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EXPERIMENTAL STUDY OF THE STRAIN OF A POLYMER JET

O. I. Skul'skii, E. V. Slavnov, A. I. Sudakov, and N. V. Shakirov

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Results of experimental investigation of the postspinneret extension of a plasticized-polyvinylchloride melt have been presented. The influence of the stretching rate and the length of the strain zone of the jet profile has been investigated. A formula describing the time change in the axial velocity has been proposed.

The elastic properties of molten polymers clearly manifest themselves in the effect of excess of the transverse dimension of the product appearing from the calibrating nozzle over the cross section of the molder tool. This swelling of the jet is called high-elasticity reduction or the Barus effect [1–3]. One recognizes a jet freely escaping from the nozzle and a constrained jet. In the second case, the jet escaping from the molding channel is additionally strained, for example, by stretching or calibration. A typical example of such strain can be the process of production of polymer fibers by the extrusion method [2–4]. In such a method of manufacture of a polymer filament, the processes of swelling and stretching of the extrudate are realized simultaneously, and it does not always happen that one is able to separate their contributions to the stressed-strained state. It is noteworthy that swelling increases the cross section of the appearing product, whereas stretching decreases it. Since the production of fibers is carried out with stretching coefficients larger than swelling coefficients, the diameter of the filament arriving at the pickup device will be smaller than the diameter of the molding spinneret, which finally leads to a nonuniform extension of the jet.

Theoretical consideration of the mechanics of fiber spinning is reduced to solution of the equations of motion and heat and mass transfer, in which the special properties of the behavior of materials (these properties determine the distinctive features of spinning of a jet) are expressed by the rheological equation of state. The general principles and methods of investigation of the rheology of uniaxial extension of polymer materials have been considered in [5, 6]. Examples of calculation of nonuniform extension and of experimental and theoretical study of the rheological behavior of polymers under uniaxial strain and stretching of jets are contained in [7–10].

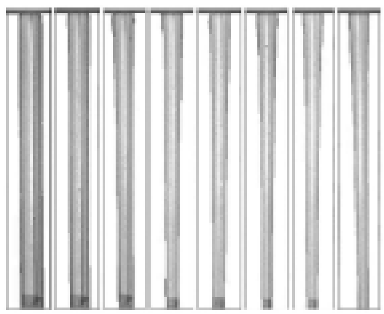
In the present work, the processes of swelling and stretching are investigated with the use of a worm-type unit.

Experimental Investigation of the Nonuniform Extension of a Jet. The experiment on determination of the shape of an extrudate jet was carried on a worm-type unit: the diameter of the worm screw was 32 mm; the rotational velocity of the worm was 35 rpm; five heating zones arranged along the length of the worm casing maintained prescribed temperature regimes from 120 to 160^{o}C.

The melt was extruded through a molding head whose structure made it possible to carry out stretching and cooling of the extrudate in a vertical bath with a controlled water level from 40 to 140 mm from the section of the molding head. The final diameter and longitudinal velocity of the jet were prescribed using a winding device which maintained the speed of pickup of a polymer cord in the range 2–8 cm/sec. The shape of the extrudate jet was recorded by a Kodak digital camera with the use of a flash lamp fixed on a stand. The pictures produced were processed on a computer. We carried out experiments with plasticized polyvinylchloride I-40-13. The selected temperature regimes were close to the actual production regimes of treatment of the material.

After the heating of the worm casing and the extrusion head to prescribed temperatures, we drove the worm and prescribed the speed of the draw-out device and the height of the water level in the cooling bath. After a certain time interval sufficient for the establishment of stationary conditions in the head and the jet formed, the visible shape of the polymer-material jet was recorded by the photocamera with a maximum possible resolution. The tension of the

Institute of Continuum Mechanics, Ural Branch of the Russian Academy of Sciences, 1 Korolev Str., Perm', 614013, Russia; email: shakirov@icmm.ru. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 78, No. 5, pp. 156–159, September–October, 2005. Original article submitted December 15, 2004.



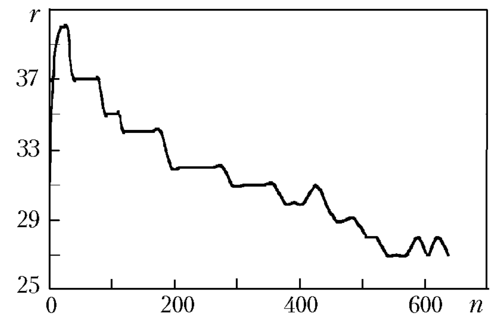
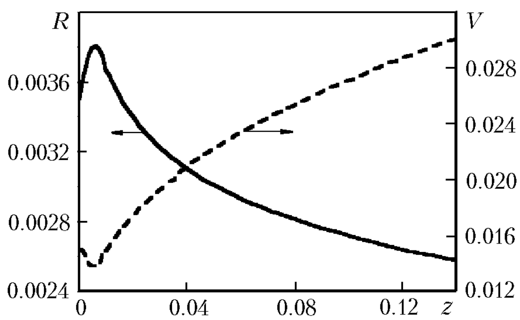


Fig. 1. Photographs of the jets of a polyvinyl melt for different extension rates.

Fig. 2. Shape of the profile of a polyvinylchloride jet in pixel representation.



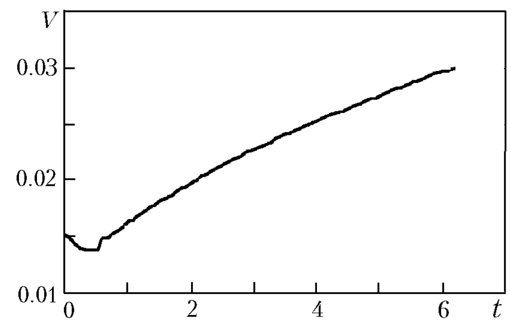


Fig. 3. Change in the radius and in the longitudinal velocity along the jet. R, m; V, m/sec.

Fig. 4. Change in the longitudinal velocity of the jet with time. V, m/sec; t, sec.

jet was measured using a special device based on measurement of the forces of lateral displacement of the extrudate at exit from the cooling bath before it arrives at the draw-out device. The sample was cut at exit from the draw-out device; its length, weight, and diameter were measured. The operations described above were repeated with extrudates differing in the stretching coefficients and the strain-zone length.

Figure 1 gives the photographs of the flowing jets arranged from left to right in order of increasing speed of the pickup device from 1 to 8 cm/sec. The photographs produced were subsequently processed using the Corel Painter program from the Corel 5.0 package. Manual scanning of the points of the jet-scale boundary and registration of the coordinates of pixel points in an Excel table were carried out. The right- and left-hand boundaries of the jet shape were averaged in this program and outlier points were corrected. The corrected table of pixel coordinates obtained enabled us to construct the plot of the jet shape (Fig. 2).

Since the length of the strain zone (distance from the section of the head to the water surface) and the diameters of the molding head and the extrudate after the cooling are known, we can introduce the scales and construct the true-size jet profile. Such a plot is exemplified in Fig. 3 by the full curve on which we can clearly recognize two portions: the zone of predominant swelling near the exit from the head and the zone of stretching of the extrudate on the remaining portion, where the effect of swelling is less pronounced.

To find the jet velocity average over the cross section we subdivided the entire zone into a certain number of portions and computed the cross-sectional area of the jet on each portion. From the known speed of the pickup device, we find the flow velocity in any cross section of the jet

$$V(z) = \frac{V_L R_L^2}{R^2},$$

TABLE 1. Values of the Parameters of Approximating Exponents

Rate, (m/sec)·10^2	A_1, m/sec	α_1, sec	A_2, m/sec	α_2, sec
2	–0.00515	1.41	0.00392	0.78
3	–0.07197		0.06514	
4	–0.02505	1.05	0.01493	0.64
5	–0.03735		0.02612	
6	–0.09794		0.08507	
7	–0.09794	0.72	0.08507	0.53
8	–0.09794		0.08507	

where V_L is the speed of the pickup device.

A change in the longitudinal velocity along the vertical coordinate is presented in Fig. 3 by the dashed curve. Knowing the value of the longitudinal velocity in the cross section and the length of a portion, we can easily find the time interval in which this portion is traversed and determine the change in the longitudinal velocity with time. The results of such a calculation are presented in Fig. 4.

Three zones — the initial zone of decrease, nonlinear increase, and a nearly linear growth in the longitudinal velocity with time — are clearly seen in Fig. 4; what this means is that in the case of simultaneous processes of swelling, stress relaxation, and stretching the longitudinal velocity is equal to the sum of the velocities characterizing each of the above processes.

Analysis of the Results. In extension with rates lower than 3 cm/sec (see Fig, 1, the last two samples on the left), the jet profile is determined by the aftereffect strain. The form of the curves given in Fig. 3 qualitatively coincides with the data for a PENP melt [4], synthetic fibers [2], and a polyoxyethylene solution [7].

Since the curve in Fig. 4 and the analogous curves reflect the relaxation processes in the jet for other stretch ratios, an attempt can be made to find the times (characteristic of these regimes of strain) of relaxation and aftereffect of a medium by approximation of such curves.

It is desired to create a procedure for processing of the experimental data obtained that would take the above components into account. It is proposed that a linearly varying velocity corresponding to the process of extension be determined from the portion near the draw-out device. The difference between the velocity observed and that linearly growing can be approximated by the sum of two exponents corresponding to the processes of relaxation of stresses and their realization in their process of swelling:

$$V = B + Kt + A_1 \exp\left(-\frac{t}{\alpha_1}\right) + A_2 \exp\left(-\frac{t}{\alpha_2}\right).$$

To find the parameters of the exponents we composed a program in whose cycle the parameters of the exponents were exhausted by the method of bisection segmentation with selection of the criterion of minimum deviation of the exponents from the difference between the observed velocity and the linear longitudinal velocity. The parameters of the approximating exponents for different stretching rates are given in Table 1, from which it is clear that the exponents decrease with growth in the speed of the pickup device. If we assume that α_1 and α_2 are the effective times of relaxation and aftereffect, it follows from the data of the table that these times decrease with growth in the stretch ratio (effective longitudinal velocity gradient).

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NOTATION

A_i and B, empirical constants, m/sec; K, empirical constant, m/sec^2; L, jet length, m; n, axial coordinate, pixel; R and R_L, running and final jet radii, m; r, running radius, pixel; V and V_L, running and final flow velocities, m/sec; t, time, sec; z, axial coordinate, m; α_i, empirical constants, sec.

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