The Effect of Rheology on Extrusion Process

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ABSTRACT

One of the most widespread practical methods of polymer processing is the extrusion method that is based on pressing a polymeric melt through channels of the molding tool which have different geometrical cross-sections. The basic performance of extrusion is based on the pressure and flow performance which sets functional correlation between volumetric flow rate of a polymer medium, pressed through a molding tool, and created pressure drop.

INTRODUCTION

Extrusion is a widespread practical method in polymer processing. It is based on pressing a polymeric melt through channels of molding tools which have different geometrical cross-sections. This processing method produces polymeric parts with miscellaneous profiles for various applications[1-4].

The basic performance of extrusion is based on the pressure/flow performance which sets functional correlation between volume flow rate of a polymer medium, pressed through the molding tool, and created pressure drop. Arguments of this correlation are the rheological parameters of polymer and the geometrical characteristics of the channel in which the polymeric melt flows. Analytically, such performances are mostly known for simple geometrical cross-sections channels, round and flat slot[5]. Without considering elastic properties of polymers, there are limitations in practical application of the correlation. Furthermore, adequate results have been observed only or low rate pressure gradients, when the elastic properties of polymer mediums are slightly performed[6].

The prediction of pressure/flow performances of polymeric melts flow with consideration of their elastic properties in cylindrical channels with arbitrary geometrical cross-sections is still a crucial practical problem which remains to be solved.

RHEOLOGICAL MODELLING

For consideration both viscous and elastic properties of polymeric melts, following viscoelastic model is implemented[7,8].

$$\begin{cases} \overline{\sigma} + p\overline{\delta} = 2\overline{c}W_1 - 2\overline{c}^{-1}W_2 \\ \overline{e}_f = \dfrac{1}{\theta_0(T)G_0(T)} \cdot f(I_1, I_2) \cdot \left[\left(\overline{c} - \dfrac{I_1}{3}\overline{\delta} \right) W_1^s - \left(\overline{c}^{-1} - \dfrac{I_2}{3}\overline{\delta} \right) W_2^s \right] \\ \dfrac{d\overline{c}}{dt} + \overline{\omega c} - \overline{c}\,\overline{\omega} - \overline{c}\left(\overline{e} - \overline{e}_f\right) - \left(\overline{e} - \overline{e}_f\right)\overline{c} = 0 \end{cases} \quad (1)$$

where:

$\bar{\sigma}$ :: stress tensor;

P :: Lagrange multiplier, determined by boundary condition;

$\bar{\delta}$ :: identity tensor;

$\bar{c}$ :: Cauchy strain tensor;

$\bar{e}_f$ :: flow strain rate tensor;

$\bar{\omega}$ :: vortex tensor;

$\bar{e}$ :: strain rate tensor;

$\theta_0(T)$ :: relaxation time;

$G_0(T)$ :: tensile modulus;

W :: strain energy function $W = W(I_1, I_2)$;

I_1, I_2 :: primary and secondary strain tensor invariants;

f(I1,I2) :: dimensionless function that defines relaxation time, and

$2W^S = W(I_1, I_2) + W(I_2, I_1)$ :: symmetric function of W.

The last one can be shown by:

$$W_1 = \frac{\partial W}{\partial I_1},\ W_2 = \frac{\partial W}{\partial I_2},\ W_1^S = \frac{\partial W^S}{\partial I_1},\ W_2^S = \frac{\partial W^S}{\partial I_2}. \qquad (2)$$

RESULTS AND DISCUSSION

Following rheological model for fixed shear rates can be derived from the viscoelastic model and elastic potential presented by Eq. 3.

$$\Gamma \equiv \dot{\gamma} \cdot \theta_0(T) = \frac{c_{12}}{1 - c_{12}^2} \cdot \frac{1}{f} \qquad (3)$$

Where $c_{12} = \left|\frac{\sigma_{12}}{G_0(T)}\right| \equiv \left|\frac{\tau}{G_0(T)}\right|$ and $f = \frac{1 - c_{12}}{(1 + c_{12})^2}$ is a result of theoretical and experimental studies provided in literatures[9,10].

By substituting Eq. 2 and 1 in expression 3:

$$dV_z(r_h) = sign\left(\frac{dp}{dz}\right)\frac{(1+k)}{\theta_0(T)}\frac{|ar_h|}{(1-|ar_h|)^2}(1+|ar_h|)dr_h \qquad (4)$$

where $a \equiv \frac{\Delta p}{G_0(T)}\frac{1}{L}$.

Following boundary condition on channel wall can be realized for integration of differential Eq. 4.

$$V_z(r_h = R_{hw}) = 0 \qquad (5)$$

Integrating Eq. 4 with considering condition 5, results in:

$$V_z(r_h) = sign\left(\frac{dp}{dz}\right)\frac{(1+k)}{\theta_0(T)\cdot|a|}\left[3ln\frac{1-|ar_h|}{1-|b|} - \frac{2}{1-|b|} + \frac{2}{1-|ar_h|} - |b| + |ar_h|\right] \qquad (6)$$

Volumetric flow rate of polymeric medium passing through the channel can be determined by integration of equation 2 using expressions 3 and 6, applying conditions 5.

$$Q_z^{New} \approx -sign\left(\frac{dp}{dz}\right)\frac{1}{\eta_0(T)}\frac{|\Delta p|}{L}\frac{(1+k)}{(3+k)}\frac{S_w^3}{P_w^2} \qquad (7)$$

CONCLUSION

Derived expressions from gained analytical solution, confirm validity of the presented hypothesis as formulated in this paper. This feature allows forecasting a maximal value for pressure drop which may occur in channels of molding tools of extrusion machinery. This issue ensures a correct estimation for maximal force loadings that affect equipment components.

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