ENERGY REQUIRED TO FILL A CHANNEL WITH POLYMER MELT UNDER PULSATING PRESSURE

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Results are shown of measurements which have been made for the purpose of determining the work of external forces required to fill a rectangular channel with polymer melt under constant pressure or periodically variable pressure (at a frequency of 6-17 Hz). It has been established that filling a channel under pulsating pressure requires 1.5-1.7 times less energy than filling it under steady flow conditions.

Periodic shear deformation of molten polymers produces structural changes during their flow, and the result is a thixotropic decrease in both their viscosity and elasticity [1, 2]. This decrease in the effective values of viscoelastic properties becomes more appreciable as the vibratory action is intensified, i.e., as the amplitude of the periodically varying shear rate is increased. Such a phenomenon has been observed also during vibrations under steady flow conditions. In that case the viscoelastic properties depend on the steady shear rate as well as on the amplitude of the periodically varying shear rate [3, 4].

This characteristic of polymers can be utilized for improving the processing of such materials [5-11].

Preliminary studies made by the authors have shown that a 2.0-2.5 times deeper rectangular channel can be filled with polymer melt, if the inlet pressure is fluctuated.

The purpose of this study was a comparative analysis of the energy economy involved in extending the fill depth of polymer melt in a rectangular channel by either fluctuating the pressure or raising the pressure level.

It was necessary, for such an analysis, to determine the work of external forces (constant or periodically varying) expended, under vibratory conditions, on filling a channel of the corresponding maximum depth and to compare it with the work expended on filling the same channel depth without vibratory action. The temperature had to be maintained the same in both cases.

The work of external forces throughout the period of filling a channel with molten material is calculated as follows:

$$A = \int_{t_1}^{t_2} N(t)\,dt = \int_{t_1}^{t_2} q(t)\,\overline{P}(t)\,dt.$$

In order to determine the quantities in this equality, we have assembled a test apparatus shown schematically in Fig. 1. In an industrial model TP-63 molding machine was installed a special nozzle with an oscillating plunger, the latter being actuated by a vibrator through an eccentric. The inlet pressure to the channel was measured with a diaphragm-type strain-gage pressure transducer built into the nozzle casing. Signals from this transducer were transmitted to a model 8ANCh amplifier and from there to a model N102 oscillograph.

The cavity to be filled was made in the shape of a channel with a rectangular cross section and closed at one end, its dimensions were 200 × 35 × 2. Through the open end of this channel was inserted a

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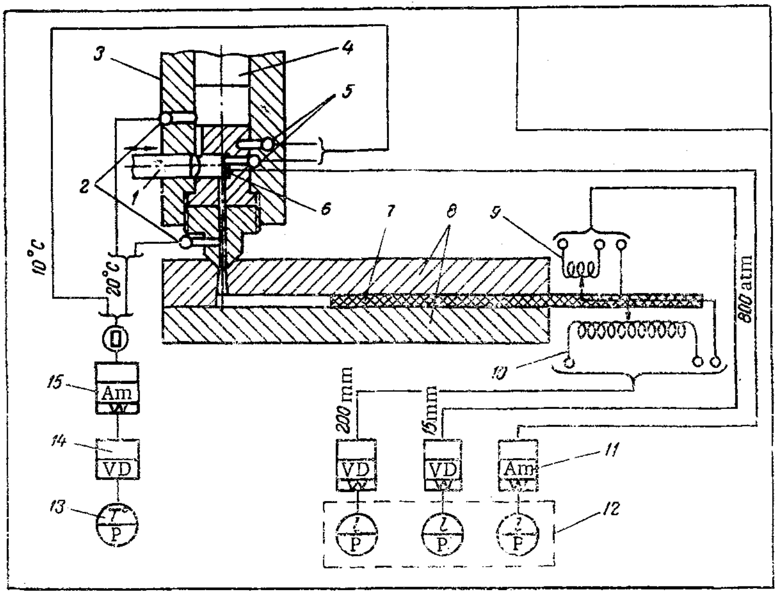

Fig. 1. Schematic diagram of the test apparatus: 1) oscillating plunger, 2) differential thermocouple, 3) injection cylinder of the molding machine, 4) injection ram, 5) differential thermocouple, 6) strain-gage pressure transducer, 7) flat-faced plunger, 8) mold, 9) and 10) rheostat-type displacement transducers, 11) model 8ANCh strain-gage instrument amplifier, 12) model N102 oscillograph, 13) model KSP-4 potentiometer, 14) voltage divider, 15) model F359 compensating dc amplifier.

plunger made of Textolite, which during the filling of the mold was moving together with the front of the molten mass. The apparatus was first checked out and the drag due to this plunger was found to amount to 0.2-0.3 kgf, quite insignificant as compared to the total flow head (150-200 kgf) and thus to have no appreciable effect on the mode of mold filling. In order to study the kinetics of a flat-faced plunger and thus of the moving front of polymer mass, we had installed on the former the sliders of two rheostat-type displacement transducers. Transducer 10 was designed for a continuous plotting of the polymer front displacement along the entire fill path and, therefore, it was a low-sensitivity but long-travel device. Transducer 9, on the other hand, was a short-travel but high-sensitivity device, with which a large-scale graph of the melt front displacement along discrete small segments of the channel could be plotted.

The melt temperature was measured with two fast-response differential thermocouples in the nozzle region of the molding machine.

The purpose of the first thermocouple was to measure the temperature variations in the zone of vibratory action. For this, one of its junctions had been placed in the melt directly at the oscillating plunger and its other junction had been placed 5 mm away in the nozzle casing.

The purpose of the second thermocouple was to measure the temperature variations in the polymer melt after the latter had passed through the zone of maximum shear deformation, i.e., at the nozzle outlet. For this, its one junction had been placed at the nozzle inlet and the other junction 20 mm away from the nozzle outlet (total length of the nozzle channel was 100 mm, its diameter was 3 mm).

Signals from the differential thermocouples were fed through a dc amplifier to a model KSP-4 recording potentiometer. With this measuring system the temperature could be read accurately within ±0.1°C.

The tests were performed as follows. The molding pressure, the melt temperature, and the vibration parameters (amplitude and frequency) were set at definite levels, whereupon the channel was filled to the maximum depth possible under given test conditions. While the mold was being filled, signals from a displacement transducer and the pressure transducer were continuously recorded by the oscillograph on photographic film moving at a speed of 100 mm/sec, while signals from the thermocouples were recorded on the potentiometer strip chart moving at a speed of 7200 mm/h.

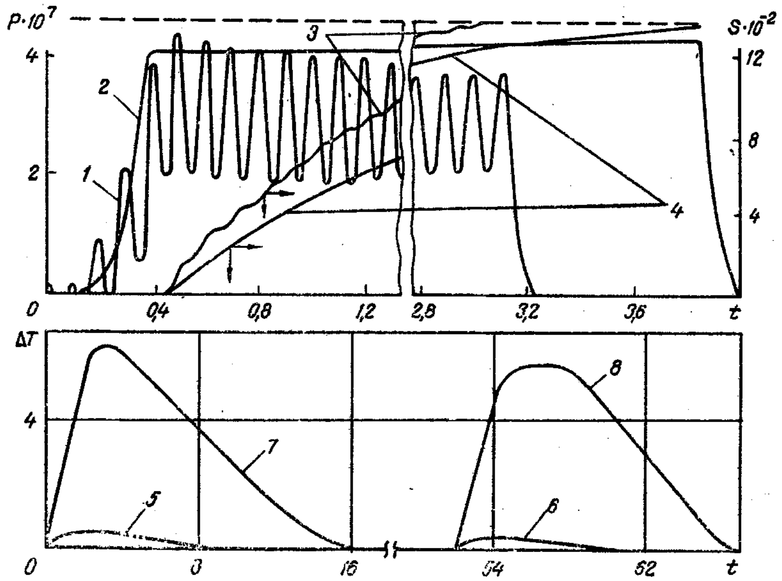

Fig. 2. Variation of inlet pressure P(t) (N/m^2), fill depth S (m), and melt temperature ΔT(°C) as functions of time, during mold filling with polystyrene melt at T = 250°C, measured at a distance of 0.14 m under a molding pressure periodically varying at a frequency of 10 Hz (curves 1, 3, 5, 7) and under a constant molding pressure (curves 2, 4, 6, 8).

In order to plot the motion of the melt front through the entire fill depth, we performed a series of repetitive tests with the pickup element of the high-sensitivity displacement transducer in different positions along the channel from test to test.

An analogous series of tests was performed with the vibrator shut off but with the injection pressure raised to such a level as to make the maximum fill depth in the channel the same as before with the vibrator on. The temperatures in all zones of the molding machine were held constant throughout all these tests. Each test in this series was repeated three times.

The tests were performed with impact resistant polystyrene and with high-density polyethylene at temperatures of 160, 180, and 220°C over a range of molding pressures from 250 to 600 kgf/cm^2. The vibration frequency was 10 Hz, the oscillating plunger was 12 mm in diameter and its travel was 8 mm.

As a result of these tests, we have obtained oscillograms of pressure and temperature variations in the melt at the channel inlet during cavity fillout under either a constant or a periodically varying force, also detail graphs of the melt front displacement along the entire flow path.

The test results shown in Fig. 2 pertain to impact resistant polystyrene filling a channel 140 mm deep at a temperature of 250°C under either vibratory or steady flow conditions. According to the graph, vibratory action produced pressure fluctuations with an amplitude of 120 kgf/cm^2 at the cavity inlet. The peak pressure during these fluctuations did not exceed the constant pressure level during steady flow to the same fill depth.

The curve of the melt front displacement during the vibratory mode of filling (curve 3) reflects a stepwise attenuation, indicating velocity fluctuations in the polymer mass. The time required for filling the cavity to a given depth was 15-20% shorter than under steady flow conditions.

The curves in Fig. 3 (curves 3 and 4) are based on the displacement test curves. On the same diagram have been plotted corresponding oscillograms of pressure variation at the channel inlet (curves 1 and 2), From these data and according to the equation shown earlier, we have plotted curves of instantaneous power as a function of time (Fig. 3, curves 5 and 6) and then calculated the total work of external forces necessary for filling the channel under a constant or a periodically varying injection pressure. These calculations have shown that this work is 1.5-1.7 times less in the vibratory mode than in the steady mode of cavity filling.

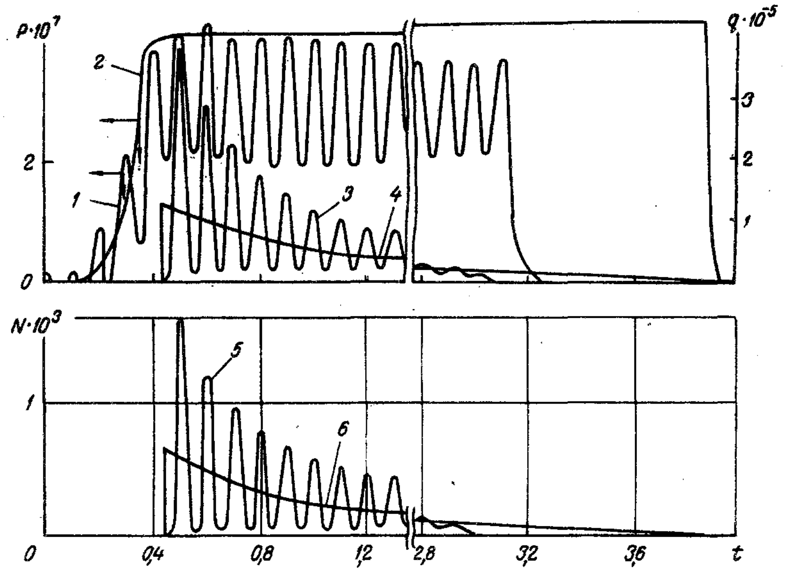

Fig. 3. Variation of bulk velocity q(t) (m^3/sec), power N(t) (W), and inlet pressure P(t) (N/m^2) as functions of time, during mold filling by the vibratory method (curves 1, 3, 5) and by the conventional method (curves 2, 4, 6).

Finally, it is necessary to establish whether this energy gain is a consequence of a lower viscosity at an extra higher temperature, the additional temperature rise being due to the heat generated during vibration. In order to establish this, we turn to the test data on the variation of the melt temperature within the vibration zone (Fig. 2, curves 5 and 6) and at the exit from the zone of maximum shear deformation (curves 7 and 8). According to the curves, during conventional molding the melt temperature rises by 0.8°C and the temperature at the nozzle outlet rises by 6.5°C as a result of the heat generated and dissipated in the channel zone before vibrations occur in the cavity. In the case of vibratory molding the temperature rises by 0.4-0.6°C more at the same points of measurement. Such a temperature rise causes the viscosity of the melt to drop by not more than 1-2%.

Thus, our experimental studies have demonstrated that, when a channel is filled by the vibratory method, the total work of external forces may be reduced to 1.5-1.7 times less than under steady conditions. This energy gain is not associated with the drop in viscosity due to a higher temperature, but rather is a consequence of reduced viscoelastic parameters in the melt during periodic deformation. This phenomenon can be advantageously utilized for reducing the energy requirement in pressure molding of polymer materials.

NOTATION

A is the work of external forces necessary for filling a mold cavity, J;
N is the instantaneous power of external forces, W;
P(t) is the instantaneous pressure at the mold inlet, N/m^2;
q(t) is the instantaneous bulk velocity of the polymer mass during mold filling, m^3/sec;
S is the instantaneous fill depth, m;
t_1, t_2 are the beginning and the end of the molding, sec;
T is the temperature of the polymer melt, °C;
ΔT is the variation of the melt temperature, °C.

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