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**TECHNOLOGICAL CHARACTERISTICS OF MATERIALS
BASED ON METAL-CONTAINING POLYMERIC WASTES PRODUCED
BY SEAM-FORMING METHOD**

The technological characteristics of materials based on metal-containing polymeric wastes to calculate and optimize the seam-forming process parameters were defined. According to the method of the disk compression between parallel plates, the parameters of the flow law, consistency coefficient, and the exponent were determined. The data on the conditional yield strength, coefficient of friction, diffusivity and shrinkage of compositions based on polymer waste were obtained. The effect of the amount of metal-containing wastes on the technological characteristics of the compositions was determined. The level of viscous properties gives the possibility of processing the compositions by the seam-forming method from metal-containing up to 70% polymer waste. The parameters of the conversion process in the product compositions based on metal-plastic waste by seam-forming method were estimated. Depending on the geometry and mass of the resulting products the parameters that determine the performance of the process and selection of basic technological equipment were calculated.

Key words: metal-containing polymer waste, seam-forming, technological parameters, cycle time, performance.

Introduction. For developed countries, the problem of waste processing resulting from consumption and manufacture of polymer industry products will always be relevant. Its solution allows, firstly, to reduce the volume of dumping of municipal solid waste in landfills, and, secondly, to obtain relatively cheap raw materials for the production of new products.

In Belarus, considerable attention is paid to recycling of polymer waste. So, one of the promising environmental projects in JSC “Beltsvetmet” is the processing of spent automobile storage batteries. At the end of 2009 modern equipment has been put into operation for this purpose. The batteries are cut into constituent fractions not manually but mechanically. The result obtained by cutting produces two waste types [1]:

1) waste generated as a result of storage battery jars cutting (hereinafter SBJ);

2) polymer-containing wastes which are formed by cutting the internal part of storage batteries (hereinafter PWSB).

Currently these wastes are not implemented. So companies have a strong interest in the development of technological methods of their processing into products.

In previous studies [1, 2], considerable attention was paid to the structure and composition of waste, as well as the physical and mechanical characteristics of materials based on them. It has been found that the SBJ composition consists of about eight various materials (polypropylene, ABS-plastic, resin, high density polyethylene, rubber, wood, fiber glass, and polyvinyl-chloride). The weight content of polypropylene in the SBJ wastes is greater than 90%, which means that they can be used as a binder. PWSB wastes also contain

approximately eight different materials (cross-linked high pressure polyethylene, ebonite, polyvinyl chloride, ABS plastic, lead, fiber glass, rubber), but unlike SBJ wastes mass content of their infusible components is about 90%. This indicates that they may be used only as filler. Besides, PWSB wastes are metal-containing, since their composition is about 1% lead.

As a result of investigation of physical-mechanical properties of materials based on the above mentioned waste, it was ascertained [2] that their strength properties are preserved at a quite acceptable level in comparison with the primary and secondary unfilled polymers. That is, such materials can be used for the manufacture of products the characteristics of which do not meet the highest standards.

The principal possibility and economic feasibility of processing compositions based on SBJ and PWSB wastes (with a mass content up to 70%) by the methods of plastic forming or pressing a pre-plasticized preform have been also presented in this study [2]. However, for the calculation and optimization of the parameters of the plastic forming process, which determine its performance, we need data concerning the technical characteristics of the compositions, which are currently lacking.

The objective of this work is to define technical characteristics of materials based on metal-containing SBJ and PWSB wastes required to optimize parameters of the technological plastic forming process.

Main part. The process of manufacturing products by plastic forming comprises the following steps (Fig. 1): preparing and combining the components in a measuring device, plastication

of the composition in a screw extruder, dose accumulation and preform forming in the accumulating mechanism, moving the preform into a mold; preform deforming in a hydraulic press (products shaping); cooling in a mold and ejection of the product.

To ensure the competitiveness of products, cycle time, labor and energy intensity of its production should be minimized. This condition implies the need for a high efficiency of the product molding process.

Efficiency of the plastic forming process is determined by two main factors: composition plasticizing capacity and duration of the products cooling in the mold.

Preform flow time t_f having an initial thickness h_0 to a final thickness h is determined according to the formula [3]:

$$t_f = 2,5nB^{-s} (h^{-2,5s} - h_0^{-2,5s}), \quad (1)$$

where $B = \frac{F}{2\pi f \mu R_{rr}^3} \sqrt{\frac{(1-f^2)^n}{3^{n-2} \cdot h^3}}$; μ – consistency factor; n – composition flow index at a molding temperature; $s = 1/n$; f – friction coefficient; F – pressing force; R_{rr} – reduced radius.

Duration of the flat product cooling t_{cool} is calculated by the following formula:

$$t_{cool} = \frac{h^2}{\pi^2 a} \ln \left[\frac{4 T_f - T_1}{\pi T_f - T_2} \right], \quad (2)$$

where a – thermal diffusivity of the composition in direction perpendicular to the product plane; T_1 and T_2 – initial and final temperature of the material; T_f – mold temperature.

The cycle time is calculated by adding the duration of forming by formula (1) and the duration of cooling by formula (2) and multiplying by a k_{ts}

coefficient, taking into account the time required for auxiliary operations:

$$t_c = k_c (t_f + t_{cool}). \quad (3)$$

The force required to deform the preform into a disk with the radius R_{rr} and thickness h can be approximated by the final (quasi-equilibrium) state based on the composition model as a plastic body with a yield pressure according to the Tresk-Sen-Venan criterion and friction on the surface [3]:

$$F = 2k_F \tau_0 A \cdot \left[1 + \frac{f}{3} \cdot \frac{R_{rr}}{h} \right], \quad (4)$$

where k_F – safety force factor, taking into account the heterogeneity of the material and possible deviations of forming conditions from the nominal; τ_0 – composition yield pressure; A – plan product area.

The plates with dimensions $250 \times 250 \times (5-10)$ mm were produced from SBJ wastes with the PWSB mass content 20, 30, 50 and 70% to determine the processing characteristics in formulas (1)–(3) using the plastic forming method and the operating conditions described in [2].

Parameters of the melt flow power law (consistency factor μ and index of power n) were evaluated by the method of disk compression between the plane-parallel plates [4]. Temperature dependence parameters of the consistency coefficient were calculated in the Arrhenius law form by the values of the consistency factor in the temperature range studied:

$$\mu = \mu_0 \exp \left(\frac{E_a}{RT} \right), \quad (5)$$

where μ_0 – material viscosity constant; E_a – activation energy; R – absolute gas constant; T – thermodynamic temperature.

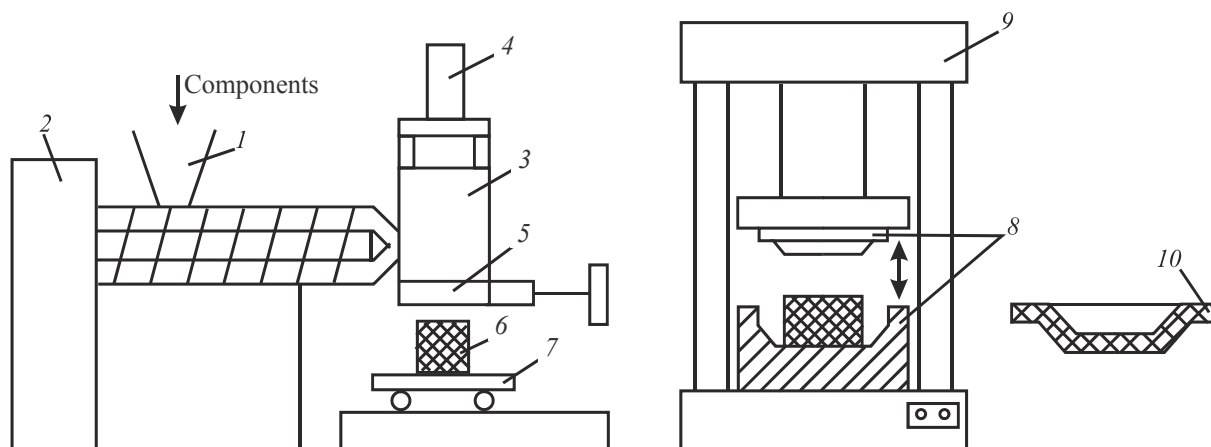


Fig. 1. Plastic forming process diagram:

1 – measuring device; 2 – extruder; 3 – accumulating mechanism; 4 – hydraulic cylinder; 5 – choker bar; 6 – preform; 7 – haul off; 8 – mold; 9 – hydraulic press; 10 – product

Friction coefficient of the composition on the forming plates surface was determined by the method described in the article [5]. The steel band was stretched between two samples, fixing the frictional force. Test temperature was varied from 20 to 140°C. The sliding speed was varied from 5 to 20 mm/c. The pressure was varied from 210 to 350 kPa.

Thermal diffusivity was determined by the length of time needed to reach the temperature equal to half of the plate temperature at the center of a rectangular cross section sample with dimensions 50×50×(14.0 ± 0.2) mm. The sample was heated between plane-parallel plates (plate temperature (100 ± 1)°C).

The coefficient of thermal diffusivity a was calculated by a formula:

$$a = \frac{h_0^2}{\pi^2 \cdot t} \cdot \ln \left(\frac{4 \cdot (T_1 - T_0)}{\pi \cdot (T_1 - T(t))} \right), \quad (6)$$

where h_0 – sample thickness; T_1 – plates temperature; T_0 – initial sample temperature; $T(t)$ – temperature at the center; t – time needed to achieve the predetermined temperature at the center.

The linear shrinkage of the material was determined as the relative difference in the size of the mold and molded therein samples, and it was expressed as a percentage of the mold dimensions (GOST 18616-69).

Parameter values of the melt flow power law of the test compositions are given in Table 1. The table shows that the consistency factor increases with the increase of the PWSB content. If PWSB content is 70 wt %, the consistency coefficient increases almost threefold.

Table 1

Flow power law and Arrhenius law parameters

Parameter	SBJ	PWSB content, wt %				
		20	30	50	70	
μ , Pa · s ⁿ	200°C	2,630	4,311	4,423	6,646	10,390
	230°C	807	1,631	2,416	3,109	7,831
n	200°C	0.93	0.86	0.80	0.61	0.30
	230°C	0.92	0.86	0.79	0.56	0.30
τ_0 , Pa	200°C	967	1,338	1,350	2,368	4,368
	230°C	577	941	1,214	1,683	3,631
E_a , kJ/mole		77.9	64.1	39.8	50.1	18.6
μ_0 , Pa · s ⁿ		6.6 · 10 ⁻⁶	3.6 · 10 ⁻⁴	0.175	0.02	90.7

With the increase of temperature, the consistency coefficient decreases, as is typical of filled thermoplastics. Fig. 2 shows the consistency coefficient dependence on the PWSB mass content.

Flow law power index in the studied temperature range is practically independent of temperature, but essentially depends on the PWSB weight content. The higher the PWSB content, the lower is the power index. Offset yield strength increases

with the PWSB content increase and decreases with the temperature increase.

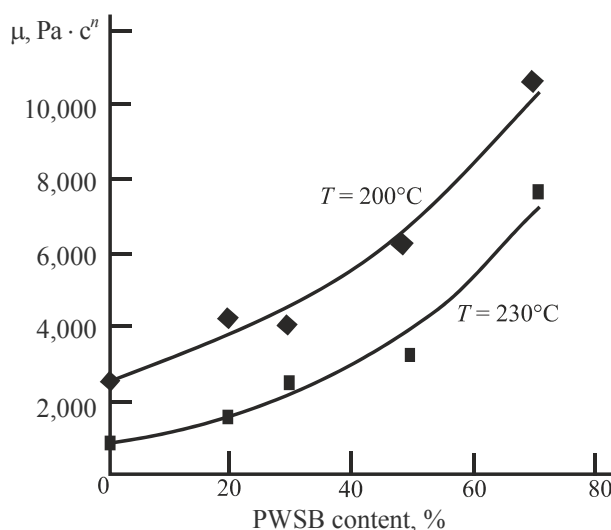


Fig. 2. Consistency coefficient dependence on the PWSB mass content

In evaluating the yield stress it is assumed that the stickage is ideal at the interface of melt with the forming surface. This assumption is justified if the molding surface temperature equals the temperature of the melt. In the process of plastic forming the mold temperature is usually less than the melt temperature. Therefore, when the preform spreads over the contact surface, sliding occurs. In this case friction coefficient significantly depends on the PWSB content and surface temperature.

SBJ friction coefficient ($f = 0.32$), obtained in the experiment at room temperature is in the range typical for thermoplastic polymer materials. With the increase of the PWSB content, friction coefficient increases either up to $f = 0.5$, the PWSB content being 70 wt %. This suggests that in forming articles from the compositions with a high PWSB content, large pressing force is required due to the increased consistency coefficient on the one hand, and friction coefficient on the other.

When temperature increases, the friction coefficient decreases (Table 2), which is not typical for unfilled thermoplastic polymers (in the range up to the softening temperature it increases due to the increase of the actual contact area). Reducing the friction coefficient is probably due to the presence of filler particles on the friction surfaces. This prevents deformation of the contact surfaces roughness.

The values of thermal diffusivity and linear shrinkage of the materials tested are given in Table 3. When the PWSB content increases, thermal diffusivity increases slightly, but shrinkage decreases.

Table 2
Friction coefficient in dependence to temperature
for the SBJ + 50% PWSB material

Temperature, °C	20	50	80	110	140
f	0.50	0.43	0.37	0.33	0.28

Table 3
Thermal diffusivity coefficient and linear shrinkage

Parameter	SBJ	PWSB content, wt %			
		20	30	50	70
a , mm ² /s	0.093	0.099	0.099	0.100	0.120
Shrinkage, %	2.5	2.5	2.7	2.1	1.9

Using indicators of technological properties of materials based on metal-containing polymer wastes obtained in the result of experiments, plastic forming parameters determining, primarily, the performance process were evaluated by formulas (1)–(3).

Fig. 3 shows time dependence of the products forming cycle (using the plastic forming method) on the product wall thickness and temperature to which cooling occurs. The calculations were performed for a range of thicknesses from 4 to 10 mm at $T_1 = 220^\circ\text{C}$, $T_f = 50^\circ\text{C}$ and thermal diffusivity values from Table 3.

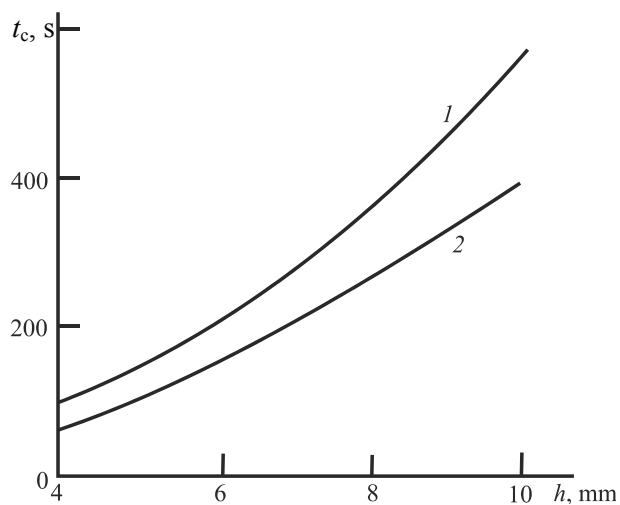


Fig. 3. The cycle time of forming products:
1 – $T_2 = 55^\circ\text{C}$; 2 – $T_2 = 65^\circ\text{C}$

Calculations showed that the preform spreading time t_f can be neglected since it is small compared with the time of cooling. Thus, the products

pressing cycle time from plasticized preforms is approximately $1.5t_{\text{cool}}$.

To ensure the continuity of the process of obtaining products it is necessary for the plasticator (screw extruder) to provide (for some time t_c) the manufacture of a new preform in an accumulating mechanism. The necessary capacity of the extruder depends on the mass and maximum wall thickness of the resulting product (Fig. 4).

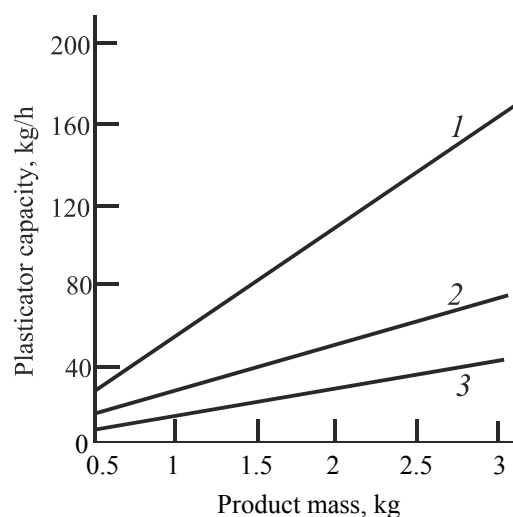


Fig. 4. Required plasticator capacity
if product thickness is:
1 – 4 mm; 2 – 6 mm; 3 – 8 mm

The data in Fig. 4 can be used for the selection of the extruder while preparing specific products by plastic forming method.

Conclusion. The technological characteristics of materials based on metal-containing polymeric wastes were defined. PWSB waste content has a significant effect on the viscous properties of the compositions. If PWSB content is 70 wt %, the consistency coefficient increases almost threefold. This greatly limits the choice of the method of such waste processing. These characteristics have allowed to estimate the technological parameters of the products forming process by the method of plastic forming. Using plastic forming method, it is possible to process materials with PWSB mass content up to 70%.

The data obtained can be used for the technological processes design of production of competitive products from metal-containing polymer wastes.

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