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The effect of inner assisted gas length on the gas-assisted extrusion forming of plastic micro-tube

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Abstract. The effect of inner assisted gas length on the gas-assisted extrusion forming of plastic micro-tube was numerically studied in this paper. The 2D geometric models with different lengths of inner assisted gas were established. Under the same boundary conditions and material parameters, the profile changes of extruded plastic micro-tubes were obtained. To ascertain the reasons of profile changes induced by different lengths of inner assisted gas, the radial and axial flow velocities, shear stress and the first normal stress differences of melt were all obtained. Numerical results show that the diameter swell or shrinkage phenomenon occurs when the inner assisted gas length mismatches the outer assisted gas length. The deformations are generated by the unbalance axial flow velocity of melt induced by the mismatch of two assisted gases lengths, especially at the outlet of assisted gases. At the same time, the shear stress focus and first normal stress difference focus of melt are also existed at the outlet of assisted gases. In practice, the lengths of two assisted gases should be equal in the gas-assisted extrusion of plastic micro-tube.

1. Introduction

Plastic micro-tube is usually prepared by using the extrusion forming technique [1] for the polymer melt. However, some extrusion problems, such as extrudate swell [2], melt fracture [3], and extrusion deformation [4] are often generated due to the high viscoelastic properties of melt and the larger stresses of melt suffered in the channel. There are some methods used to eliminate the extrusion problems, such as the polymer additive, fluorination coating of die channel, vibration extrusion, and gas-assisted extrusion. Among these methods, the gas-assisted extrusion method has the advantages of well environment, convenient and high efficiency. Therefore, the gas-assisted extrusion method [5, 6] was used in this work. In the gas-assisted extrusion forming of the plastic micro-tube, the design of gas-assisted extrusion die is one of most important factors that impact the extrusion quality of plastic micro-tube. As same as the traditional extrusion die, the mandrel is also existed in the gas-assisted extrusion die of plastic micro-tube. However, the length of mandrel is one of most important components in the gas-assisted extrusion die. For the gas-assisted extrusion of plastic micro-tube, the length of inner assisted gas is related with the length of mandrel. Therefore, in this work, the effect of inner assisted gas length on the gas-assisted extrusion forming of the plastic micro-tube was numerically studied by using the finite element software Polyflow. In the numerical simulations, the different structures of gas-assisted extrusion die with different lengths of inner assisted gas were designed. Under the same boundary and material parameters, the extrudate profiles of plastic



micro-tube with different lengths of inner assisted gas were obtained, At the same time, the velocities and stresses distributions of melt for different length of inner assisted gas were obtained and compared to analyze the reasons.

2. Numerical simulations

2.1 Models

The geometric models of plastic micro-tubes with different lengths of inner assisted gas are shown in Figure 1. The lengths of assisted gas are 3mm, 5mm, and 8mm, respectively. The width of annual melt is 0.5mm, the width of inner and outer assisted gases are all 0.2mm. The length of inner die and outside die are all 5mm. The finite element meshes of geometric models for plastic micro-tubes with different lengths of inner assisted gas are shown in Figure 1(d). In the models, the meshes are refined near the boundaries and the interfaces to improve the computing precision. The mesh number is about 1040.

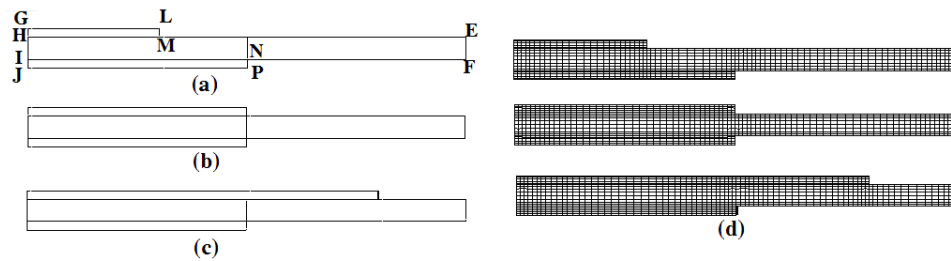


Figure 1. The geometric models of plastic micro-tubes with different lengths of inner assisted gas. (a) 3mm; (b)5mm; (c)8mm; (d) the finite element meshes

2.2 Mathematic equations

The continuity and momentum equation equations are shown as follows,

$$\nabla \cdot \mathbf{v} = 0 \quad (1)$$

$$\nabla p - \nabla \cdot \boldsymbol{\tau} = 0 \quad (2)$$

where, ∇ is Hamilton operator, \mathbf{v} is the velocity vector, p is the pressure vector, $\boldsymbol{\tau}$ is the extra stress tension.

In the paper, Giesekus model [7] was used as the constitutive equation of melt, which is given as follows,

$$\boldsymbol{\tau}_I = \boldsymbol{\tau}_{Iv} + \boldsymbol{\tau}_{Ie} \quad (3)$$

$$\boldsymbol{\tau}_{Iv} = 2\eta_{Iv}D_I \quad (4)$$

$$\boldsymbol{\tau}_{Ie} + \lambda \boldsymbol{\tau}_{Ie} + \alpha \frac{\lambda}{\eta_{Ie}} \{\boldsymbol{\tau}_{Ie} \cdot \boldsymbol{\tau}_{Ie}\} = 2\eta_{Ie}D_I \quad (5)$$

In Eq.(3)-Eq.(5), $\boldsymbol{\tau}_I$ is the extra stress tension consists of extra stress tensions of viscous component ($\boldsymbol{\tau}_{Iv}$) and elastic component ($\boldsymbol{\tau}_{Ie}$). λ is the relaxation time. α is the parameters of melt controlling the ratio between the first normal stress and the second normal stress difference. η_{Iv} and η_{Ie} are the viscosity of melt for the viscous component, and elastic component, respectively. D_I is the deformation rate tension of melt.

The assisted gases are all regarded as the iso-thermal and Newtonian fluid, the rheological equations are shown as follows,

$$D_{II} = \frac{1}{2}(\nabla \mathbf{v}_{II} + \nabla^T \mathbf{v}_{II}) - \frac{1}{3} \nabla \mathbf{v}_{II} \delta_{II} \quad (6)$$

$$\boldsymbol{\tau}_{II} = 2\eta_{II}D_{II} \quad (7)$$

where δ_{II} is the second-order unit tensor. D_{II} is the strain-rate of the tensor of gas. η_{II} is the viscosity of gases, which is a constant under a certain pressure and temperature. τ_{II} is the inelastic stress tensor of gases.

2.3 Boundary conditions

1) Inlet: In the Figure 1(a), HI is the inlet of melt, GH and IJ are the inlets of two assisted gases. Supposed that the melt and gases are all full-developed at the time of melt flows into the forming section of die channel, the following dynamic equations can be satisfied, i.e., $v_x=0$, $\partial v_y/\partial y=0$. where v_x , and v_y are the flow velocities of melt and gases at the direction of x , and y coordination, respectively.

2) Wall: GL and JP are the walls of die channel. In this paper, the no slip boundary condition was used, i.e., $v_n=v_s=0$. where v_n , v_s are the flow velocities at the normal and tangential direction.

3) Free boundaries: ME and PF are the free boundaries of melt. The following relationships are satisfied, i.e., $f_n=f_s=0$, and $v_n=0$. where f_n and f_s are the shear stresses at the normal and tangential direction.

4) End: EF is the end of melt, LM and NP are the ends of two assisted gases. There are no any normal traction force and tangential velocity imposed on the ends. i.e., $f_n=v_s=0$.

2.4 Material values

The material values of melt and assisted gases are given in Table 1.

Table 1. Material values of melt and gases

Parameters	η_v	η_e	λ	α
Melt	22 Pa.s	536 Pa.s	0.019 s	0.1
Gas	2.6×10^{-5}	0	0	0

3. Numerical results and analyses

3.1 Effect of inner assisted gas length on the extrudate profile of plastic micro-tube

In the simulations, the inlet volume flow rate of melt is $1\text{mm}^3/\text{s}$, the inlet volume flow rate of two assisted gases are all $2\text{cm}^3/\text{s}$. The extrudate profile changes of plastic micro-tubes under the different lengths of inner assisted gas are obtained, which are shown in Figure 2(a), respectively. Then, the inlet volume flow rate of two assisted gases are all $10\text{cm}^3/\text{s}$, the extrudate profile changes of plastic micro-tubes under the different lengths of inner assisted gas are obtained, which are shown in Figure 2(b).

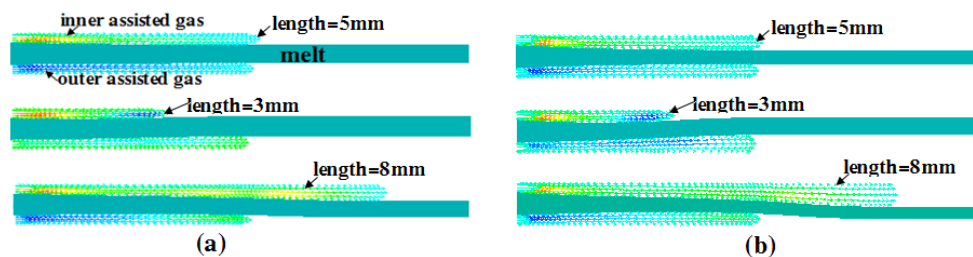


Figure 2. Extrudate profile of plastic micro-tubes under the different lengths of inner assisted gas. (a) inlet volume flow rate of two assisted gases are $2\text{ cm}^3/\text{s}$; (b) inlet volume flow rate of two assisted gases are $10\text{ cm}^3/\text{s}$

From Figure 2(a) and (b), it can be seen that under the same material parameters and boundary conditions, the extrudate profiles of plastic micro-tube with different lengths of inner assisted gas are different. That is, when the length of inner assisted gas is shorter than that of outer assisted gas, the extruded plastic micro-tube is inclined towards inner cavity. When the length of inner assisted gas is longer than that of outer assisted gas, the extruded plastic micro-tube is inclined towards outer wall. However, when the length of inner assisted gas is equal to that of outer assisted gas, the inclination phenomenon doesn't occur. At the same time, with the increase of the inlet volume flow rate of

assisted gases, the wall thicknesses of extruded plastic micro-tube become thinner and thinner. For the gas-assisted extrusion of plastic micro-tube with shorter length of inner assisted gas, the inclination towards inner cavity is more serious with the increase of inlet volume flow rate of assisted gases, which leads to shrink the diameters of plastic micro-tube. For the gas-assisted extrusion of plastic micro-tube with longer length of inner assisted gas, the inclination towards outer wall is more serious with the increase of inlet volume flow rate of assisted gases, which leads to swell the diameters of plastic micro-tube.

3.2 Flow velocities distributions

The radial velocity distributions and axial velocity distributions of melt for plastic micro-tubes with different lengths of inner assisted gas along the axial direction of die channel were obtained, which are shown in Figure 3(a), and (b), respectively.

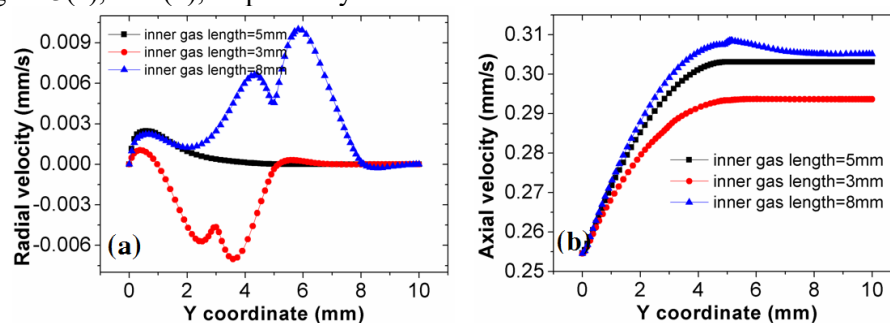


Figure 3. Flow velocities distributions of melt for plastic micro-tubes with different lengths of inner assisted gas along the axial direction of die channel. (a) Radial velocity distributions; (b) Axial velocity distributions

From Figure 3(a), it can be sent that, for the gas-assisted extrusion of plastic micro-tube with the inner assisted gas of 5mm, there are the radial flow velocity only existed at the inlet of die channel, which is resulted from the roles of normal and tangential stresses. For the gas-assisted extrusion of plastic micro-tube with the inner assisted gas of 3mm, there is negative radial velocity existed inside die channel, and reached the maximum value near the outlet of inner assisted gas, which demonstrates that the melt flows towards the inner cavity, which will shrink the diameter of plastic micro-tube. For the gas-assisted extrusion of plastic micro-tube with the inner assisted gas of 8mm, there is positive radial velocity existed inside die channel, and reached the maximum value near the outlet of outer assisted gas, which demonstrates that the melt flows towards the outer wall, especially at the outlet of outer assisted gas, which will swell the diameter of plastic micro-tube.

In Figure 3(b), the axial velocity of melt decreases when the length of inner assisted gas is shorter than that of the outer assisted gas. In contrast, the axial velocity of melt increases when the length of inner assisted gas is longer than that of the outer assisted gas.

3.3 Stresses distributions

The shear stress distribution nephograms and the first normal stress different distribution nephograms of melt for plastic micro-tubes with different lengths of inner assisted gas are shown in Figure 4(a), and (b), respectively. The shear stress distribution curves and the first normal stress different distribution curves of melt for plastic micro-tubes with different lengths of inner assisted gas are shown in Figure 4(c), and (d), respectively.

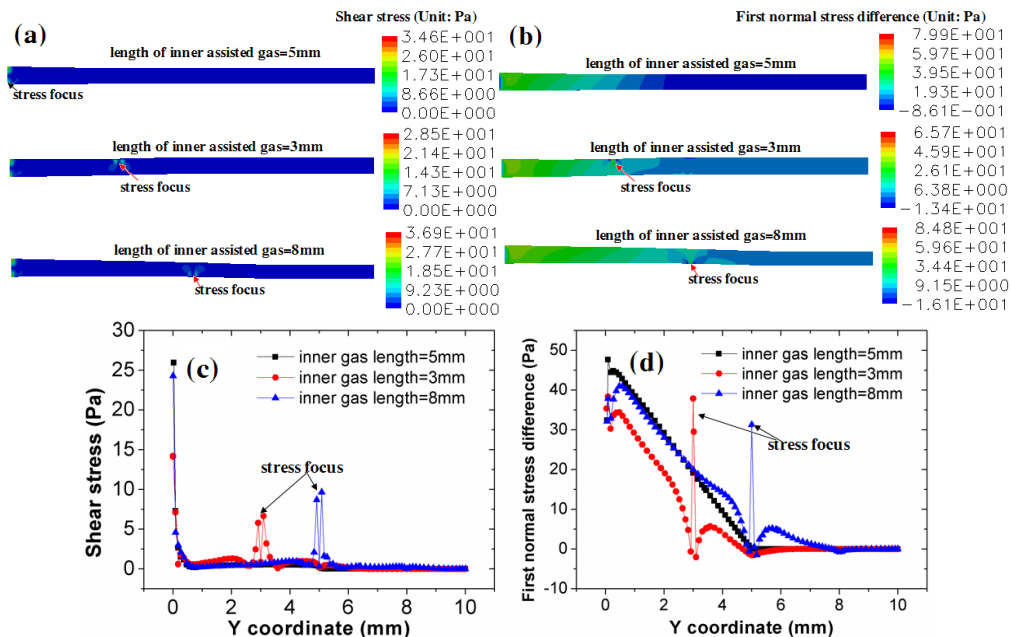


Figure 4. Stresses distributions of melt for plastic micro-tubes with different lengths of inner assisted gas. (a) shear stress distribution nephograms; (b) first normal stress difference distribution nephograms; (c) shear stress distribution curves along the axial direction of die; (d) first normal stress difference distribution curves along the axial direction of die

From Figure 4(a) and (c), it can be seen that for the plastic micro-tube with inner assisted gas length of 5mm, the shear stress focuses at the inlet of die, but the shear stress is very few at the outlet of two assisted gases. However, for the plastic micro-tubes with inner assisted gas length of 3mm and 8mm, the shear stresses of melt focus at the outlet of inner assisted gas and outlet of outer assisted gas. From Figure 4(b) and (d), it can also found that the first normal stress difference of melt is largest at the inlet of two assisted gases for the plastic micro-tube with inner assisted gas length of 5mm. For two others, the first normal stress difference of melt also focus at the outlet of inner assisted gas and outlet of outer assisted gas. For the plastic micro-tubes with the inner assisted gas length of 3mm and 8mm, the shear stress and the first normal stress difference of melt are generated by the flow unbalance induced by the mismatch between the inner assisted gas length and the outer assisted gas length. Therefore, the swell or shrinkage of diameter are directly related with the lengths of inner assisted and outer assisted gases. In the practice, the match between the inner assisted gas length and outer assisted gas length should be remained.

4. Conclusion

In this paper, the effect of inner assisted gas length on the gas-assisted extrusion forming of plastic micro-tube was numerically investigated. The 2D geometric models with different lengths of inner assisted gas were established. Under the same material parameters and boundary conditions, the extrudate profile changes of plastic micro-tubes under different lengths of inner assisted gas were obtained. At the same time, the flow velocities and stresses distributions of melt were also obtained. Numerical results show that the diameter shrinkage occurs for the plastic micro-tube with the inner assisted gas length is shorter than that of the outer assisted gas. When the inner assisted gas length is longer than that of the outer assisted gas, the diameter swell occurs. Therefore, the inner assisted gas length should be equal to that of the outer assisted gas in the gas-assisted extrusion forming of plastic micro-tube.

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References

- [1] Elnagmi, M., Jain, M., Britten, J. F. (2011) Orientation development in solid-state extrusion and hot forming of polypropylene tubes. *Polym. Eng. Sci.*, 51:1446-1454.
- [2] Mijangos-Santiago, F., Dealy, J. M. (2010) Effect of filler content and additives on the extrudate swell of polyethylene pipe resin. *Polym. Eng. Sci.*, 31:1176-1181.
- [3] Ren Z., Huang X, Y., Xiong, Z. H. (2018) Numerical studies of temperature effect on the extrusion fracture and swell of plastic micro-pipe. *IOP Conf. Series: Mater. Sci. Eng.*, 322: 022036.
- [4] Mamalis, A. G., Petrosyan, G. L., Manolakos, D. E., et al. (2006) Mathematical modelling of plastic deformation processes of bimetallic tubes with porous-internal layer in conical dies. *J. Mater. Process. Tech.*, 172: 243-248.
- [5] Ren, Z., Huang, X. Y., Liu H. S., et al. (2015) Numerical and experimental studies for gas assisted extrusion forming of molten polypropylene. *J. Appl. Polym. Sci.*, 132:1-13.
- [6] Ren, Z., Huang, X. Y. (2016) 3D numerical simulation of the hollow square-typed polymer based on gas-assisted extrusion method. *Mater. Sci. Forum*, 861:189-194.
- [7] Hagen, T., Renardy, M. (1997) Boundary layer analysis of the Phan-Thien-Tanner and Giesekus model in high Weissenberg number flow. *J. Non-Newton. Fluid Mech.*, 73:181-189.