Analysis of the properties of the mixture’s components on the basis of construction and polymeric materials waste

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Abstract. The paper presents the technologies of obtaining composite structures on the basis of secondary polymeric and construction materials filled with coordination compounds, got by the mixture’s coextrusion through the coextrusion head as well as by the extrusion pressing-out through the fillister head. It has been found out that with the decrease in the size of the layer’s boundary and with the increase of the layers’ durability the friction coefficient diminishes. Besides, reaching the friction coefficient’s value at the established stage happens during a longer period than for a single-layer structure. The value of the tear-and-wear for a multilayer composite structure is much less than for a single-layer one. A multilayer composite structure is recommended to be used as an antifriction material under low pressures at a high slip velocity. It is demonstrated that due to the addition of the filler on the basis of coordination compounds into separate layers during the coextrusion molding it is possible to obtain the material with the improved wear resistance.

1. Introduction

Secondary polymeric materials on the basis of domestic waste along with primary polymers can be used for producing rotating parts and mechanisms, gaskets, and details in the friction units of machines and mechanisms. According to the physico-mechanical properties these materials slightly yield to the primary materials due to the presence of different polymers with dyes and fillers in their composition, as well as having undergone thermal processing for many times. However, according to the tribotechnical properties some composite materials excel the primary polymeric ones [1, 2]. They are characterized by a low friction coefficient, good wear resistance, the ability to run in easily to the shaft, and withstand considerable loads [3]; they also have some advantages in comparison with ordinary antifriction materials [4]. Their wear resistance can be several times higher than of polypropylene, polyethylene, and polyamide. They can work at higher speeds and under higher pressures. The presence of limestone waste in their structure, being regulated in the wide range (up to 25%), for example, allows increasing durability preliminarily [5].

Due to the manufacture needs there appears a possibility of using multilayer materials, containing elements of several layers, as antifriction multilayer materials. The task to improve properties can be accomplished due to the unification of a polymeric plastic matrix with the fillers which are coordination compounds. At such phases’ combination a considerable enhancement of the bearing
material capacity in tribounits is achieved, as well as a high wear resistance and durability against abrasive tear-and-wear. Apparently, to use a multilayer composite structure as an antifriction material is of great interest.

The objective of the research is to elaborate the technology of obtaining composite multilayer structures on the basis of secondary polymeric and construction materials filled with the coordination compounds with an enhanced wear resistance due to the control of the structure during the coextrusion molding.

2. Methodology of the research

To create an antifriction material the following waste was used: crushed domestic waste of polymeric materials, limestone waste, obtained from the industrial waste, and the filler from coordination compounds [6]. The samples were obtained by two molding schemes: the mixture’s extrusion through a fillister head [7], and by the coextrusion through three annular canals of the coextrusion head [8].

The samples for the research were got by the extrusion in the laboratory extruder under the pressure of 3.9 MPa, the model EL-1. The molding was done in the single-auger extruder (the composition of the secondary materials’ mixture: 94% - secondary polymer, 5% - limestone waste, 1% - a filler on the basis of coordination compounds) according to the temperature regime [9]: heating up to the temperatures of 140-150 °С, 150-160 °С, 150-155 °С, maintaining the set parameters of the temperature. Then the mixture was extruded through the extrusion head at the temperature of 154-158 °С.

Tubular samples with the diameter of 16 mm, the length of 100 mm, were manufactured by the coextrusion of three layers in the coextrusion machine. The molding was done through the coextrusion head in the same regime. After the molding the samples were cooled down. The coextrusion molding was done with the addition of the filler into each layer sequentially [10-12].

The structure and physico-mechanical properties, such as density, tensile strength, the change of friction coefficient depending on the covered distance, tear-and-wear because of the load were studied on the manufactured samples. The structure was studied with the help of the metallographic inverted microscope METAM PB-34.

The density was determined by the method of hydrostatic weighing. The antifriction properties of the samples, obtained by the extrusion and coextrusion molding, were studied after each filler’s addition in the conditions of dry friction in the tribometer SMC-2. The pair “bush-shaft” was used for modeling the work of the dry friction tribounits.

The tests for tear-and-wear in the dry friction conditions were done on the samples with the dimensions 8×8×60 mm. The unit load on the samples (0.1 and 2.2 MPa) and the slip velocity (0.5 and 1.1 m/s) during the tests satisfied the working conditions of the friction units. Before the beginning of the tests the sample was run in for 2 hours, including 1 hour of constant unit load being equal to 20% of the rated load. After the run-in the sample and the counterbody were washed in the solvent and then they were weighed. The tests continued for 15 hours. Then the sample and the counterbody were again washed and weighed. The value of the friction force was registered automatically every second with the help of the microprocessor built in. In the case of the obtained samples by the method of coextrusion molding the plane of the material flow served as the friction surface, and the friction direction was chosen crosswise the samples. The friction coefficient and tear-and-wear were determined. The experimental researches of the strength properties of polymeric tubes obtained by the extrusion and coextrusion methods were carried out in the universal disruptive electromechanical machine REM-50-1.

It has been ascertained that the polymers, modified by the filler on the basis of coordination compounds, considerably excel the polymers without addition of the filler in the tensile strength.

3. Results of the research

The samples, obtained by the extrusion, had a heterogeneous structure (Figure 1, a). The density of the sample is 1.19 g/cm³. The compaction of the structure is observed after the addition of the filler into
the each layer during the coextrusion molding on the cut out sample. If before the coextrusion without the filler the size of the layer’s boundary was 0.82 mm, then after the addition of the filler into the first layer an average size of the layer’s boundary was 0.59 mm (Figure 1, b). A quazihomogeneous structure with less-curved boundaries and the presence of the deformation texture is observed. The absence of visible pores indicates a high density of the material [13].

The degree of the structure’s homogeneity increases after the addition of the filler into the second layer during the coextrusion molding; and the size of the layer’s boundary decreases monotonously with the increase of the filler’s amount (Figure 1, c). The layer’s boundary, stretched perpendicularly to the molding direction, acquires much smoother form; a complete absence of pores is observed on the layer boundary, the density of the sample was 1.21 g/cm³ [14-18]. A more homogeneous structure was formed. An average size of the layer’s boundary was 0.34 mm.

After the addition of the filler into the third layer during the coextrusion molding we got a homogeneous, ordered, smooth microstructure, having less-curved boundaries; along with this the layer’s boundaries had an evident texture of molding (Figure 1, d). An average size of the layer’s boundary in the middle layer with the dimension of 0.44 mm was obtained.

Figure 1. The microstructure of the samples: a – after the extrusion molding; b – after the addition of the filler into the first layer during the coextrusion molding; c – after the addition of the filler into the second layer during the coextrusion molding; d – after the addition of the filler into the third layer during the coextrusion molding.

The change of the samples’ density after the molding is presented in Figure 2. After the molding practically an even structure with an average density of 1.20 g/cm³ along the sample’s length was obtained. After the coextrusion molding the density along the sample’s length changes unevenly since all the fillers have been added. The most density is got in the extreme zone of the sample, moreover, with each addition of the filler the size of the compaction’s boundary grows. That is why the sample for researching the antifriction properties was cut in the extreme zone of the compaction.

Figure 2. The change of the density along the length of the samples: 1 – after the addition of the filler into the first layer during the coextrusion molding; 2 – after the addition of the filler into the second layer during the coextrusion molding; 3 – after the addition of the filler into the third layer during the coextrusion molding; 4 – after the extrusion molding.
A low friction coefficient and a good run-in, i.e. the ability to change the configuration of the friction surface in respect of the counterbody’s surface, are characteristic of the structures with the improved antifriction properties.

Figure 3 shows the dependence of the friction coefficient on the distance of the samples, obtained by two schemes of molding and having a different size of the layer’s boundary. Two stages are observed on each curve. First, the run-in of the sample’s surface happens; this corresponds to the increase of the friction coefficient. In connection with a good hardness of the composite structure, this stage is prolonged. Since the surface of the samples is not ideally smooth, at this stage the samples are pressed to the steel disk, macroscopic protuberances are flattened. The deformation of the protuberances leads to the emergence of the complex configuration’s zones on the surface; units of catching emerge between these zones and the steel disk. Then they deform, taking a streamlined shape, and the established stage sets in. Along with this the transition to the established stage for a single-layer composite material, obtained by the extrusion, happens during a longer period and the friction coefficient is high; this is explained by a low hardness and durability of the single-layer composite structure and by the adhesion of the material’s particles in the process of slip. For the material, obtained by the coextrusion molding, the period of the established stage is more, but the friction coefficient is less. The multilayer has a considerable impact. The large multilayer of the material leads to the decrease in the friction coefficient and the increase of the run-in stage. After the three-fold addition of the filler during the coextrusion molding the friction coefficient for a multilayer structure was 0.45.

The change of tear-and-wear depending on the load is presented in Figure 4. With the growth of the load the tear-and-wear increases, but the speed of the tear-and-wear of the multi-layer composite structure, obtained after the three-fold addition of the filler [12] during the coextrusion molding, is less than of the single-layer structure, obtained by the extrusion molding. The multi-layer structure decreases the tear-and-wear of the material.
The multi-layer structure of the material, obtained by the coextrusion, provides a lesser value of the friction coefficient and a less tear-and-wear; this is connected with the growth of the hardening – the growth of the durability in comparison with the composite structure, obtained by the extrusion.

The forces, operating in the area of the inter-phase interaction between the layers, play a special role in the multi-layer composite materials.

4. Conclusions
The technology of obtaining a multi-layer composite structure of the materials with the enhanced wear resistance due to the addition of the filler on the basis of the coordination compounds into separate layers during the coextrusion molding was elaborated. The recommendations on determining the conditions of creating composite material and its usage were formulated. The optimum amount of the filler (in the percentage-mass equivalent) for getting the composite mixture, having the best characteristics, which provide the improvement of the operational properties of the material, was determined. The research showed that with the decrease of the layer boundary and the increase of the structure’s durability the friction coefficient decreases. Besides, reaching the friction coefficient’s value at the established stage happens during a longer period than for a single-layer composite material. The value of the tear-and-wear for a multi-layer composite structure is much less than for a single-layer one. Hence it follows that a multi-layer composite structure on the basis of secondary polymeric and construction materials filled with coordination compounds can be used as an antifriction material under low pressures and at a high slip velocity.

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Acknowledgements
The study was carried out with the financial support of the Ministry of Science and Higher Education of the Russian Federation within the framework of the scientific project FZEG-2020-0030.