Dynamic Frictional Data

New Findings for Describing the Processes in the Extruder Feed Zone

Walter Michaeli, Jochen Hennes and Stefan Quadflieg, Aachen/Germany

A special test apparatus allows pressure coefficients and coefficients of friction of plastics pellet stock to be measured for the first time in a dynamic state. The results obtained are relevant for practical purposes, since the pellet stock is in motion in the feed zone of extruders. New findings on the frictional properties of bulk plastics materials permit even more precise simulation of the processes taking place in single-screw extruders.

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The design of extruders is often preceded by a computer simulation. This provides an economical tool for assessing in advance how the screw geometry and material properties will affect the final product [1]. The better the material data used in the simulation correspond to real data, the better are the simulation results.

The frictional force in the feed zone of extruders can be determined by means of the pressure in a radial direction, and the coefficient of friction determined. Here, the pressure is a key parameter for describing the conditions within the feed zone [2 to 6]. In the solid zone, pressure anisotropy occurs in bulk plastic materials, which results in much lower pressure laterally than in the conveying direction. This pressure difference is expressed as the pressure coefficient, the quotient of radial to axial pressure. To allow precise determination of the frictional properties of a bulk plastic material, it is necessary to know not only the coefficient of friction but also the pressure coefficient. It is important to determine these values under realistic conditions.

In the past, various test apparatus have been developed for measuring the pressure coefficient of the bulk material in a static state [3 to 6]. However, in the feed zone of extruders the bulk material is in motion and subject to completely different boundary conditions. Therefore, the results cannot be readily used for determining the processes occurring in the feed zone of extruders [3, 6].

A test apparatus designed and operated at the Institute for Plastics Processing (IKV) in Aachen permits measurement of pressure coefficients and coefficients of friction in a dynamic state.

Construction of the Test Apparatus

The construction of the test apparatus is shown schematically in Fig 1. Two pistons compress the bulk plastic material in a test cylinder. In contrast to the processes in the extruder, the bulk material does not move along the cylinder wall, but the cylinder wall moves over the bulk material. The test cylinder is operated dependent on position by means of a hydraulic cylinder. A second hydraulic cylinder controls a piston as a function of pressure, thus adjusting the pressure acting on the bulk material.

The test cylinder is surrounded by a further cylinder containing the heating and cooling coils for temperature control. This temperature control allows the test parameters to be recorded at different temperatures. In addition, the temperature control dissipates the heat generated during the measurement by friction of the plastic against the test cylinder.

The modular construction allows test cylinders of different geometrical dimensions and materials to be used, in order to determine friction factors in cylinders of different surface areas and sizes. By means of a test cylinder with a grooved surface, the boundary conditions can be adjusted to resemble those in grooved feed-section extruders.

The radial pressure is measured by means of the extension of a thin region incorporated into the test cylinder. Strain gauges are used for this, which convert a change in length into a change in electrical resistance. The frictional force, or the normal forces acting on the piston in an axial direction, are recorded as hydraulic pressures of the pistons and strain gauges on the piston rods.

Apart from the pressures, the position of the piston rod, and thus the size of the measurement chamber, is also recorded. This allows determination of the density of the bulk material.

From Measurements to a Practically Useful Equation

To allow computer processing of the plastic's frictional properties, it is necessary to determine the dependence of the friction values on temperature, pressure and velocity by means of a statistical experimental design and regression analysis. The regression analysis yields an equation containing all the important relationships between friction factors and influencing parameters. It takes into account not only the linear dependencies of frictional values on the parameters, but also the square-law dependencies. Since it cannot be ruled out that, e.g., the dependency of frictional force on temperature may change as pressure increases, reciprocal effects must be incorporated into the regression equation.

Results

The measurements were carried out with a blend of polycarbonate and ABS

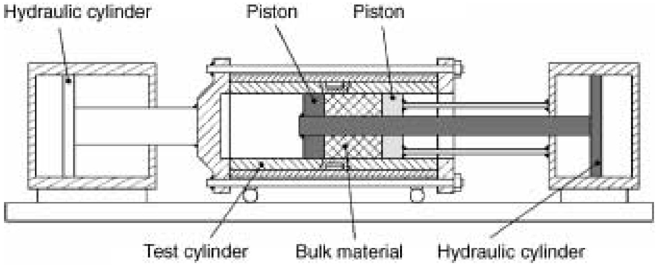

Fig. 1. Schematic construction of the test apparatus

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		Pellet stock 1	Pellet stock 2	Pellet stock 3
Form		Cylindrical	Cylindrical	Cylindrical
Weight per pellet	mg	25	27	16
Length	mm	3.0	4.7	3.0
Diameter	mm	3.1	2.6	2.6

Table 1. Geometrical properties of the test pellet stock

(PC+ABS, type: Bayblend T85 from Bayer). The different pellet stocks have various geometries, which are listed in Table 1.

To describe the processes taking place in the feed zone of single-screw extruders, it is generally sufficient to know the product of the coefficient of friction and the pressure coefficient. This product is termed the *friction factor* below. Its relationship to pressure, temperature and velocity is investigated here.

Fig. 2 shows the profile of the friction factor calculated with the regression equation as a function of axial pressure, at a constant temperature of 60 °C and a constant velocity of 60 mm/s. As the pressure increases, the friction factor decreases linearly. At a pressure change of 500 %, the maximum decrease in friction factor in the case of pellet stock 1 is 40 %. Since higher axial pressures act at the cylinder wall than at the screw root, the friction factor is smaller there. However, the frictional force, the product of the friction factor and axial pressure, is always higher at the cylinder wall than at the screw root because of the small decrease in friction factor. The best behaviour here is shown by pellet stock 3, since the decrease in friction factor is least with increasing pressure.

Another conspicuous point is that the friction factor increases with increasing weight per pellet. Pellet stock 2, with the highest pellet weight, has the greatest friction factor, followed by pellet stock 1 and 3 in that order. The friction factor has thus been shown to depend on pellet weight. This has also been confirmed by the IKV's investigations, which show a correlation between pellet weight and mass throughput [8].

The profile for the friction factor computed at different temperatures under constant pressure of 60 bar and a constant velocity of 60 mm/s is shown in Fig. 3. The friction factor for all pellet forms initially falls with increasing temperature; passes through a minimum at approximately 60 °C, and then increases again. This profile can be attributed to an initial reduction in the coefficients of friction with increasing temperature. At much higher temperatures, however, the material can be more easily deformed. This results in an increased contact area between cylinder wall and bulk material, which, under constant pressure, leads to a higher friction factor and therefore a higher frictional force. With the exception of two data points, there is again a dependency of the magnitude of the friction factor on pellet weight.

Fig. 4 shows the calculated friction factor as a function of velocity for a constant temperature of 60 °C and a constant pressure of 60 bar. The friction factor varies linearly with increasing velocity. However, this dependency is an order of magnitude smaller than the pressure dependency.

The test apparatus also allows measurement of how the density of bulk polymer materials depends on pressure, temperature and velocity. Fig. 5 shows the variation of density with temperature, calculated with a regression equation for a constant pressure of 60 bar and a constant velocity of 60 mm/s. The commonly held view that the bulk density is only dependent on pressure is shown to be incorrect. The measurements rather demonstrate that the density of the pellet stocks investigated increases to the same order of magnitude with pressure and temperature. No dependency of the bulk density on velocity was found.

Summary

The new test apparatus allowed for the first time determination of pressure coefficients and coefficients of friction of bulk material in a dynamic state. Since the bulk material is also in a dynamic state in the feed zone of extruders, the tests are carried out under realistic boundary conditions. In addition to frictional values, the test apparatus can also determine the density of plastic bulk materials as a function of pressure, temperature and velocity.

The early investigations have shown that the test apparatus is capable of precisely determining the frictional behaviour of various materials and material geometries. It was found that even small differences in the geometry of pellets can lead to considerable differences in their frictional properties.

The results obtained can be numerically evaluated and the material behaviour subsequently described by regression polynomials. These polynomials can be used in simulation computations to describe the process in single-screw extruders for any boundary conditions. The new description of the frictional behaviour of bulk plastic materials in the feed zone allows a further improvement in the simulation results, since the early investigations have shown that it is not warranted to assume constant frictional values as an input parameter for the modelling of extruder screws.

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Fig. 2. Friction factors of ABS+PC pellet stock as a function of pressure at constant temperature of 60 °C and constant velocity of 60 mm/s
Reibbeiwert = Friction factor, Druck = Pressure, Granulat = Pellet stock

Fig. 3. Friction factors of ABS+PC pellet stock as a function of temperature at a constant pressure of 60 bar and constant velocity of 60 mm/s
Reibbeiwert = Friction factor, Temperatur = Temperature, Granulat = Pellet stock

Fig. 4. Friction factors of ABS+PC pellet stock as a function of velocity at a constant temperature of 60 °C and constant pressure of 60 bar
Reibbeiwert = Friction factor, Geschwindigkeit = Velocity, Granulat = Pellet stock

Fig. 5. Bulk density as a function of temperature
Reibbeiwert = Friction factor, Temperatur = Temperature, Granulat = Pellet stock