N·m]
A	3.92	46.3162	46.306	0.0102	$4.63 \cdot 10^{-7}$
	4.71	45.6965	45.6882	0.0083	$3.77 \cdot 10^{-7}$
B	3.92	52.2135	52.1848	0.0287	$13.4 \cdot 10^{-7}$
	4.71	53.0911	53.0667	0.0244	$11.09 \cdot 10^{-7}$
C	3.92	54.3310	54.3178	0.0132	$6.0 \cdot 10^{-7}$
	4.71	55.5260	55.5168	0.0092	$4.18 \cdot 10^{-7}$

As seen in Table 8, increasing sliding speed reduces the linear wear rate. The wear rate was lowest in Sample A, which had the most wood powder. The rate of wear was greatest in Sample B, when the proportions of coconut fiber and wood powder were balanced. This is because the optimal bonding qualities, in addition to the ratio of materials, determine the best wear rate. The composites' high wear resistance comes from the natural fibers' strong bond to the resin.

As seen in Table 8, increasing sliding speed reduces the linear wear rate. The wear rate was lowest in Sample A,

On the other hand, the higher wear resistance of sample A is due to the high cellulose content of the wood powder. This can only be achieved through careful formulations of selected materials in the right proportions.

In order to test the organic material produced in the laboratory, friction couplings' contact regions had their heat fields examined on an experimental installation that allows testing under intensive braking. To carry out the experiments, brake pads were made from each recipe developed and were mounted in the installation. Figure 5 shows the brake pads made according to recipes A, B and C, and Figure 6 shows the experimental installation. Experiments are based on which the temperature is recorded with a thermographic camera after each of 10 separate braking events. According to specialized literature, the temperature after the ten successive braking must be lower than, $\tau_s \leq 300^0 C$, [20]. The brake disc in the installation is a ventilated one made of cast iron, brand G2500 according to ASTM A 159 norms intended especially for road vehicles.

A thermographic camera was used to measure the temperature of the brake pads where they made contact with the disc brake.

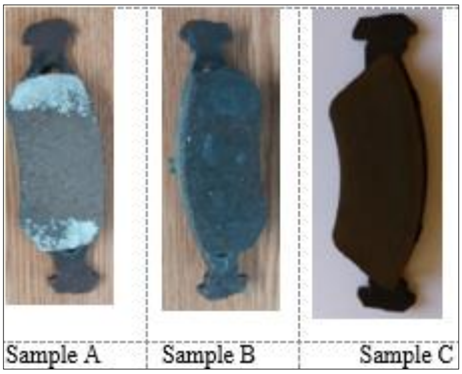

Figure 5. Brake pads made from the composite materials

Figure 6. Experimental installation for intensive braking

Table 9 shows the brake pad temperatures recorded at each braking for the composite materials tested. The initial temperature was 22°C, and successive braking were performed at an interval of 2 s.

Table 9. Temperature values during successive braking

Samples	Pedal power (N)	Temperature during braking τ (°C)									
		1	2	3	4	5	6	7	8	9	10
A	120	24	28.4	36.6	62.7	97.8	133.6	149	245.1	235.3	206.5
B		30	42.1	68.9	89.5	103.8	145.7	178.2	257.9	268.1	269
C		28	37.9	42.3	65.7	99.1	145.7	167.9	256.2	254.9	253.7

For all materials tested, the temperature of the brake pads rises rapidly at the beginning of the test period. This is explained by the fact that part of the heat generated during braking accumulates in the brake pads. After eighth braking, for samples A and C the temperature starts to decrease, this being explained by the fact that it dissipates in the external environment. Sample A had a lower temperature than Sample C after 10 cycles of severe braking. The deterioration of organic components in composite materials is reduced if the temperature throughout the contact region is low.

Also, the temperature during the experiments does not exceed 300°C, which complies with the recommendations in the specialized literature, [19]. The highest temperature accumulated after the ten braking was in sample B, and sample A had the best behavior.

Like any research developed on a given theme, it cannot be said that it is completed at this moment, because opportunities for development and deepening can constantly open up, with the resumption of the stages completed in the research under a different approach or by imposing new work techniques.

4. Conclusions

At the end of the previously presented research, Consequently, we may infer the following:

- the use of agricultural waste in the manufacture of friction material intended for making brake pads is a sustainable source of raw materials;

-because biomass fibers are composed of many diverse components, each of which has its own unique qualities, it affect their performance in use:

-because of their high structural quality, the friction materials that are manufactured have excellent physical mechanical properties;

-the composite materials developed in laboratory have a low density compared to the metals;

hhardness and compressive strength increase with the increase in the amount of wood powder;

-samples with equal proportions of wood powder and coconut fiber did not give good results in terms of physical-mechanical and tribological characteristics;

-increases in wood powder content and decreases in coconut fiber content lead to a higher friction coefficient;

-sample A, with the best tribological behavior, has the friction coefficient with a value of 0.4;

-the linear wear rate decreases with increasing sliding speed;

-at the end of the ten intensive braking, the temperature in sample A is lower than in sample C, which means that the composite material produced according to recipe A has better ability to dissipate heat into the atmosphere;

-the biomass fibers used had a suitable behavior and can be used as a filler material for the production of brake pads for small vehicles with medium performance, if their proportion in the recipe is adequate.

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