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Estimation of adhesive friction of the molten polymer by flow through a capillary rheometer

RAPID COMMUNICATION

Summary — The possibilities to estimate adhesive friction (T_a), which is a constituent of friction force, during polymer flow by the use of capillary piston rheometer were analyzed. The linear dependence between T_a constituent and the height of polymer material column in capillary rheometer (h) was applied to determine the coefficient of adhesive friction (ξ). It was found that ξ value, first of all, depends on the load imposed (P), whereas temperature within the range studied had no effect on its value.
Key words: adhesive friction, capillary piston rheometer, coefficient of adhesive friction.

OCENA TARCIA ADHEZYJNEGO PODCZAS PRZEPŁYWU TWORZYWA PRZY WYKORZYSTANIU KAPILARNEGO REOMETRU TŁOKOWEGO
Streszczenie — Omówiono próbę oceny tarcia adhezyjnego (T_a), która jest składową siły tarcia w czasie przepływu tworzywa przez kapilarę reometru tłokowego (rys. 1 i 2). Liniowa zależność pomiędzy składową T_a, a zmianą wysokości słupa tworzywa w reometrze kapilarnym (h) (rys. 4 i 5) posłużyła do wyznaczenia współczynnika tarcia adhezyjnego (ξ). Stwierdzono, że jego wartość zależy w głównej mierze od przyłożonego obciążenia (P), a temperatura prowadzenia pomiaru nie wpływa na wartość współczynnika w badanym zakresie (130—140 °C).
Słowa kluczowe: tarcie adhezyjne, kapilarny reometr tłokowy, współczynnik tarcia adhezyjnego.

Friction is a physical effect existing by the relative movement of two substances. Prior to setting any substance in motion, an oppositely directed friction force must be overcome. A friction force is characterized by two constituents depending on the load and the adhesion of two friction surfaces.

$$T = c_1 A + c_2 N \quad (1)$$

where: c_1, c_2 — *constants*, A — *contact surface*, N — *load*.

When an adhesion is significantly low, the value of T, according to Amontons' law is directly proportional to N [1, 2]:

$$T = \mu N \quad (2)$$

where: μ — *stands for dimensionless friction coefficient*.

For viscoelastic materials, the phenomenon of friction depends mainly on an adhesion value. The theory of an adhesive friction is based on a cyclic formation and destruction of a friction contact between sliding surfaces [2]. Therefore, the resistance of molten polymer flow in the cylinder of capillary rheometer, due to adhesion forces, can be defined as an adhesive friction in processing by injection molding [3] and extrusion [4, 5, 6] resulting in a flow disturbance in the near wall layer of displacing polymer [7, 8]. This phenomenon is commonly observed by the determination of flow rate values.

The determination of the mass flow rate (*MFR*) and the volume flow rate (*VFR*) is an important method of evaluation of major properties of thermoplastic material by processing. It was observed that the size of the segments of a successively cut-off bar flowing out from the rheometer die is changing within the period of measurement. Therefore, according to the standard (PN-EN ISO 1133), in order to determine the real *MFR* value, the extruded polymer bar should be cut when the piston shifts along the route marked by two orifices. Additionally, the construction of rheometer should exclude the formation of polymer layers between the cylinder wall and the piston. The observed increase in mass of the successive segments of bar at a constant piston load and a constant cutting time, depends on the height of polymeric material in the cylinder, and on the decreasing resistance related to the adhesion between the molten polymer and the cylinder wall. This adhesive interaction decreases, as the height of the polymer column in the reomether is decreasing, what consequently causes a progressive increase in mass of the successive segments of the extruded material. It can be assumed that the analysis of this phenomenon may be applied to determine the scope

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of adhesive interactions between the molten polymer and the cylinder wall.

The aim of our studies was to analyse the possibility to determine the adhesive friction between polymer and cylinder wall by the use of a capillary rheometer.

EXPERIMENTAL

Materials

Plasticized polyvinyl chloride (P-PVC GFM/4K-40--TR, produced by Alfa PVC) and low-density polyethylene (PE-LD Lupolen 3020D, Basell Orlen) were applied in our investigations.

Processing

The capillary piston rheometer, of the own design (Department of Polymer Technology, University of Technology and Life Sciences Bydgoszcz, Poland), presented in Figure 1 was used in our studies. The modified construction of the rheometer enables a simultaneous and continuous measurement of the force charged by polymer on the die, and the displacement of the piston [9].

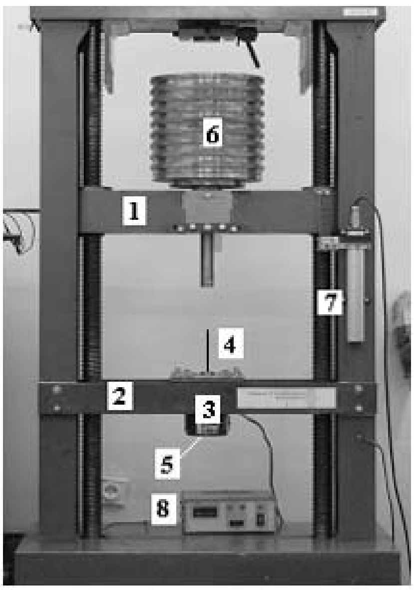

Fig. 1. Capillary piston rheometer: 1 — moving toolbar, 2 — stationary toolbar, 3 — cylinder with heating system, 4 — piston, 5 — force sensor, 6 — piston load, 7 — linear displacement transducer, 8 — temperature control system

The measurement data are recorded and processed using a computer program Chem41U [10]. A preliminary model of loads in the rheometer is presented in Figure 2. This model allows to determine the adhesive friction coefficient (ξ).

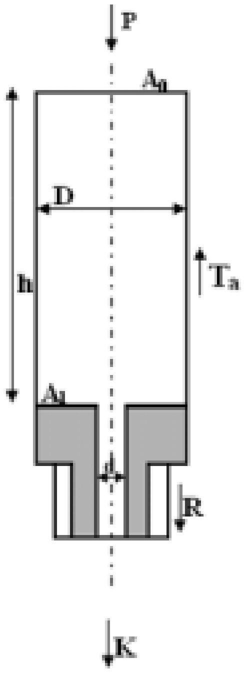

Fig. 2. Loading system in the rheometer during material flow: P — set load, A_0 — cross-section area of cylinder, A_1 — upper plane of the die, R — value measured by the force sensor, T_a — adhesive friction, K — flow resistance in capillary tube, D — diameter of cylinder, d — capillary tube diameter, h — height of polymer column level in the cylinder

According to Fig. 2 the load charge P of the piston is divided into two force components, *i.e.* the force K giving a flow of the molten polymer through the die, and the force R charging the extrusion die. The force T_a is a consequence of the adhesive friction of the molten polymer in the cylinder die. Therefore, the recorded load of the polymeric material in the die is following:

$$R = P - T_a - K \tag{3}$$

where: R — *value of load measured by the force sensor,* T_a — *force of the adhesive friction,* P — *load imposed on the piston,* K — *force leading the flow of the molten polymer in the capillary tube.*

T_a value is a function of height of the polymeric material level in the cylinder of reometer, what may be expressed as:

$$T_a = \xi \pi D h \tag{4}$$

where: ξ — *coefficient of an adhesive friction,* D — *diameter of the cylinder,* h — *height of polymer column level in the cylinder of rheometer.*

The pressure in the cylinder produced by initial load of piston is given by an equation:

$$p = P/A_0 \tag{5}$$

Assuming a constant pressure p in the entire volume, the flow resistance in capillary tube may be expressed by dependence:

$$K = p\frac{\pi}{4}d^2 \tag{6}$$

where: d — *diameter of capillary in the die.*

After substitution of equations (4) and (6) to (3) one and after transformations the expression allowing calculation of ξ is obtained:

$$\xi = \frac{4(P-R) - p\pi d^2}{4\pi D h} \tag{7}$$

RESULTS AND DISCUSSION

A characteristic run of the force R measured by a force sensor, recorded during extrusion of P-PVC at temp. 130 °C, is presented in Figure 3.

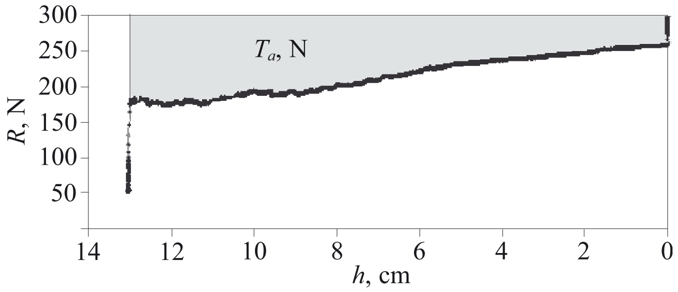

Fig. 3. Dependence of load R as a function of height of polymer column level in cylinder of the rheometer (h) recorded at temp. 130 °C

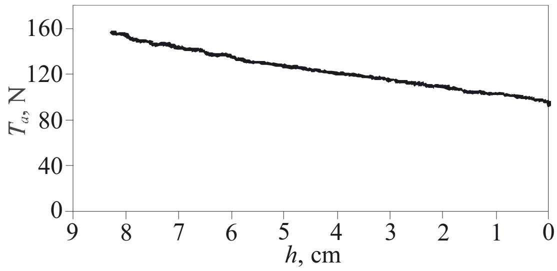

Fig. 4. Dependence of adhesive friction (T_a) as a function of height of polymer column level in cylinder of the rheometer (h)

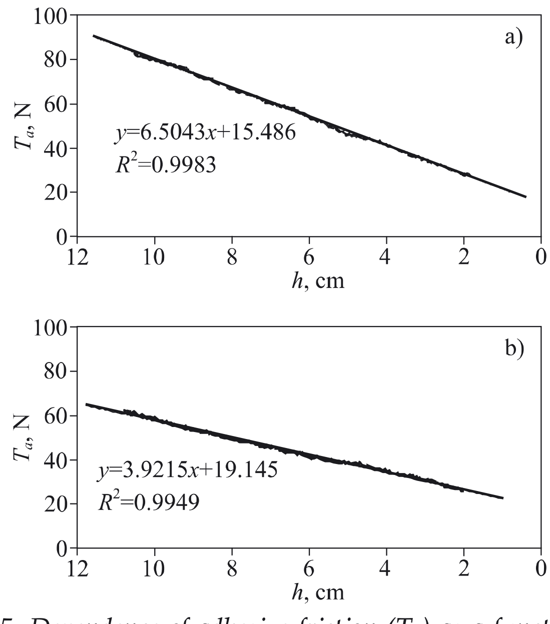

Fig. 5. Dependence of adhesive friction (T_a) as a function of height of P-PVC level in cylinder of the rheometer (h) at temp. 140 °C for different imposed load P: a) 400 N, b) 300 N

At the beginning of the curve slight oscillations of the measured force R occur, probably due to the stick-slip effect, related to a large contact surface between the polymeric material and the rheomether wall [11, 12]. The rectilinear segment of the curve of force R, versus h was converted according to eq. (3) into the dependence of the adhesive friction T_a on the decreasing h. This dependence is presented in Figure 4.

Determination of T_a was also carried out for P-PVC at a constant temperature of 140 °C using two different P value of 300 N and 400 N, respectively. The adhesive friction T_a as functions of decreasing h value are presented in Figure 5.

Similar measurements were carried out also for PE-LD, at temp. 130 °C and 140 °C using the load of 300 N.

On the basis of the measurements results the coefficient ξ was evaluated according to eq. (7). The coefficients ξ calculated for PE-LD at constant load are of the same value 0.075 N/mm^2 for both investigated temperatures (130 °C and 140 °C). However, two different values of adhesive friction were obtained for P-PVC for two different P load values, *i.e.* 0.017 N/mm^2 for the load of 300 N and 0.021 N/mm^2 for the load of 400 N. It was found that the temperature of the measurement, within the range studied, has an insignificant effect on the value of coefficient ξ. However, an increase in the coefficient ξ for P-PVC with increasing load was observed.

CONCLUSIONS

On the basis of the measurements it was found that the dependence between T_a and h value presents a linear function and therefore, it may be used to evaluate the coefficient ξ. It was observed that P load had a significant effect on the coefficient ξ under given conditions of the measurement, what consequently led to changes in the flow rate of the molten polymeric materials.

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