Aspects regarding manufacturing technologies of composite materials for brake pad application

A L Craciun, T Hepuț and C Pinca-Bretotean
Politehnica University of Timisoara, Engineering and Management Department,
5 Revolutiei Street, 331128 Hunedoara, Romania

E-mail: camelia.bretotean@fih.upt.ro

Abstract. Current needs in road safety, requires the development of new technical solutions for automotive braking system. Their safe operation is subject to following factors: concept design, materials used and electronic control. Among the factors previously listed, choice of materials and manufacturing processes are difficult stage but very important for achieving technical performance and getting a relatively small cost of constituting parts of brake system. The choice is based on the promotion of organic composite material, popular in areas where the weight of materials plays an important role. The brake system is composed of many different parts including brake pads, a master cylinder, wheel cylinders and a hydraulic control system. 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. The aim of this paper is to presents the manufacturing technologies for ten recipes of composite material used in brake pads applications. In this work will be done: choosing the constituents of the recipes, investigation of their basic characteristics, setting the proportions of components, obtaining the composite materials in laboratory, establishing the parameters of manufacturing technology and technological analysis.

1. Introduction

Current trend in road safety impose the development of new technical solutions for vehicle „vital” systems. These systems are made of components with multiple functions inside the vehicle. The optimal operation of vehicle is ensured as part of each subassembly and the links between them. Each subassembly is made up of several parts that can be made from a wide variety of materials. Technical performance of the vehicle subassemblies and default of which they are part, depend on physical and mechanical characteristics of the materials which they are made, [1].

Many parts of vehicles contributes active and passive to increased operating performance. Safety is closely linked to the effectiveness of the braking system, which is one of the most important components of a vehicle. On the other hand, the correct operation of braking systems is essential for the safe transport of goods and people, [2]. In the case of brake components, the safety in operation is conditioned by three factors, [1]: concept design, materials used and electronic control. Among the factors previously listed, choice of materials and manufacturing processes are difficult stages to achieve technical performance of vehicles. The choice of materials is based on the promotion of low-cost, which will be readily purchased, being carried out the optimum use of their technological properties, [2]. On background of sustainable raw material resources and environmental problems
caused by plastics and metals, readily degradable, automotive manufacturers are always looking for new materials with low environmental impact. These materials must provide the same performance in function, as the metals but will be produced as friendly is possible. Due to the environmental problems caused by the large volume of waste, the world is moving towards organic composite materials. These are popular in the fields in which the weight of the material plays an important role, such as automotive, [3].

Regarding manufacturing technologies of brake pads, the literature indicates that there are government rules that restrict the use of materials in the brake pads applications, [3]. In this context, current issues of research in materials science and engineering aims to develop new materials with superior performance to meet the requirements of modern industry, simultaneously with the application of technology for the processing of maximum economic efficiency.

This paper presents the manufacturing technologies for ten recipes of composites used in brake pad applications. In this work will be done: choosing the constituents of the recipes, investigation of their basic characteristics, setting the proportions of components, obtaining the composite materials in laboratory, establishing the parameters of manufacturing technology and technological analysis.

2. Technical Requirements

2.1. Design and fabrication of mold for producing composites
To produce composite materials for brake pads, it was designed and built a metallic mold. The main components of the mold were made with Autodesk Inventor and are shown in Figure 1a-e. Figure 2 shows the mold assembly designed to produce the samples in laboratory, [4].

![Figure 1. Components of mold for making samples](image1.png)

![Figure 2. Mold assembly](image2.png)

2.2. Establishing the proportion of constituents
In the literature, the main categories of materials used in organic brake pads are: filler, abrasive, solid lubricant, binder, friction modifier and additives, [3]. The composition of organic composites for different components of vehicles, a great importance are lingo-cellulosic fibres. This are used to reinforcement composite materials and can be obtained from a wide variety of plants, such as, [5]: cereal straw stalks (wheat, barley, rice, rye); fibre plants (flax, hemp, raffia, cotton); plants with tough fibres (cane sugar, cane, reed, oilseed rape, coconut, bamboo, banana, sisal, etc.). In this paper, was chosen as a filler and reinforcement material, coconut fibre.

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. Their choice was made in accordance with the properties required for brake pads in vehicle operation. The properties of each material that is independent of the recipe are further analyzed, [6]:

- aluminium forming alloys and it has a high plasticity and low specific weight. It is used as a matrix because of its low density and high resistance to progressive oxidation;
- Zirconium oxide is a material with high resistance. It is used to achieve the components which are resistant to thermomechanical stresses. It shows a very good resistance to abrasion and impact, it has high compressive strength, low density and porosity;
- Silicon carbide has a crystalline structure which gives high rigidity, tensile strength and high hardness values. Add in aluminum alloys contributes to increased wear resistance, in particular to abrasive wear, but the mechanical processing will lead to intense wear of cutting tools. It has high hardness which gives a proper behavior of the composite under conditions of friction wear or abrasion.
- Graphite introduced in composites in which is added silicon carbide improves the anti-friction properties, leading to a low friction coefficient. Due to the difference in specific gravity between the matrix and graphite to obtain a homogeneous mixture is required mechanical mixture.
- Titanium oxide is stable and has a low density. Titanium gives superior mechanical strength, corrosion resistance in marine environments, acids, alkali, water, natural and industrial chemicals. It has high heat transfer in operating conditions and a superior oxidation resistance at ambient temperature. Titanium may be alloyed with aluminium, vanadium, molybdenum, and other elements, to produce light alloy and mechanical high strength;
- Phenolic resin has excellent high temperature properties and form carbon-carbon bonds that develop resistance to high temperatures. This is thermosetting and provides unique properties of composite materials, such as: chemical resistance and superior mechanical characteristics. It is used in applications that support high operating temperatures.

On the other side, the composition of the material which contain silicon carbide and aluminium have high rigidity, resistance to wear and to high temperatures. These are used in manufacturing of braking systems components, [6].

Aluminium used in the preparation of composites was obtained by cutting the pieces presented in Figure 3a. In Figure 3b it is shown aluminium after the cutting process. Phenolic resin used in new developed composite materials is fluid, Figure 4, and coconut fibre was obtained by grinding the shells of fruit, Figure 5. In Figures 6a, b, c, d are shown other materials used to obtain composites for brake pads.

![Figure 3](image1.jpg), Aluminium used in the manufacture of composites

![Figure 4](image2.jpg), Phenolic resin

![Figure 5](image3.jpg), Coconut fibre

![Figure 6](image4.jpg), Materials used in the manufacturing technologies of composites for automotive brake pads

**a**-Graphite  **b**- Zirconia oxide  **c**- Silicon carbide  **d**- Titanium oxide
Table 1 shows ten recipes for composite materials used in vehicles brake pads.

| No. of sample | Aluminium (%) | Graphite (%) | Zirconia oxide (%) | Silicon carbide (%) | Titanium oxide (%) | Phenolic resin (%) | Coconut fibre (%) |
|---------------|---------------|--------------|--------------------|---------------------|--------------------|-------------------|------------------|
| P1            | 45            | 8            | 2                  | 15                  | 13                 | 13                | 2                |
| P2            | 30            | 8            | 2                  | 15                  | 13                 | 30                | 2                |
| P3            | 20            | 10           | 2                  | 2                   | 10                 | 40                | 0                |
| P4            | 15            | 8            | 2                  | 10                  | 15                 | 10                | 2                |
| P5            | 20            | 8            | 2                  | 10                  | 14                 | 40                | 2                |
| P6            | 20            | 10           | 2                  | 13                  | 10                 | 40                | 5                |
| P7            | 25            | 10           | 2                  | 13                  | 10                 | 40                | 5                |
| P8            | 20            | 10           | 2                  | 13                  | 10                 | 40                | 5                |
| P9            | 15            | 10           | 2                  | 13                  | 10                 | 40                | 10               |
| P10           | 10            | 10           | 2                  | 13                  | 10                 | 40                | 15               |

2.3. Experimental equipement

In the manufacturing technologies of organic composite materials was used powder metallurgy. Thus, the materials used in recipes are prepared in powder form, [7]. In this regard, they are milled in a ball mill, type PM100, which is shown in Figure 7. Technical characteristics of the mill are: ball diameter: 8 mm, the initial particle size of the material: < 10 mm; the final particle size: < 40 µm, rotor speed: 6.000 rot/min, rotor diameter: 99 mm and capacity: 900 ml.

![Figure 7. The ball mill machine type PM 100](image)

![Figure 8. Sartorius balance CP2202S-OCE](image)

![Figure 9. Oven type Nabertherm model L15/12/B180](image)

After milling, the components were weighed in proportions according to the recipes. Their weighing was performed by a Sartorius balance, type CP2202S-OCE, which is shown in Figure 8, [8]. Technical characteristics are: minimum quantity of measuring 0.5 g; maximum quantity of measuring of: 2200 g; precision: 0.01 g. The mixture was placed in the mold and the assembly mold-sample was placed in an oven, Nabertherm mark, model L15/12/B180. Technical characteristics of the oven are: the maximum heating temperature 1200°C, tension 220V, frequency 60 Hz, amperage 15.7 A, power 3.6KW.

3. Discussion and results

New composite materials developed were obtained in laboratory based on a number of ten recipes with the composition shown in Table 1. Their implementation was based on the thorough documentation in technical literature and many attempts and experiments. Manufacturing technology was improved step by step, from one sample to another, trying to solve the drawbacks and identifying the causes occurred to obtain each sample. Table 2 shows the parameters of manufacturing technology.
for each sample. Technological analysis on the results obtained in terms of compactness, integrity, elasticity and appearance of the sample, [9].

Table 2. Manufacturing technology and the resulting sample

| Sample | Heating temperature (°C) | Heating time (min) | Retention time (min) | Pressing force (Hot KN) | Pressing force (Cold KN) | Cooling Medium | Cooling Time (h) | Appearance of sample |
|--------|-------------------------|-------------------|---------------------|------------------------|--------------------------|----------------|-----------------|---------------------|
| P1     | 220                     | 15                | 15                  | -                      | -                        | Water          | 0.15            | ![Sample Image](image1) |
| P2     | 220                     | 15                | 25                  | -                      | -                        | air            | 10              | ![Sample Image](image2) |
| P3     | 200                     | 15                | 25                  | -                      | -                        | air            | 10              | ![Sample Image](image3) |
| P4     | 180                     | 15                | 30                  | -                      | -                        | air            | 10              | ![Sample Image](image4) |
| P5     | 200                     | 15                | 45                  | -                      | -                        | air            | 10              | ![Sample Image](image5) |
| P6     | 200                     | 15                | 45                  | 15                     | 15                       | air            | 10              | ![Sample Image](image6) |
| P7     | 200                     | 15                | 45                  | 5                      | 5                        | air            | 10              | ![Sample Image](image7) |
| P8     | 200                     | 15                | 45                  | 5                      | 5                        | air            | 10              | ![Sample Image](image8) |
| P9     | 200                     | 15                | 45                  | 5                      | 5                        | air            | 10              | ![Sample Image](image9) |
| P10    | 200                     | 15                | 45                  | 5                      | 5                        | air            | 10              | ![Sample Image](image10) |
Implementation steps for P1 sample were: mixing the constituents of the ground; the phenolic resin is added; the composition is manually homogenized; the mixture is introducing into the mold; the piston of the mold is take up; the assembly sample-mold is insert in the oven.

Technological analysis of P1: the sample obtained was destroyed when removed it from the mold because of its tendency to stick to the bottom of the mold. This requires the search for a solution to protect the sample. The sample is inadequate in appearance and structure. The explanation is the small amount of phenolic resin compared with the other components of the sample. It will increase the amount of resin. On the other side, the sample is brittle because the heating-cooling regime was inadequate. So, heating temperature will decrease. In this sense, will increase the holding time in the oven and will give up water to cool the sample.

To achieve the second sample (P2) were developed certain corrections imposed by non-compliance observed at the previous sample. In order to obtain a better link of the recipe components, it has doubled the amount of phenolic resin and reducing the amount of aluminium. To remove the sample from, the mold have taken steps against sticking composite on the bottom of the mold and the active surface of its piston. Thus, these surfaces will put a layer of aluminium foil and a layer of graphite.

Implementation steps for P2 sample were: mixing the constituents of the ground at a time; the phenolic resin is added; the composition is manually homogenized; an aluminium foil is placed at the base of the mold and on the active surface of the piston; the base mold was coat with a thin layer of graphite; the piston mold is take up; the assembly sample-mold is insert in the oven.

Technological analysis of P2: this sample is inadequate in appearance and structure. It shows areas with dismantling in the structure, which is due to the small amounts of phenolic resin in the composition compared to other sample constituents. It will increase the amount of resin. The homogenization of the components was inadequate. In the structure of sample it can be observe traces of graphite non-homogenized. The sample obtained has an incompletely circular shape which is due to the mold clamping force which was not applied consistently and uniformly. It has been found that the aluminium foil in combination with graphite layer solved the problem of sample sticking.

To achieve the third sample (P3) was kept the same level of heating-cooling regime at the previous sample but it has increased the amount of phenolic resin.

Technological analysis of P3: the sample was removed from the mold without problems which means that the solution to protect the lower mold with a layer of foil and graphite is suitable. The sample obtained has good look in shape, but in terms of structure is inadequate. This presents small areas with craters due the inhomogeneity of phenolic resin, which requires remedial action: homogenization of the components of the recipe using a mini-mixer.

To achieve the sample four (P4) will increase the holding time in the oven for 30 minutes. The other parameters were kept the same to the previous sample. Another modification consists of mixing the constituents using a mini-mixer.

Technological analysis of P4: The sample obtained has a good look in shape and structure. The link between constituents is good. There is a proper mixing of the constituents which means that the adoption of mechanical mixing is suitable. There are craters due to nehomogeneity of resin and will change the steps in operations. All the constituents will introduce in phenolic resin. The sample has a high porosity, to remove this shortcoming will try pressing the mixture in a hydraulic press. There will be changes to the heating-cooling regime.

To achieve the sample five (P5) the components are homogenized and then are introduced into the phenolic resin homogenizing the composition and than performs a cold pressing on a hydraulic press, type PH 40. Technical characteristics of the hydraulic press are: maximum pressing force: 100KN, the size of the table surface: 700 x 600 mm, table height: 700 mm, voltage: 380 V, power: 9.7 KW. In the oven will increase the holding time.

Implementation steps for P5 sample were: the phenolic resin is put into the mixing tank; homogenize the constituents with a mecanical mixer; constituents homogenized are introduced in the phenolic resin; the composition is homogenized with a mixer; place a layer of aluminium foil on the base of the mold and on the active surface of the piston; place a layer of graphite on the based mold;
the mixture is introducing into the mold; the piston of the mold is take up; performing a cold pressing force on a hydraulic press; the assembly sample-mold is insert in the oven.

Technological analysis of P5: the sample obtained has good look in shape but lacks toughness. Homogenization of constituents was performed properly, but it has been observed that there is excessive phenolic resin. Porosity is still high. It will explore ways to increase hardness.

To achieve the sample six (P6) will try a cold pressing of the mixture after placing it in the mold. 15 minutes after introduction the sample in the oven and will be performing a hot pressing force. It is used the same sequences of operations used in P5. Fifhteen minutes after the introduction into the oven, the mold assembly is removed from the oven and is performed a hot pressing force. After that, the sample is return in the oven and maintained for 30 minutes.

Technological analysis of P6: the sample obtained has a low porosity, but it is brittle. The force pressing is too much and it is lost a considerable amount of resin, because of this fact unrelated solid constituents remaining in the structure and the sample was cracked when extracted from the mold. It aims to reduce the pressing force.

To achieve the sample seven (P7) the pressing force is 5 KN and will performing a hot pressing force. It is used the same sequences of operations as in P6 sample.

Technological analysis of P7: the sample has an appropriate consistency and is satisfactory in shape and structure. In the central part of the sample it can be seen a crater. This is not due to the material sticking on the piston mold because its surface does not show traces of material. Crater formation is due to accumulation of gases resulting from the sintering process. Due to excessive pressing, the gases could not be released outside. This solution of pressing will cancel. This is considered a successful sample and can be used for collecting samples necessary for the characterization of the new composite.

To achieve the sample eight (P8) it is used the previous parameters and the sequence of manufacturing steps.

Technological analysis of P8: good sample as consistency, form and structure with a satisfactory hardness. It is noted that the foil bonding of the surface sample. Sample surface is quite smooth, only occasionally seen of adhesions. The test is considered a good sample.

To achieve the sample nine P9 were maintained the parameters and manufacturing technology used in P7 and P8 samples.

Technological analysis of P9: the sample obtained has a low porosity, and the hardness is satisfactory. The shape and structure of the sample are appropriate. The surface is smooth but the touch is off a fine black powder which is due to the graphite the composition.

To achieve the sample nine P10 were maintained the parameters and manufacturing technology used in P7 P8 and P9 samples.

Technological analysis of P10: The sample obtained showing good shape and structure and has a satisfactory hardness. There is a proper mixing of the constituents and a suitable solidification which shows that the order of operations is appropriate to obtain composite materials the heating-cooling is adequate pressing force applied to both hot and cold compaction performed efficiently material. Sample surfaces are smooth and these were considered good in terms of quality.

For further experiments and tests it was selected four samples made from recipes P7, P8, P9 and P10. Thus P7 has the largest amount of aluminium and 0% coconut fibre, P8 has 5% coconut fibre, P9 has 10% coconut fibre and P10 has the smallest aluminium of all and the largest proportion of coconut fibre coconut, respectively 15%. The disc samples are shown in Figure 10. From each sample will make specimens to determine the mechanical characteristics of composites materials for brake pad application.

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.
4. Conclusions
From the results and discussion of this study it can be observed:

The laboratory phase to obtain composite materials have encountered a number of difficulties such as, [10]: failure of proper mixing of the components in the recipe; correlating the ratio of the powdered material / phenolic resin; determine the dosage of constituents in the recipes; sticking the samples to the mold’s wall samples and its piston.

Solving these shortcomings was made by:
- using a mecanic stirrer to obtain a homogenous mixture
- increasing the amount of phenolic resin to make a link between constituents;
- aluminum foil and the layer of graphite, solve the problem sample sticking on the active surface of the mold and its piston.

During the components mixing it has been observed that the factors that influence a homogenous mixture are:
- mixing rate;
- the amount of the phenolic resin and the order of constituents mixing.

Regarding, the order of mixing the components can be generalized as follows: the first mixed is the material which has low specific weight, using a lower speed mixer. These will be introduced over the materials with higher specific weight and they are mixed with a high speed mixer.

Obtaining a compact sample is influenced by:
- the heating-cooling regime;
- pressing force.

During the experiments were made the following observations:
- if the time of mixing is small it is possible to obtain inhomogeneity of constituents
- overgrowth the mixing time does not lead to further improve the homogeneity of the constituents;
- excessive tightening and pressing of the mold leads to the accumulation of gases in the middle of the sample, it solidifies accomplished with a crater.

Manufacturing technology parameters and sequence of operations that have yielded good samples are those used in obtaining P7, P8, P9 and P10. These samples are considered appropriate, both in terms of concentration of constituents and in terms of manufacturing technology. These samples may be used to make specimens to determine the mechanical characteristics of the new composite material for brake pads application.
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