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PHYSICAL AND MECHANICAL PROPERTIES OF COMPOSITE MATERIALS POLYMER WASTE JSC "BELTSVETMET"

On the basis of polymer waste of "Beltsvetmet" samples made of composite materials with different contents of waste. Materials produced by the method of the seam-forming and injection molding. Identified the main technological parameters of manufacturing processes. Restrictions on the weight content of the waste to the methods of manufacture. For determined materials derived basic physical and mechanical characteristics: density, tensile strength and tensile modulus and bending strength, tensile shear strength, impact strength. It has been established that the strength properties of composite materials based on polymer waste stored on a completely acceptable level in comparison with the primary and secondary unfilled polymers. The influence of the method of manufacture and maintenance of waste on the mechanical properties of materials. The fundamental possibility of recycling of polymer waste by seam-forming and injection molding products irresponsible destination to which no high requirements.

Key words: polymer-waste, composite material, seam-forming, injection molding, physical and mechanical characteristics.

Introduction. Polymer-containing wastes formed in JSC "Beltsvetmet" as a result of mechanical cutting of worked out car batteries are characterized by considerable heterogeneity of the content and sizes. They include polymeric pieces, polymer film, polymer strands and filaments, rubber, wood, polymeric labels, glass wool, ebonite, lead. At present these wastes are not used and the company is interested in the development of effective methods of their recycling into products. This will allow, firstlyl, to solve the environmental problem associated with the removal and disposal of waste and, secondly, to produce competitive products due to the low raw material cost.

One of the most common methods of processing the filled and unfilled thermoplastic polymeric material is injection molding [1].

The method allows to obtain different product configuration, however, its application is limited by the heterogeneity of polymer waste and the filling degree of infusible components. Another method suitable for mixed polymer waste recycling into products is pressing of plasticized composition, or layer-molding [2].

The process of shaped article producing using this method includes the preparation of a feedstock (washing, drying, grinding of mixture components), dosing and compaction of the composition plastication with screw extruder, an accumulation of plasticized material dose, the formation of a workpiece, its moving into a mould and the product molding.

One of the method advantages is the possibility of processing of highfilled heterogeneous waste compositions having high viscosity in the molten state. To determine the effective sphere of material application based on polymer-containing wastes the information about their physical and mechanical properties that are not currently available is needed. Purpose of this article is to determine the possibility of polymer waste recycling resulting from the cutting of worked out automotive batteries by injection molding and layer-molding, and the study of physical and mechanical properties of materials based on the given wastes.

Main part. The composite materials obtained from the two types of waste were investigated:

1) wastes generated as a result of cutting enclosure batteries (hereinafter KAB);

2) the polymer-containing wastes, which are formed by cutting an internal part of the batteries (hereinafter POAB).

Before the production of material samples, the wastes were ground in the milling crusher CES 0090 M. The particle sizes of the crushed wastes are up to 10 mm. The crushed wastes were laid out on trays in a thickness of 20 mm and dried in an oven at 80°C for 4 hours (for the layer moulding method) and at a temperature of 90°C for 2.5 hours (at injection molding).

KAB wastes were used as a binder, POAB wastes – as filler. Materials' samples were produced from compositions with a mass content of waste POAB 20, 30, 50 and 70% at a layer-forming and 5, 10, 15, 20% at injection moulding. Mixtures were obtained mechanically by mixing of KAB and POAB wastes directly before manufacturing. The technological process of the articles' manufacturing by workpiece molding from the preplasticized thermoplastic composition (a layer-forming) includes the following steps: preparing and combining the components; the composition plasticizing in a screw extruder; dose accumulation and the workpiece formation; the workpiece moving into a mould; the workpiece deformation (product shaping); cooling in the form and recovering the product. The experimental plant in which samples for material testing were prepared, includes screw extruder PE 32×25 with a composition loading means; cylinder-accumulator of 1 dm^3 with the sealing piston and the valve; cylinder piston drive; pneumatic cylinder actuator valve; hydraulic pump; compressor; press-mold for manufacturing slabs with plan dimensions 250×250 mm; hydraulic press P-50 with a rated pressing force of 500 kN; control and measurement devices for process parameters – temperature, drive power and compression forces. Shredded, dried and mixed compositions in the above proportions, were plasticized in a screw extruder PE 32×25. The dose of the compositions to 600 g weight were formed in a melt storage cavity. The workpiece extruded from a reservoir was placed in the press-mold cavity with the plan dimensions of 250×250 mm. The plates with a thickness of 4–8 mm were pressed After cooling, the plates were removed from the mold. Technological modes of manufacturing the plates are shown in Table 1.

Table 1

Plates manufacturing modes by layer-forming

Technological modes	KAB	POAB content, %			
		20	30	50	70
The temperature of the extruder zones, ±5°C	180, 200, 220				
Storage temperature, ±5°C	220				
Moulding pressure, ±0,1 MPa	3.2	4.8	4.8	8.0	8.0
The mould temperature, °C	30–80				
Soak time under pressure, s	120 ± 20				

Samples were cut from plates to determine the physical and mechanical properties. The sample preparation by injection molding was performed on injection molding machine Kuasy 60/20 under the following conditions: temperature of machine zones ((175, 190, 200, 210) ± 5)°C; injection pressure (90 ± 0.1) MPa; mold temperature 30–80°C; the cooling time of 30–60 s.

For the samples obtained by the two methods, physical-mechanical characteristics were determined. The density ρ was determined in accordance with GOST 15139–69 on the results of measurement and weighing of rectangular cros-section samples. The elasticity modulus E_p, breaking stress σ_p, and the relative elongation δ at tension were found when loading of the second type samples according to GOST 11262–80 (in the form of blades) at a rate of the movable grip movement (50 ± 0.5) mm/min. Breaking bending stress σ_b in accordance with GOST 4648–71, and elasticity modulus E_e in accordance with GOST 9550–81 were determined on the three-point scheme. The distance between the supports of 60 mm, testing loading rate were (2 ± 0.5) mm/min. Shearing stress τ_{str} was found in accordance with GOST 17302–71. Samples were loaded at the punch movement rate 10 mm/min. Sharpy impact strength was determined in accordance with GOST 4647–80.

The resulting test indicators of physical and mechanical properties of materials manufactured by the method of layer-molding are shown in Table 2.

Table 2

Physical and mechanical properties of materials obtained by layer-forming (in brackets the variation coefficient)

Indicator	KAB	POAB content, %			
		20	30	50	70
ρ, g/cm^3	0.92 (1.5)	1.02 (1.7)	1.00 (1.2)	1.15 (1.9)	1.20 (4.1)
σ_p, MPa	18.4 (2.2)	16.6 (4.2)	14.8 (5.9)	12.7 (4.3)	11.2 (6.6)
δ, %	10.9 (36)	5.2 (25)	5.0 (31)	2.4 (16)	1.9 (13.4)
E_p, MPa	903 (5.2)	920 (4.5)	977 (4.6)	1045 (5.2)	1113 (6.1)
σ_b, MPa	34.7 (4.6)	28.3 (7.7)	28.3 (4.6)	23.8 (7.1)	21.6 (7.4)
E_e, MPa	918 (3.7)	850 (15)	948 (6.5)	1071 (9.8)	1069 (6.5)
τ_{str}, MPa	25.9 (4.0)	22.1 (6.9)	18.7 (4.5)	16.2 (8.5)	16.2 (6.4)
a, kJ/m2	10.2* (12)	19.6 (33)	12.9 (30)	7.8 (23)	7.0 (18)

* Samples with the B type notch.

Indicators of tensile and flexural strength for KAB wastes, containing more than 90 wt % of polypropylene, are significantly (by 30–50%) less than for the primary polypropylene [3]. Impact strength is substantially less practically in 3 times. It is obviously, that the lower strength values are associated with the recycling and the presence of other materials' particles, without any relationship between them. The relative change in the mechanical characteristics at POAB waste introduction into KAB content is shown in Fig. 1.

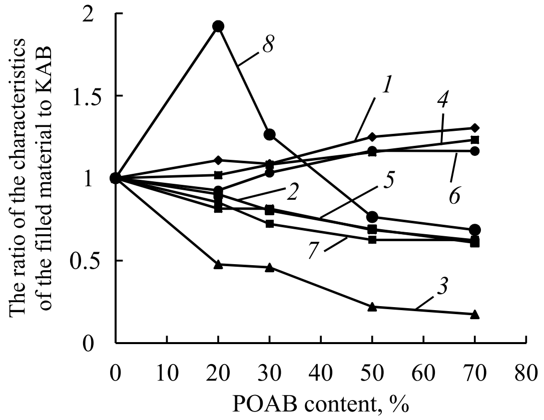

Fig. 1. Relative changes of mechanical characteristics at POAB filling by layer moulding:
1 – ρ; *2* – σ_p; *3* – δ; *4* – E_p; *5* – σ_b; *6* – E_e; *7* – τ_{str}; *8* – *a*

At the POAB waste introduction into KAB content, strength characteristics are reduced. At POAB content of 70 wt % ultimate tensile, bending and shear strengths reduced on average by 40%. The spread of the strength indicators increases with increasing of the POAB content. In general, there is a slight variation of the strength (coefficient of variation is less than 7%).

The elasticity modulus at tension and bending slightly increases with increasing of POAB content. When the POAB content reaches 70 wt %, elasticity moduli increase on average by 20%. The spread of elasticity modulus indicators is also insignificant, the coefficient of variation of not more than 7%. However, the spread is significant for flexural modulus indicators at bending (coefficient of variation of 15 at 20 wt % POAB and 10 at 50 wt % POAB respectively). This is due to the fact that the flexural modulus at bending significantly depends on the filler particle arrangement along cross-sectional height.

When stretched, the samples are destroyed without necking. With POAB content increasing the relative elongation at break reduces. The spread of this indicator is significant (over 30%), indicating the heterogeneous distribution of the filler particles in the sample cross-section. At more than 50 wt % POAB content, the destruction is of the fragile nature (Fig. 2). The destruction of samples containing the POAB, took place on the border of solids (more often ebonite).When bending the destruction occurred in the stretch zone.

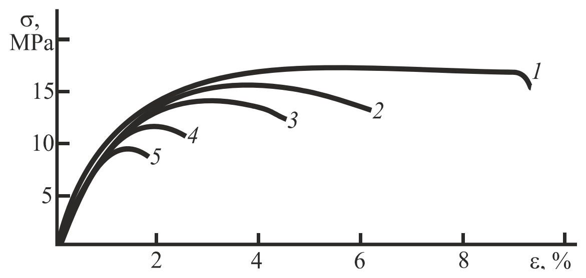

Fig. 2. Diagrams of deformation under tension for materials containing POAB: *1* – 0%; *2* – 20%; *3* – 30%; *4* – 50%; *5* – 70%

Impact strength decreases with increasing POAB content. This indicator has also a significant spread (coefficient of variation in the range 12–30%). The indicators of physical and mechanical properties of materials produced by the method of injection molding are shown in Table 3.

For material obtained by injection molding with the introduction of POAB wastes into KAB content, the strength characteristics reduce. At the POAB content of 20 wt % ultimate stretching and bending strength reduce by 30 and 7% respectively. The spread of the strength indicators increases with increasing of POAB content. In general, the spread of strength indicators does not exceed the accuracy for engineering calculations. The increase in the POAB waste content in KAB when processing by injection molding, as well as in the case of the layer-forming method, reduces the material strength characteristics.

Table 3

Physical and mechanical characteristics of materials obtained by injection moulding (in brackets the coefficient of variation)

Indicator	KAB	POAB content, %			
		5	10	15	20
σ_p, MPa	24.2 (1)	20.3 (3)	18.4 (7)	18.2 (3)	17.1 (9)
δ, %	45.8 (47)	11.8 (30)	8.1 (21)	8.0 (21)	6.5 (13)
E_p, MPa	807 (4)	679 (2)	670 (6)	645 (3)	643 (6)
σ_b, MPa	32.7 (2)	33.4 (1)	31.6 (2)	30.2 (6)	28.7 (8)
E_e, MPa	1136 (2)	1193 (1)	1165 (2)	1117 (7)	1099 (6)
a, kJ/m^2	39.3 (40)	46.7 (31)	38.0 (13)	28.7 (19)	27.3 (23)

Due to the great heterogeneity of POAB waste distribution, indicators of relative elongation at stretching and Sharpy impact strengh have a large spread (19–47%), as being most sensitive to the distribution of filler particles incompatible with the base polymer. It was noticeable that there was accumulation of the filler particles in the central parts of the cross section fracture at tension and bending. By comparing the results of the determination of physical and mechanical characteristics of the material samples with the same POAB content obtained by layer-forming and injection molding (Table 2 and 3, respectively), it was revealed, that the sample properties differ from each other to a very small extent, and the differences can be explained by the particular methods of recycling (injection molding allows to obtain samples with a more homogeneous structure and a more compact macromolecule packaging).

Conclusion. Physical and mechanical properties of materials on the basis of the characteristics of KAB compositions filled by POAB wastes were determined. They remain at a quite acceptable level in comparison with the primary and secondary unfilled polymers [3]. This indicates that such composites can be used for manufacturing of less critical products both by injection moulding and layer-forming methods. Using injection moulding from materials based on KAB and POAB it is possible to obtain samples of a homogeneous structure having higher strength characteristics, however by this method the possibility of filler introducing into the polymeric material is limited to a certain extent. At the same time the undoubted advantage of the layer-forming is that this method makes possible to obtain samples from the compositions with high filler content (POAB content in Composites can reach 70%, while the injection molding samples typically contain less than 20% filler). The obtained results can be used when selecting and calculating products from polymer-containing wastes.

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