DEVELOPMENT AND RESEARCH OF HYBRID POLYMER COMPOSITE MATERIALS BASED ON PHENYLONE

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Abstract: The article presents the results of studying the designed hybrid compositions based on phenylone reinforced with a mixture of organic and carbon fibers. An example of calculation of molds' construction for the manufacture of composites is given. It has been found that the intensity of wear of the developed composites is significantly higher than that of the initial phenylone, while possessing the reduced coefficient of friction by 1.6 - 2 times, and the increased physico-mechanical characteristics by 10 %.

Key-words: hybrid polymer composites, polyamide, organic and carbon fiber, mold, matrix

1. INTRODUCTION

This century, by analogy with a Bronze or Iron Age, can be called the Composite Materials (CM) Age. The emergence of the term refers to the middle of the previous century, but the concept itself is not new. Combinations of different materials were used in the construction of homes by engineers of ancient Babylon and Rome, the masters of ancient Greece, and Moscow architects (Composite materials, 2013).

Most of the properties of the obtained CM are advantageous over the properties of initial components. The introduction of such materials gave a possibility to selectively choose CM properties essential for particular applications. CM application provides for a new qualitative leap in increasing the engine power, energy and transportation systems, reducing the weight of machines and appliances. CM turned out to be cost-effective and easy-to-design, and are now used everywhere - from the

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production of toys and tennis rackets to use in spacecraft (insulation, chips, etc.) (Composite materials, 2019; Naberezhnaya & Burya 2016).

Fibrous composite materials are composite materials in which various fibers are used as fillers. The peculiarity of the fiber composite structure is uniform distribution of high-strength, high-modulus fibers in the plastic matrix (where their content can reach 75%).

Within fibrous CM, fibers perceive major stresses in the composite material in case of the external loads, and provide for the strength and hardness of the composition in the direction of fiber orientation. Matrix filling interfiber space enables the interaction of individual fibers due to its own hardness and interaction existing at the interface matrix-fiber.

Mechanical properties of fibrous CM are determined by three parameters: high strength of reinforcing fibers, rigidity of matrix and binder strength at the interface matrix-fiber (Naberezhnaya & Burya 2016; ZUKM, 2016). There are several papers which examine different characteristics of phenylone. Investigation of creep in phenylone was done by authors (Vikhauskas, et al. 1988). Energy disipation of carbon-filled plastics based on phenylone was done in paper by (Burya, 2005). Curing and thermo-destruction processes of prepreg based on phenylone paper (Khabenko, et al. 1992), influence of aggressive media on tribotechnical properties of phenylone (Burya, et al. 1994). Investigation of the properties of carbon plastics based on polyetheretherketone and temperature fields at consolidation of powder material is given in papers (Burya, et al. 2016a; 2016b).

Fiber composites were obtained for the first time at the beginning of the twentieth century and were represented by phenoplasts with cotton fiber. Usually, a common name of polymer composites corresponds to the nature of fibers: glass -, carbon, ogano-, boroplastics, or - in case of hybrid options - glass carbon plastics, organoboroplastics, etc. (Astanin, 2011). Depending on the technology of molding, CM indicators may significantly differ. The choice of a technology depends on the product's construction, terms of its exploitation, the volume of production and available production resources (ZUKM, 2016).

Wrong organization of the technological process, poor preparation of initial components, failure to comply with technological modes (pressing pressure, duration and temperature of the process, the requirements for the preparation of raw materials), and many other reasons can significantly change the properties of finished products. Therefore, it is essential to organize the process not only correctly, taking into account the construction and exploitation conditions of the products, but also complying with technological modes during implementation. In order to achieve this, current control of technological parameters and properties of the manufactured products must be carried out at all stages of the process (Bobovich, 2016).

When developing products for engineering or instrument construction, wide application of construction plastics is often constrained due to lack of information about the full set of characteristics of new construction plastics, about their behavior in various tribological systems, though their use in the manufacture of products for engineering will significantly enhance the area and operating conditions and will increase the resource of products, knots, mechanisms or constructions (Dariyenko, 2012). On the basis of the mentioned above, an opportunity to develop CM polymers based on thermoplastic matrix has been studied and their properties have been researched.

2. OBJECTS AND RESEARCH METHODS

As a binder an aromatic polyamide phenilon C-1 has been selected (TC 6-05-221-101-71). It is a fine-dispersed pink powder with bulk density of 0.2 - 0.3 g/cm3 and specific viscosity of a 0.5 % solution in dimethylformamide with 5 % of chloride lithium of at least 0.75, characterized by the following properties: shock viscosity of 24 kJ/m2, hardness of 18 HRB, breaking stress at extension of MPa. For reinforcement a mixture of discrete fibers has been used:

• organic (OF) of Tanlon brand, 3 mm long; elastic modulus at extension of 7.45 GPa, elongation at break of 20-25 %, density of 1.42 g/cm3;

• carbon (CF) Toreyka, 3 mm long, elastic modulus at extension of 220 - 230 GPa, density of 1,76-1,80 g/cm3.

A certain composition (Table 1) has been prepared and carried out by dry mixing within a rotating electromagnetic field (0.12 T) (Burya, et al. 2014).

Table 1. **The formulations**

Designation of compositions	**Filler fiber wt/%**				**The content of the binder mass. %**	
Compositions 1		-		-		100
Compositions 2		4		5		91
Compositions 3	Tanlon	5	Toreyka	7	Aromatic polyamide phenylone C-1	88
Compositions 4		5		15		80
Compositions 5		15		5		80

Processing of the prepared compositions into cylindrical products (10x15 mm) has been made by compression pressing.

This method of processing the aromatic polyamide is the preferred one, because the polymer placed in the loading camera mainly experiences compressive deformation, and there is almost no strong shear deformation. Particular attention has also been paid to the choice and maintenance of processing temperature with high accuracy (Burya, et al. 2016).

Studies of microstructure have been carried out with the help of Biolam M microscope on specially prepared samples with the multiplication of 200. Density and Rockwell hardness (HRE scale) of the obtained polymer composites have been determined in accordance with GOST 15139 - 69 and GOST 2422-91, respectively. Tribological properties of hybrid materials have been studied on the disk drive friction machine in the mode of dry friction by the scheme "disk-finger" at specific pressure P = 0.6 MPA and sliding velocity of 1 m/sec, the track of 1000 m.

3. DEVELOPMENT OF MOLDS

Shape and size of a finished product have been formed in specially designed molds. In order to ensure safety and security while operating the molds, the solution of some problems during their construction is required. This especially concerns such factors as creep of polymer materials, stress relaxation, fatigue by static or cyclic loads, aging by changes in the environment. It is extremely important to determine the correct construction of the geometric configuration in order to avoid a sharp increase of stress concentration and as a consequence of high values of product deformations. Local increase of stress in case of linear-elastic behavior of the polymer is characterized by the coefficient of stress concentration Ks (Naberezhnaya & Burya 2016), (1):

$$K_H = \frac{\sigma_{Max}}{\sigma_{NOM}} \tag{1}$$

which is a ratio of the maximum local stress σ_{Max} to the nominal stress σ_{Nom}.

For the manufacture of prototypes, molds have been developed consisting of the following details: matrix, upper poinson, sign, lower poinson.

One of the main details of technological application is the matrix in which the product acquires the necessary configuration and sizes. The matrix is a cylinder with holes in it, relevant in size to outer dimensions of the manufactured products. In the process of operation the matrix experiences stress, different in intensity, therefore, calculation of mechanical strength of matrices' walls is required. The calculation of the thickness of the matrix walls has been carried out by the formula (2).

$$\delta = r \cdot \left(\sqrt{\frac{\sigma_p + 0{,}4 \cdot P_o}{\sigma_p + 1{,}3 \cdot P_o}} \right) \tag{2}$$

where δ is the wall thickness, m; r is the radius of a shaping nest, m; P_o is the specific pressure of molding, N/m^2; σex is the allowed tension at extension, N/m^2.

The height of the matrix, which often plays the role of the loading camera, is not really calculated. Depending on the specific amount of material it is accepted as being 5-6 times as high as the height of the pressed products. Mechanical strength of other details of technological application is not calculated, their dimensions are determined by the size of the pressed details taking into account the shrinkage (relative reduction of the product size compared to the size of forming areas of molded details). These dimensions are determined by the expression (3).

$$l_{FA} = l_D \cdot y_0 + l_D \tag{3}$$

Where l_{FA} is the size of the forming area, mm; l_D is the desired size of a product, mm; y_0 is relative linear shrinkage of the processed material, %.

Correctly selected technological modes of pressing products made of polymeric materials are some of the most important prerequisites of achieving the desired strength properties. As a result of an incorrectly selected production mode the following problems may occur:

- partial crystallization of the melt;
- high degree of polymer orientation;
- lack of filling within the forming cavities of the mold;
- porous formation caused by failure to maintain a given pressure during product cooling;
- cold junction formation.

During exploitation, the details of technological application are subject to long-term heating and are affected by chemically active agents. Therefore, materials of which mold details are made, must possess minimum deformation during thermal processing, high hardness after heat treatment, and must be well processed. With this concern, mold details have been thermally treated to the hardness of 48-51 HRCe, and the purity of the surface of the forming elements made Ra 0.10 - 0.16 mcm.

Mold details (matrix, upper and lower poinsons, sign) were made of stainless heat-resistant steel ХВГ GOST 5950-73, and auxiliary equipment (heating plates, out-pressing sleeves, plates, etc.) was made of ordinary carbon steels Art. 3, Art. 5, Art. 20.

Samples of hybrid compositions for their complete study have been obtained by means of previously (Sokolov, 1975) selected optimal processing modes.

4. RESULTS AND DISCUSSION

The analysis of the microstructure of the received samples has shown that the selected way of products processing does not disturb uniform distribution of fibers within the polymer matrix (fig. 1).

Nowadays one of the most important tasks is the reduction of construction mass. This can be achieved by means of replacing metal details with polymer ones, as they have significantly lower density and not inferior mechanical characteristics. It has been found that the developed PCM possess low density (fig. 2), namely: its values are changing in the range of 1.34 - 1.39 g/ sm^3, which is almost 7 and 6 times below bronze OCS 5-5-5 (most widely used for the manufacture of rubbing details) and steel, respectively. Analyzing the obtained dependency curves of density on the content of filler in the matrix, it is possible to say that during the experiment more porous structure of the samples compared to the calculated data is formed. This is due to the fibers' hardness and the lack of the embracing ability of the polymer. Taking this into consideration, it seemed particularly important to study the influence of a reinforcing component on mechanical properties of the obtained materials.

For many materials a clear dependence between the hardness of a material and its mechanical and technological characteristics (strength, wear resistance, stability under stress) has been set. Therefore, a study of hardness has been conducted, and it turned out that reinforcement leads to an increase in this index by 10 % compared to pure phenylone (table 2), reaching the maximum value of 103 HRE in case of filling a binder with a mixture of fibers at the amount of 15 wt.% of organic and 5 wt.% of carbon ones.

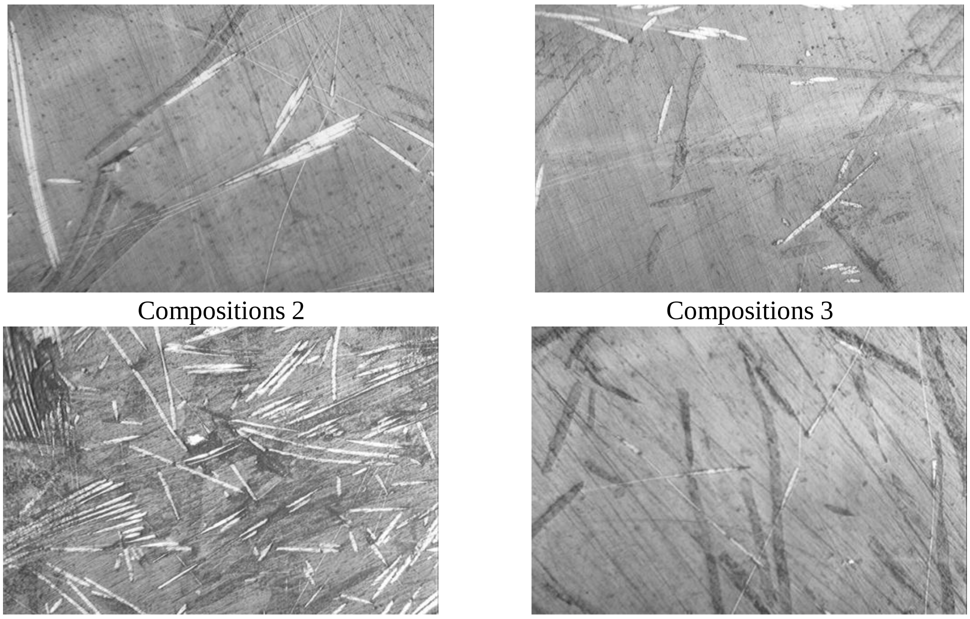
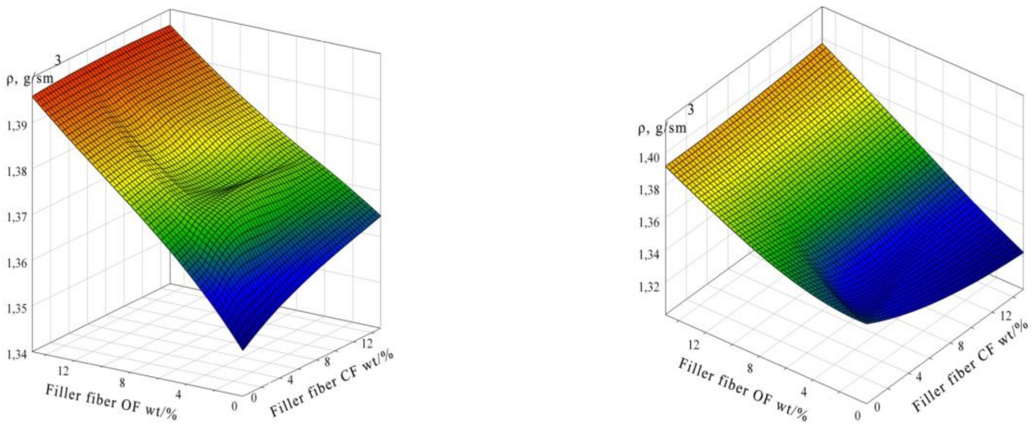


Fig. 1. Microstructure of hybrid compositions (multiplication 200).



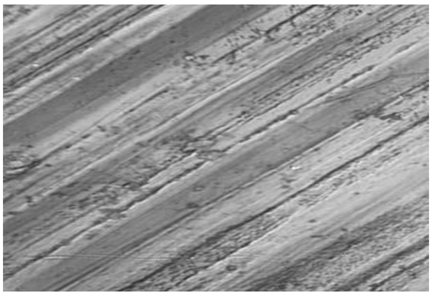
a b

Fig. 2. Calculated (a) and experimental (b) density of hybrid compositions based on phenylone.

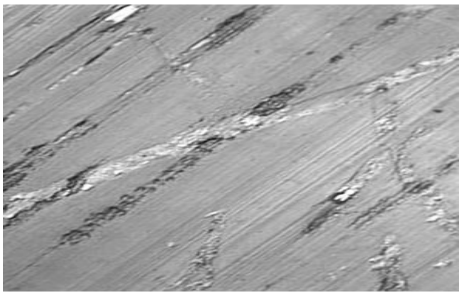
During the test aimed at defining tribotechnical characteristics, it has been found (table 2) that the intensity of wear of the obtained compositions is significantly superior to the initial polymer, while reducing the coefficient of friction by 1.6 - 2 times. This is obvious in the study of microstructure of the friction surface (multiplication 200), where the reduction furrows and friction tracks have been clearly seen (fig. 3.).

Table 2. **Properties of hybrid polymer composites**

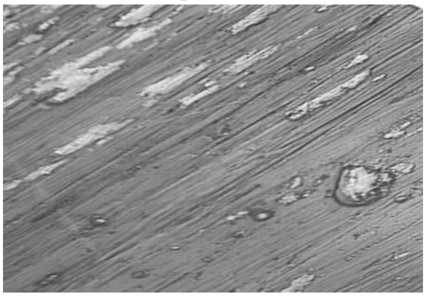
Indicators	**Compositions 1**	**Compositions 2**	**Compositions 3**	**Compositions 4**	**Compositions 5**
Rockwell hardness (HRE scale)	97,3	101,3	102,2	102,5	103
Coefficient of friction	0,52	0,259	0,294	0,310	0,320
Intensity of wear	$2{,}2\cdot10^{-8}$	$2{,}43\cdot10^{-9}$	$1{,}36\cdot10^{-9}$	$1{,}94\cdot10^{-9}$	$3{,}9\cdot10^{-9}$



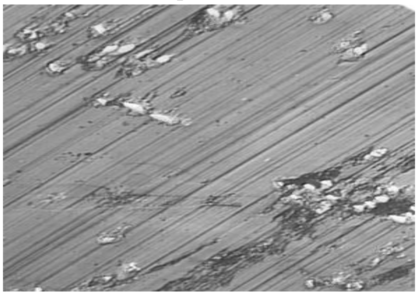
Compositions 1



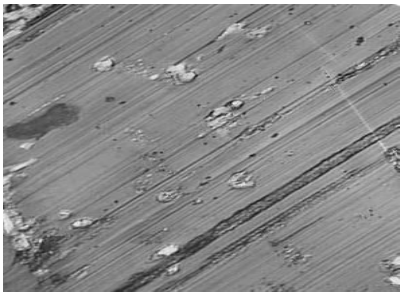
Compositions 2



Compositions 3



Compositions 4



Compositions 5

Fig. 3. Friction surface of polymer hybrid compositions, multiplication ×200.

This fact is most likely due to a good adhesion between the components of compositions, as well as to structuring of the macromolecular structure - transition of a globular structure of phenilon (Spumaker 2004) into the fibrillar one.

5. CONCLUSIONS

On the basis of the obtained results, we can conclude that the developed new construction materials based on polymers are able to operate as the details of friction knots in hard dry conditions with quite high loads.

It has been shown that the reinforcement with a mixture of fibers of different nature improves both tribotechnical and physico-mechanical properties. This can easily recommend materials used as structural components and responsible use.

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