Pressure and temperature influence on the friction coefficient of granular polymeric materials on the metal surfaces

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Abstract

Introduction. The research is carried out to determine the friction coefficients (FR) of granulated polymeric material on a metal surface, in particular, to describe the principles of their movement in the feeding zone of a screw extruder.

Materials and methods. To study the movement of polymer granules in the channel of an extruder the four types of granules are used: high density polyethylene (PE), ethylene-vinyl acetate copolymer (EVA), polystyrene (PS) and polyvinylchloride (PVC). The FR are defined using a plane-parallel model of the extrusion process.

Results and discussion. Analysis of the results showed a general decrease of FR with the increasing pressure, but upon the reaching the maximum values at almost all curves is a transition through a minimum, after which values of FR begin to rise.

For the PE the FR decreases from 0.35 to 0.26 in a load 200 Pa and from 0.23 to 0.17 in 2000–2200 Pa, with the increasing of a channel depth from 7 to 23 mm. For the EVA the FR increases from 0.15 to 0.44 in 200 PA and from 0.15 to 0.17 in 1900–2100 Pa. For the PS the FR changes from 0.6 in 200 Pa to 0.3 in 2100 Pa and doesn't depend on the changes a channel depth. For the PVC the FR increases from 0.3 to 0.7 in 200 Pa and from 0.22 to 0.43 in 1900–2100 Pa.

With the increasing of a temperature of a working surface to 90 °C the FR of the PE becomes independent on the changes a channel depth and acquires medium values to 0.3 in 200 Pa and to 0.2 in 2100 Pa. For the EVA in 80 °C the FR for each depth increases and reaches values from 0.25 to 0.4 in 200 Pa and from 0.19 to 0.23 in 1600–1700 Pa. For the PS in 100 °C the FR decreases to 0.5 in 200 Pa and to 0.2 in 2100 Pa. For the PVC the FR doesn't depend on the heating of the working surface.

The difference between the described dependencies for four researched types of polymer is explained by the different mechanical properties of investigated polymers, including the values of strength, FR and deformation at different temperatures.

Conclusions. The obtained results allow to improve the process of extrusion, increase its productivity and reduce its energy consumption by increasing the accuracy of calculations.

Introduction

Analysis of scientific papers

In most of the existing research papers, polymer materials are performed using the continuous samples, ignoring the interaction between the individual particles. This is especially true for studies of the friction coefficients (FR) of polymeric materials on the metal surface, for example on the working bodies of the extruder.

For example, the authors of [1] suggests a general nature depending on the FR on the normal load and the temperature for the most known polymeric materials. They write that during the friction of polymers, the contact is partially elastic and partially plastic with the predominance of an elastic component at low loads and the predominance of the plastic component when increasing loads, and the dependence of the FR on the temperature varies depending on the change in the hardness, the viscosity and the other physical and mechanical properties of the polymers.

The paper [2] also shows the study of the dynamic FR for some polyethylene resins and shows its dependence on the surface temperature, the pressure and the velocity.

The authors [3] carried out the investigations to determine the static and dynamic coefficients friction of the polyethylene of low pressure for different temperatures. The conducted research shows that the static FR reaches the values are similar to the values of the dynamic FR.

The paper [4] describes the relationship between the temperature, the load and the velocity dependence on the FR for various types of polymer materials and noted that the FR of all polymers are very sensitive to the state of the metal surface that is in contact with the polymers during experiments.

And although the works for granular polymers exist, for example, the authors [5] found the effect of the pressure, the temperature and the velocity of polypropylene pellets on the FR between them and the metal surface and the impact on friction the form of granules, but the uniform regularities for the different types of granules are not revealed and in each case it is necessary to conduct the separate researches.

Also, the studies using the granular polymer were carried out by authors [6], showed the effect of the selected granulometric properties on the main parameters of extrusion and found that the process is the most effective when using the granules which length is close to the diameter of the granule, but the study was conducted only for the plasticized polyvinylchloride.

Practical tasks

The production field of plastic products is one of the most important fields of the industry. Polymer materials are widely used for the manufacture of such products as the polymeric films of various designation, the bags for packaging and the other products, constantly increases demand for finished products of polymeric materials from construction, transport, agriculture, medicine and other branches of the economy.

The significant increasing of polymeric materials manufacturing, the range of which is being constantly expanded, requires the creation of highly resource- and energy-efficient equipment for their processing. The most efficient equipment for processing of polymeric raw materials is the extrusion unit, among which the most commonly used is the screw extruders [7–9]. The productivity of the extrusion process is primarily determined by the productivity of the feeding zone of the screw extruder, where the polymeric materials often come in the form of bulk granular materials and enter through a hopper 1 (Figure 1) in the extruder channel, where they are in the solid form and transported by a helical surface of a screw 2 along the surface of the cylinder by the friction forces.

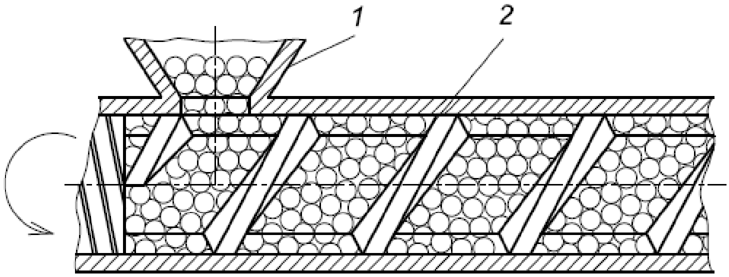

Figure 1. The movement of the material in the channel of a screw:
1 – hopper; 2 – helical surface of a screw

The friction between the recycled material, the cylinder and the screw plays a basic role as a means for moving and heating of the material. The friction also considerably influences the wear intensity of the working bodies, because material way and movement speed depends on it [10–11].

The successful design and calculations of the new equipment is largely depends on the accuracy of values and the correlation of friction forces that act on the contact borders of the material with a cylinder and a screw, which in combination with other parameters define the design of the screw, the pressure and the temperature mode of processing. The most important parameters of the operational modes of friction include the impact of the load and the temperature.

In the area of material feeding in the screw extruder the polymer is often in the form of solid granules, which can slide, roll one by one and be deformed and so on, which affects the movement of the material relatively to the working bodies of an extruder. Thus, the study of the movement of the exactly granulated polymeric materials in the area of material feeding of the screw extruder is the actual task.

The purposes of the research are the experimental determination of the FR of granulated polymeric material on a metal surface, the definition of dependency of FR on the load and the temperature, and the changes of the defined dependencies on the changes of geometrical dimensions of the working bodies of the extruder and the analysis of polymer granules movement in a feeding zone of the screw extruder.

Materials and methods

Materials

Figure 2 shows the photos of the using granules of polymers as follows:
a – high density polyethylene (PE) Marlex HHM 5502BN [12];
b – ethylene-vinyl acetate copolymer (EVA) 11104-030 [13];
c – polystyrene (PS) Denka Styrol MW-1-301 [14];
d – polyvinylchloride (PVC) SorVyl G 2171/9005 11/01 [15].

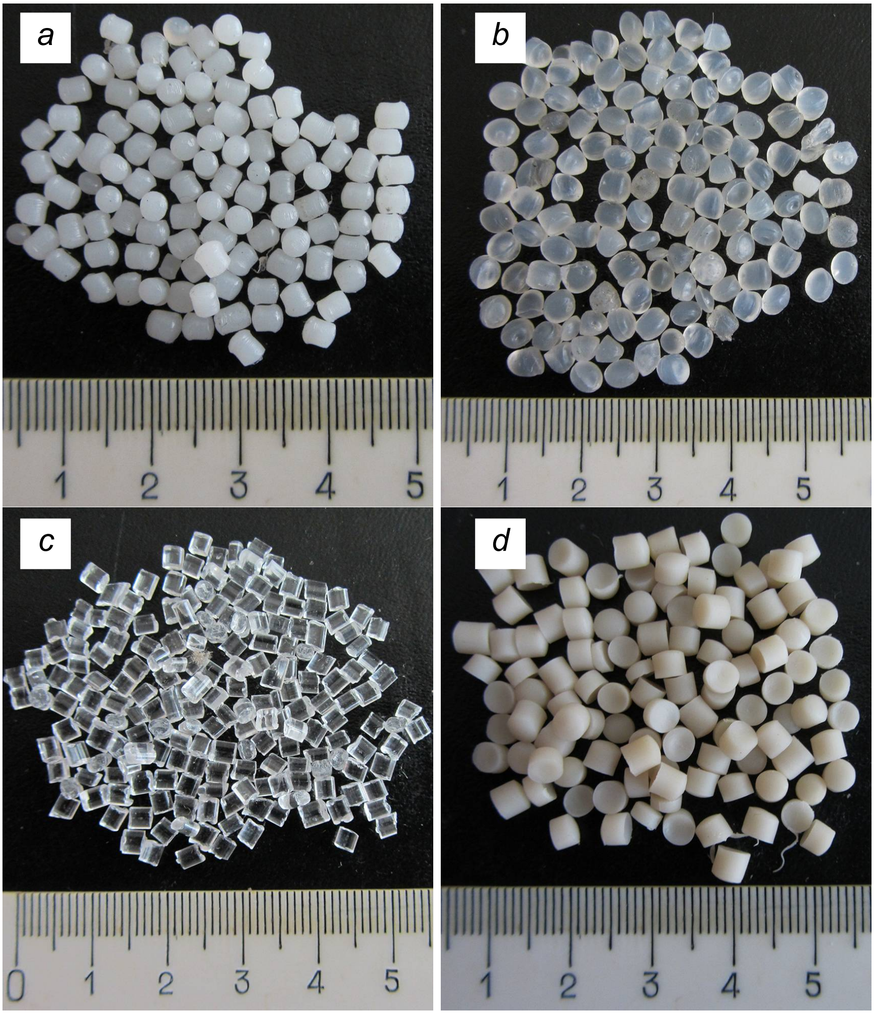

Figure 2. The photographs polymeric granules that were used during the experiments (explanation in the text)

Methods

The article presents the experimental dependences obtained from the research of polymeric granules in the extruder channel using a plane-parallel model of the extrusion process. Thus helical channel of the extruder, which is formed by the screw threading and cylinder, conditionally deployed in the plane (Figure 3) and we assume the following: the channel curvature is ignored, the screw surface is considered to be immobile and the deployed surface of the cylinder is deemed to be moving at a speed that is equal to the circular speed of the screw [16–17].

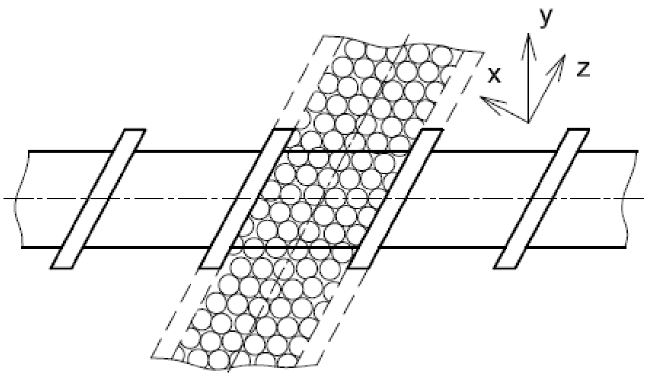

Figure 3. The scheme of the plane-parallel sweep of helical channel of the extruder

Experiment

The process is described in the Cartesian coordinate system where the *x*-axis is directed perpendicular to the spiral ridge, the *y*-axis directed by height of the channel and the *z*-axis directed along the deployed channel (Figure 3). The scheme of the experiment is shown in Figure 4.

In the steel box 1 that simulates a sweep of the screw surface are poured the polymeric granules until the box is completely filled. Further the filled box 1 flips in a way that granules found on the flat metal surface 2, which simulates the internal surface of the cylinder case. Number of granules in the box was sufficient that between her and immobile surface the certain gap in the form of the granules layer has remained.

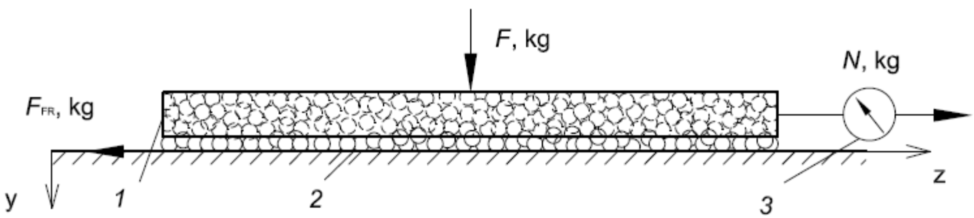

Figure 4. The scheme of the experiment: box (1); immobile metallic surface (2); dynamometer (3)

After that, the box 1 loaded the force *F*. Next given the movement to the box 1 to surface 2 into the z-axis direction, while the dynamometer 3 fixed the value of the applied force *N*. Dynamometer is connected with box using a flexible rope. The research was carried out using three boxes of height H = 7, 15 and 23 mm, which correspond to the screw extruder channel depth. Ratio of the box length to the width is no less than five to reduce the impact on friction for the end surfaces.

The coefficient of the polymeric granules friction on the metal surface K_{FR} calculated by the formula (1) for the different load values F. To display the dependencies between the load and FR, the pressure P (Pa) is additionally calculated by the formula (2).

$$K_{FR} = \frac{N}{F}; \qquad (1)$$

$$P = \frac{F}{S}, \qquad (2)$$

where S is the area on where the force F acts, that the area of the box bottom, m^2.

Results and discussions

General analysis

In Figure 5–8 shows the approximating curves which show the relationship between the calculated FR of polymer material on a metal surface K_{FR} and pressure P, by heating working surface to the temperature t. Heating temperature of the working surface is determined experimentally and for the every polymer separately as the maximum possible value for the feeding zone.

The curves built by using the linear or polynomial approximation while the average value of the approximation reliability is not lower than 0.9 for the all curves.

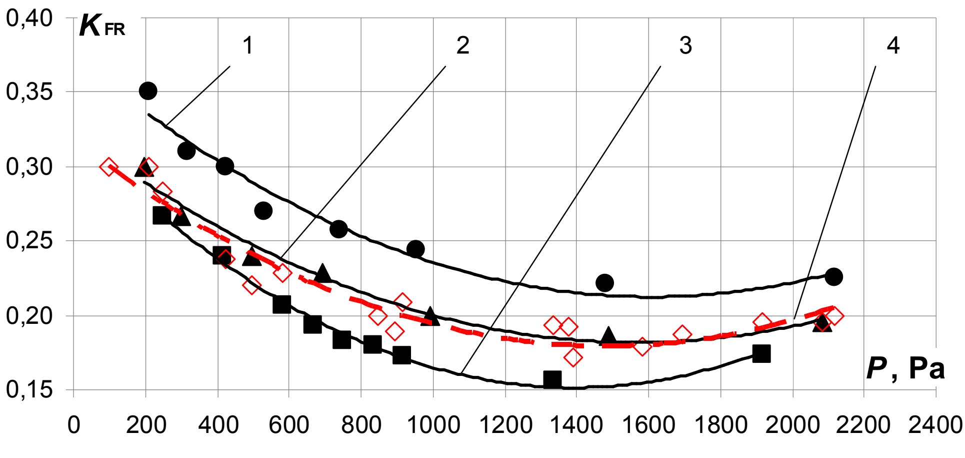

Figure 5. The dependence of the FR of PE on load at different values of channel depths *H* by heating the work surface:
1 – H = 7 mm, t = 20 °C;
2 – H = 15 mm, t = 20 °C;
3 – H = 23 mm, t = 20 °C;
4 – H = 7, 15, 23 mm, t = 90 °C

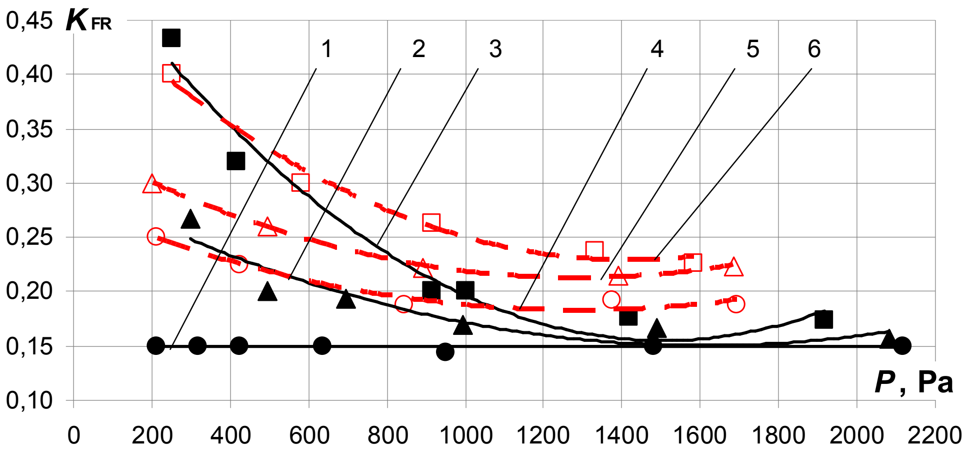

Figure 6. The dependence of the FR of EVA on load at different values of channel depths *H* by heating the work surface:
1 – H = 7 mm, t = 20 °C;
2 – H = 15 mm, t = 20 °C;
3 – H = 23 mm, t = 20 °C;
4 – H = 7 mm, t = 80 °C;
5 – H = 15 mm, t = 80 °C;
6 – H = 23 mm, t = 80 °C

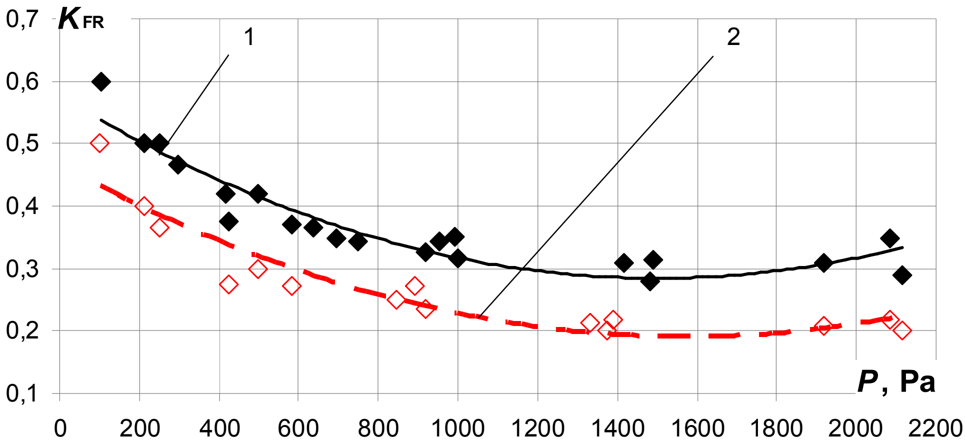

Figure 7. The dependence of the FR of PS on load at different values of channel depths *H* by heating the work surface:
1 – H = 7, 15, 23 mm, t = 20 °C;
2 – H = 7, 15, 23 mm, t = 100 °C

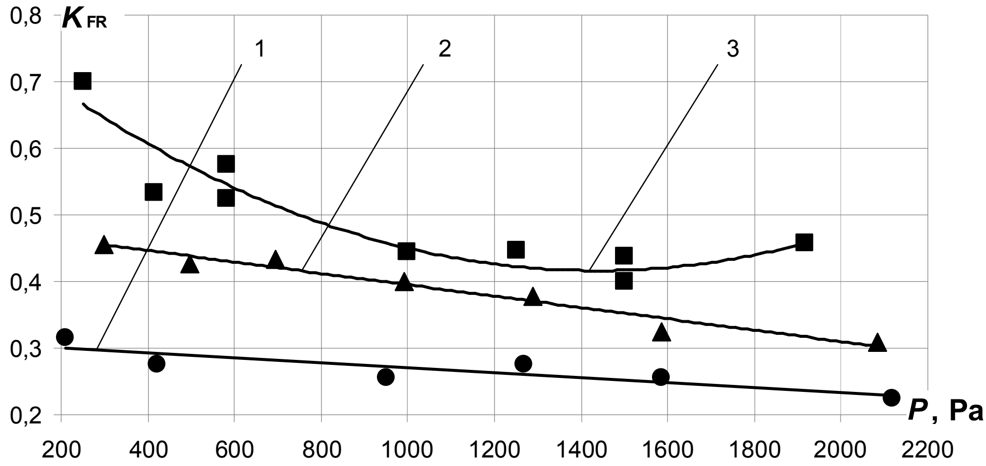

Figure 8. The dependence of the FR of PVC on load at different values of channel depths *H* by heating the work surface:
1 – H = 7 mm, t = 20, 90 °C;
2 – H = 15 mm, t = 20, 90 °C;
3 – H = 23 mm, t = 20, 90 °C

The listed graphs showed a general decrease of FR dependence on the pressure with the reducing of the channel depth. In the case of approaching the researched loads to the maximum values at almost all curves is a transition through a minimum, that is, the FR begin to rise with the increasing of the load after the certain pressure values. Obviously, this is due to the fact that the granules layer behaves like a solid body after the certain pressure values, for which the dependence of FR on the load generally has the form of the curve with a minimum [1].

High density polyethylene (PE)

The PE granules (Figure 2, *a*) have a rounded shape and is the little-deformed therefore during the movement they can slide with the rotation relative to each other. Thus, in the case of increasing the granules layer thickness *H* the sliding friction is partly changed to the rolling friction and the FR decreases from 0.35 to 0.26 in a load 200 Pa and from 0.23 to 0.17 in 2000–2200 Pa, with the increasing of a channel depth from 7 to 23 mm (Figure 5).

With the increasing of a temperature of a working surface to 90 °C the value of FR for PE becomes independent on the changes a channel depth and acquires medium values to 0.3 in 200 Pa and to 0.2 in 2100 Pa with saving the character of dependence.

Ethylene-vinyl acetate copolymer (EVA)

For the EVA, the FR increases from 0.15 to 0.44 in 200 PA and from 0.15 to 0.17 in 1900–2100 Pa with the increasing of a channel depth (Figure 6), because though its granules have a rounded form (Figure 2, *b*), like as the PE granules, and have the ability to slide with the rotation relative to each other, but there are deformed and as a result have the interaction with each other, so when the granule layer thickness *H* is small they are partially rotated and while increasing the granule layer thickness they are compressed and move as one.

When heating surface of a working surface to 80 °C the value of FR for EVA increases for each depth increases and reaches values from 0.25 to 0.4 in 200 Pa and from 0.19 to 0.23 in 1600–1700 Pa, at the same time when reaching of maximum load values the minimum of the curves for the 80 °C is less expressed than for the 20 °C.

Polystyrene (PS)

The FR of PS (Figure 7) changes from 0.6 in 200 Pa to 0.3 in 2100 Pa and doesn't depend on the changes a channel depth, the graph shows the one approximating curve from measurements for three depth values *H*. This can be explained by the fact that its granules are not spherical form, but flattened cylinders form with sharp edges (Figure 2, *c*), and they hardly deformed, therefore the rotation and compression almost doesn't happen and the granules layer behaves like a solid (as a single unit) during the movement even for the small loads.

When the PS granules are being moved on the surface heated to a temperature of 100 °C, the values of FR is decreases to 0.5 in 200 Pa and to 0.2 in 2100 Pa and the character of dependence is the similar to the non-heated surface.

Polyvinylchloride (PVC)

The dependence of the FR of PVC granules (Figure 8) is similar to the graph for the EVA, increases from 0.3 to 0.7 in 200 Pa and from 0.22 to 0.43 in 1900–2100 Pa, however, thanks to another form of granules, the flattened cylinders form (Figure 2, *d*), and less deformity PVC granules are rotated at a larger the granule layer thickness *H* and even at the maximum (of the investigated) granule layer thickness are compressed and move as one.

The FR for PVC doesn't depend on the heating of the working surface, on the Figure 8 shows the common points for the temperatures t = 20 and 90 °C.

Explanation

The difference between the described dependencies is explained by the different mechanical properties, including the values of strength, FR and deformation at different temperatures, which confirmed by many existing research.

Conclusions

As a result of the research, the FR of granulated polymeric material on the metal surface for the four types of polymer: high density polyethylene, ethylene-vinyl acetate copolymer, polystyrene and polyvinylchloride were determined. Dependences of FR on the load and the temperature and the changes of the defined dependencies on the changes of geometrical dimensions of the working bodies of the extruder are obtained. The values obtained using a scheme of the plane-parallel sweep of helical channel of the extruder.

The obtained results allow to improve the process of extrusion, increase its productivity and reduce its energy consumption by increasing the accuracy of calculations.

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