Ecological Composites Materials for Brake Pads Using Shells as Filler Material

CAMELIA PINCA BRETOTEAN[1]*, LUDOVIC DAN LEMLE[1], ALEXANDRU SZABO[2]

[1]Univesity Politehnica Timisoara, Faculty Engineering of Hunedoara, 5 Revolutiei Str., 331128, Hunedoara, Romania

[2] Politehnica University of Timisoara, Faculty of Mechanics, 1 Mihai Viteazul Str., 300222, Timisoara, Romania

The brake pads are one of the basic components for the development an ecological transport. The main objective of the paper is to produce green brake pads used shells as filler material capable to reducing the emission of fine and ultrafine particles resulting from vehicle braking systems. The stages in the development of this goal were: establishing the chemical composition of shells, formulating the recipes of composite materials, selecting parameters of technology, obtaining in laboratory and characterization of new materials in terms of physico-mechanical and tribological characteristics, evaluating their performance compared to similar materials presented in the scientific literature.

Keywords: helth, shell, brake, pad, composite

Current concerns about the environment and human health regarding fine and ultra-fine particles released to the environment from different sources have been the subject of several papers in the literature [1-5]. Recently, the vehicle braking system is considered by the European authorities as a source of pollutant emissions in urban air as a result of friction between discs and brake pads [6]. These particles emitted into the atmosphere as a result of the operation of vehicle braking systems affect the environment and human health, both by their size and concentration in the air, and by their chemical composition [7]. The main mechanism for the production of fine particles as a result of the braking process consists of exercising the friction forces between discs and brake pads during deceleration of vehicles. The secondary mechanism consists in the evaporation of the organic compounds as a result of high temperatures during braking phase [8]. Fine particles inhaled can be stored in the nose and throat causing irritation and allergies. Ultra-fine particles can penetrate the lungs, create free radicals in the cells of the body and can produce ADN changes, oxidation reactions and biological stress. Also, these very small particles can be transmitted through blood to other tissues and organs, such as liver, kidney, brain with negative effects on human health [9]. In order to reduce the impact of these pollutant emissions on the environment and human health, it is of particular importance to reduce polluant emissions directly at source, by using natural fibers in the manufacture of discs and brake pads. Researchers have shown that natural fibers can provide adequate, environmentally friendly and economical solutions while ensuring performance of braking system [4, 10]. Over the last decade, many researches has focused on the use of green engineering in the production of different components of motor vehicles that have, besides human health and environmental protection, natural resource conservation, and significant economic growth [11]. In the braking system of modern vehicles, the disc brake plays an important role in ensuring performance and braking safety. The disk and brake pad work together and are the most demanded components of the braking system. In this assembly the decisive factor determining the braking performance is the brake pad [12]. In the current context, the brake pads are one of the basic components of the race for the development an ecological transport [11]. Research on green brake pads is supported by the Sustainable Technologies Initiative that involves the use of natural fibers in their production. Thus, research has shown that renewable fibers could reduce dependence on synthetic materials and would allow the substitution of heavy metal constituents with alternatives for the environment and human health [13]. The main objective of the paper is to develop new materials for natural brake linings capable to reducing the emission of fine particles resulting from vehicle braking systems. Thus, will be produced friction material for brake pads having shells as filler material. These are ecological materials, wear-resistant and can be combined with other materials without harmful effects on the environment and human health. Several researches have been carried out in the area of development of brake pads without asbest in composition. In literature are available informations on the use of shells, palm kernel shells and coconut shells for brake pads materials. These papers are used in comparing the results obtained in this work [13-17]. The main objectives followed in the work were: establishing the chemical composition of shells, formulating the recipes of composite materials, selecting parameters of technology, obtaining in laboratory and characterization of new materials in terms of physico-mechanical and tribological characteristics, evaluating their performance compared to similar materials presented in the scientific literature.

Experimental part

The materials used in this work are: shells, phenolic resin, graphite, metal, silicon carbide [16]. The shells used in the recipes are Monodacna colorata species found in the Pontic Basin, and in Romania in the Razim complex, Figure 1. They have elongated shell, oval, thin, relatively fragile, with the anterior and posterior margins almost equal. The surface of the valves has numerous radial ribs. The shells measure 30-40 mm in length and 25-30 mm in width, the growth strings are concentric and the edge of the shell has small waves. The color is brown-red or gray with darker or lighter concentric stripes. The chemical composition of the shells is shown in Table 1.

Three different combination (sample A, sample B and sample C) will be prepared with varying content of shells and metal, Table 2.

The production of brake pad consists of a series of unit operations including grinding, mixing, cold and hot pressing,

* email: camelia.bretotean@fih.upt.ro

Element [%]	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	Na_2O	Cl	S	MnO	K_2O	ZnO
Level detected	80.3	8.98	3.2	2.8	1.3	0.768	0,543	0.638	0.530	0.277	0.664

Table 1
CHEMICAL COMPOSITION OF SHELLS

Compositions [%]	Sample A	Sample B	Sample C
Shell	40	45	50
Metal	25	20	15
Silicon carbide	4	4	4
Graphite	5	5	5
Hexametyltetramină	6	6	6
Phenolic resin	20	20	20
Total	100	100	100

Table 2
CHEMICAL COMPOSITION OF DEVELOPED MATERIALS

cooling, post-curing and finishing [12]. The raw materials were prepared in powder form, this method ensuring a good uniformity of ingredients in recipes [8, 13, 15]. The shells were inserted into a crusher that reduced the size to 3-4 mm, and then the charge was introduced into a ball mill which resulted in particles smaller than 1 mm. The product thus obtained was transferred to a set of sites that allowed sorting. The stages of the sintering process and the related parameters are presented in Figure 2. Figure 3 shows the samples obtained after the recipes at the end of the sintering process. It is noted that on extraction from the mold the samples preserved their integrity. The heating-cooling regime is suitable, and hot and cold pressing performs an efficient compaction of the material. All samples have a smooth surface and a completely circular geometric shape. Thus, the samples were subjected to a grindling and polishing process. These were analyzed from the point of view of the physico-mechanical and tribological characteristics, taking samples of each produced composite material in accordance with the standards in force [1, 13-23].

Results and discussions

The true density of the samples was determined by weighing the samples mass on a digital weighing machine and divided by measuring their volume by liquid displacement method.

The samples was cut to a dimension of 30x30x10 mm. The results are presented in Table 3.

Porosity is a characteristic of the pore structure existing in a material. It has the role of absorbing the energy and the heat result in the braking process [13]. Theoretically, lower porosity will results in higher friction coefficient and wear rate due to higher contact areas between the mating surfaces [13]. To perform the porosity test in oil was used SAE60 engine oil. For the porosity test, the samples were weighed, placed in a container with oil and keep at 90^0C for 8 hours. After that, the samples were left in the container for 12 hours, until the oil cools to the room temperature. The sample was weighed again and the value is presented in Table 3. The hardness test was conducted on a Rockwell unit PH -C -01 /02 in accordance with EN ISO 6508-1 standard : 2002. The hardness measurements were conducted under test load of 980,6 N, the stell ball diameter is 1,58 mm, using scale B as stipulated in the standard. The measurements were performed at a distance of 13 mm. Drive speed of the load is 0.8 m/s and the holding time is 10 s. The hardness of the sample is the arithmetic mean of the readings five indentations. The hardness values for each composite material are shown in Table 3.

The compressive strength test was done using theTensometric Machine. The samples has the dimensions 30x30x10mm and they were subjected to compressive force, loaded continuously until failure occurred. The load at which failure ccurred was then recorded. It is noted that experiments were carried out at a velocity of 20mm/min at 28^0C. The compression test was performed on a seies of 15 samples, the results in Table 3 representing their arithmetic mean.

The density of the samples decreased with the increase in the amount of shells, as the amount of filler material increased, the amount of metal in the recipe decreased. The lowest density is 1.7 g/cm^3, obtained for sample C. Similar conclusions were obtained in papers [13-16]. All samples have a relatively low absorption capacity. The absorption capacity of the oil decreases with the increase in the amount of shells in the recipe. The low absorption capacity of the oil can be attributed to the increase of the bond between the binder and the filler material, due to the proper homogenization of the constituents [12, 13, 17].

The hardness value of A sample is the highest of all and the hardness value of C sample show lower hardness value. This is because of too ductile nature of the material as more shells content in the composition. The same conclusions are obtained in paper [13]. Varying content of metal and shells will exhibit different hardness value of the material.

Samples with the largest amount of shells in the recipe also have the highest compressive strength, respectively the highest value of the request effort. This is explained by the fact that powdery shell particles have evenly distributed over the metal matrix, being carried out interference between them. Under deformation conditions a proper displacement of organic fibers through matrix occurred [13, 15]. The compressive strength and longitudinal elastic modulus of the composite materials increase with an increase in the amount of shells. The most suitable composite material for making brake pads can not be selected only on the basis of the assessment of the physical-mechanical characteristics. These can only be used to control the quality of formulations developed in the

Table 3
PHISYCO-MECHANICAL CHARACTERISTICS OF FRICTION MATERIAL

Samples	Density [g/cm^3]	Porosity in oil [%]	Hardness HRB	Breaking force [N]	Young modulus [N/ mm^2]	Compresive strength [N mm^2]
A	2.55	0.85	40	10557	36.29	-103
B	2.05	0.70	55	12345	27.88	-119
C	1.75	0.65	67	15778	25.66	-127

Table 4

PARAMETERS OF THE TRIBOLOGICAL PLANT

Power of the electric motor [KW]	Speed [rot/min]	The peripheral speed of the disc next to the specimen [m/s]	The maximum distance between the axis of rotation and the specimen [mm]
1	1500	11,77	75

Table 5

WEAR PARAMETERS

Sample	Initial mase [g]	Final mase [g]	Wear [g]	Time [min]	Wear Rate	Length of work [m]	Intensity of wear [g/m]	Wear of cast iron disk [g]
A	50.8657	49.3243	1.5414	8.5	0.1813	5000	0.000308	0.327
B	48.3395	47.3571	0.9824		0.1155		0.000196	0.289
C	47.3315	46.853	0.4785		0.0560		0.000095	0.198

Table 6

PARAMETERS FOR DETERMINING THE FRICTION COEFFICIENT

Wear trace diameter [mm]	Speed [rot/min]	Test time [s]	Test distance [m]
25	150	18000	2200

sintering process. Conversely, the physical and mechanical properties of the same recipes indicate that the process of obtaining the composite material is under control [13]. In order to determine wear behavior, samples made from composite materials will be subjected to tribological tests. In the research we studied the influence of the mass and dimensional characteristics on some wear parameters. The principle of tribological tests consists in pressing a pine made of the new materials produced on a rotary disk made of cast iron in order to determine the wear characteristics. For this purpose, were used pins made of composite materials and cast iron disc G 2500, according to ASTM A 159, (fig. 4). The test facility uses a dry friction regime, and the test method is *pin on disk*. Plant parameters are presented in Table 4.

Loading of the plant is done by means of a pallet where weights are placed on the known value. The assessment of the behavior of the tested materials is done by gravimetric method. For this purpose, was determined the wear intensity of pins and cast iron disk [13]. In laboratory experiments, the cast iron disc is designed to simulate the behavior of the brake disk in the braking system of the vehicle, and composite pins play the role of the brake pads [13]. In tribological experiments the speed was 3,92 m/s and the test range was R=25 mm. The wear parameters obtained at the end of the tribological tests are presented in Table 5.

Table 5 shows that the highest mass wearing was obtained for sample A and the lowest for sample C. Also, the highest wear intensity was obtained for composite A, and smallest for composite C. It is noticed that as the amount of shells in the recipe increases, it decreases the mass wearing, but also the wear intensity. The highest wear resistance is given by sample C followed by sample B. Wear of the cast iron disc is much less than the wear of composite materials. This shows that the wear resistance does not depend much on the amount of metal. This situation is very important for the practical solutions because the brake pads are replaced more easily than the disk. During the experiments, the samples were timed and weighed at intervals and lengths, the values obtained being plotted in figures 5, 6 and 7. Analyzing the graphs it was observed that significant results were obtained from the correlation of coefficients.

The determination of the friction coefficient was performed on a TR-20 test equipment. 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 parallelepiped shape with dimensions 50x50x50mm. 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 ± 0.01 mg. Test parameters use in experiment are presented in Table 6.

The evolution of friction coefficient is shown in figure 8, 9 and 10. The friction coefficient has high fluctuations around the value 0.35-0.45, so the value obtained confirm the technical literature [9, 13, 16]. At the beginning of the tests, the coefficient of friction varies as a result of the discontinuous contact between the steel ball and the composite material samples due to the irregularity of the front surface of the parallelepiped sample. The increase of the contact surface between the composite materials and the steel ball, after a certain period of time since the beginning of the experiments, led to an increase in the coefficient of friction. For all tested samples, the friction coefficient stabilizes over time after a specific test range of 16000-18000s. The highest coefficient of friction was obtained for sample C, which has the largest amount of shells. The value of the coefficient of friction for this sample is 0.45.

Conclusions

As a result of the experiments we made the following conclusions:

-the density of organic composite materials produced increases with the increase in the amount of shells in the recipe;

-low porosity was determined by proper homogenization of the constituents of the recipe;

-the hardness, compressive strength and Young's modulus increase with the increase in the amount of shells in recipes;

-the homogeneity of the mixture subjected to sintering process provided the structural integrity of the composite materials resulting in superior physical-mechanical characteristics;

-the coefficient of friction obtained is within the recommended standard for small and medium automotive brake pad;

-composite material with the best physico-mechanical and tribological characteristics is sample C, with the highest amount of shells in the recipe;

-the results obtained in this research indicate that shells can be used as a filler material in production of brake pads without harmful effect.

-the major inconvenience in producing composite materials is the recovery of shells.

References

1.CIUDIN R, VERMA P.C, GIALLANELA P. & STRAFFELINI G., Wear debris materials from brake systems: environmental and health issues, The Sust. City IX, 2 p.1423

2.OSTOIA, D., NEGOITESCU, A., TOKAR, A., THE WEARING OUT COMPENSATION OF DIESEL ENGINES COMBUSTION CHAMBERS BY MODERN SYSTEMS IMPLEMENTATION, Annals ff DAAAM for 2008 & Proceedings of the 19-th International DAAAM Symposium, Book Series: Annals of DAAAM and Proceedings, vol.19, 2008, p.999-1000

3.MIHON, L., NEGOITESCU, A., TOKAR, A., OSTOIA, D., TYRE QUALITY INFLUENCE ON FUEL CONSUMPTION FOR MOTOR VEHICLES, Annals ff DAAAM for 2009 & Proceedings of the 20-th International DAAAM Symposium, Book Series: Annals of DAAAM and Proceedings, vol.20, 2009, p. 751-752

4.NEGOITESCU, A., OSTOIA, D., TOKAR, A., HAMAT, C., Study on the Treatment of Exhaust Gases at Diesel Engines with the Purpose of Reducing the Emissions of Nitrogen Oxides, Rev. Chim (Bucharest), **60**, no. 4, 2009, p. 411,413

5.MIHON, L., OSTOIA, D., NEGOITESCU, A., TOKAR, A., SIMULATION OF VEHICLE'S POWERTRAIN FOR PERFORMANCES EVALUATION, Annals ff DAAAM for 2009 & Proceedings of the 20-th International DAAAM Symposium, Book Series: Annals of DAAAM and Proceedings, vol.20, 2009, p. 253-256

6. *** European Environment Agency EMEP/EEA air pollutant emission inventory guidebook, Technical Report, no.12, 2013

7.SANDERS P. G., XU N., DALKA T. M. & MARICQ M. M., Airborne brake wear debris: Size distributions, composition, and a comparison of Dynamometer and vehicle tests. Environmental Science and Technology, **37(18)**, 2003, p. 4060

8.IONESCU G., APOSTOL T., RADA E.C., RAGAZZI M., TORETTA V., Critical analysis of strategies for PM reduction in urban areas, UPB Sci.Bul., **75(2)**, 2013, p.175

9. GUTTIKUNDA S.K., GOEL R., Health impacts of particulate pollution in a megacity-Delhi, India. Environmental Development, **6(1)**, 2013, p.8

10.***EU Natura 2000 network - EU nature & biodiversity policy, http://ec.europa.eu/environment/nature/natura2000

11.ANDERSSON C., DETTMANN T., Environmental Footprint and Performance Analysis of a Brake Disc Production Line using Discrete Event Simulation, Department of Product and Production Development, Sweden, 2013

12.IDRIS U.D., AIGBODION V.S., ABUBAKAR I.J., NWOYE C.I., Eco-friendly asbestos free brake-pad: Using banana peels, Materials Science, no.5, 2014, p. 295

13.CRACIUN, A.L., Research on the use of composite materials in vehicle braking systems, PhD Thesis, Hunedoara, Romania, 2018

14.ELAKHAME. Z. U.,ALHASSAN A., SAMUEL A.E., Development and production of brake pads from palm kernel shell composites, Int. Jour. of Sci.&Eng.Res., **5**(10), 2014, p.735

15.ELAKHAME. Z. U.,OLUTU O.O., ABIODUN Y.O., AKUBUNZE E.U., Production of asbestos free brake pad using perinwinkle shell as filler material, International Journal of Scientific&Engineerin Research, **5**(10), 2014, p.735

16. DARLINGTON E., CHUKWUMobi O.,OKOLO P., Production of eco-friendly brake pad using raw materials soured locally in Nsukka, Int. Jour. of En. Tech. and Pol., **5**(11), 2015, p.46

17.POPESCU I.N., GHITA C., BRATU V., NAVARRO G.P., Tribological behaviou and statistical experimental design of sintered iron-copper composites, Appl. Surf. Sci., 285P, 2013, p.72

18.BORDEASU, I., MITELEA, I., LAZAR, I., MICU, L.M., KARANCSI, O., Cavitation Erosion Behaviour of Cooper Base Layers Deposited by HVOF Thermal Spraying, Rev. Cim. (Bucharest), **68**, no. 12, 2017, p.2914-2917

19.BORDEASU, I., MICU, L.M., MITELEA, I., UTU, I.D., PIRVULESCU, L.D., SIRBU, N.A., Cavitation Erosion of HVOF Metal-ceramic Composite Coatings Deposited onto Duplex Stainless Steel Substrate, Mat. Plast. **53**, no. 4, 2016, p.781-786

20.ILIESCU, N., ATANASIU, C., HADAR, A., The simulation of the mechanical behaviour of engineering structures on models made of plastic materials with special properties, Mat. Plast. **42**, no.1, 2005, p.72-76

21.TABACU, S., TABACU, I., HADAR, A., Computational modelling of vehicle interior components for impact applications: Thickness analysis, INTERNATIONAL JOURNAL OF CRASHWORTHINESS, Volume 16, Issue 4, 2011, p.421-438

22.GOANTA, V., HADAR, A., LEITOIU, B., Experimental Procedure Designed to Determine the Elastic Characteristics of Fiber-Reinforced Polymeric Composite Materials, Mat. Plast., **47**, no. 4, 2010, p.450-456

23. TABACU, S., HADAR, A., MARINESCU, D., IVANESCU, M., BALASOIU, V., Numerical Procedures for the Improvement of the Structural Response of Thermoplastic Manufactured Parts, Mat. Plast. **46**, no. 2, 2010, p.192-197

Manuscript received: 27.07.2019