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Drag material change in hot runner injection molding①

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[Abstract] Quick material change is often encountered for the different colors or kinds of polymer in hot runner injecting molding process. Time-costing and incompleteness of material change process often affects the quality and productivity of products. In the practical production, multi-injection or white material as the transition material is often adopted for quick material change. Based on the rheological behavior of the new and the previous plastic melt, the researches on the related problems were carried out. The concept of drag material change was originally presented. The physical and mathematical model on the simultaneous flow process of the new and the previous plastic melt in hot runner were built up, which can well explain the influence of the injection speed, pressure, viscosity difference, temperature and mold structure on the drag material change efficiency. When temperature in different position in the mold was increased and adjusted, the viscosity difference between the two kinds of melt can be controlled. Therefore the material change ability can be greatly improved during the whole material change process, getting rid of more and more difficult changing in the late stage.

[Key words] injection molding; hot runner; drag material change process; mold design
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1 INTRODUCTION

Hot runner injection molding process has some advantages over conventional injection molding technique such as automation, continuity, saving time and material, stable product quality, and low cost. Its structure is shown in Fig. 1. When different types of polymers or material colors are used in small scale production of multi-products, material is frequently changed in the same hot runner injection mold. At present, quick material change is achieved in production mainly by multi-injection or using white transition-material, judging completeness of material change by watching its color or smelling the odor. In a word, prior to molding a new product, the remainders of previous plastic material must be cleared out of the whole hot runner system to prevent previous material from polluting new one. The level of material change directly influences the quality of product and productivity. Because of the complexity of hot runner, manually clearing the previous material out of the hot runner system usually takes several hours (sometimes even several days). The alternative disassembling, assembling and debugging of hot runner system are a strict and loathsome job, and may be harmful to the service life of such an expensive equipment[1]. Material change for hot runner is the most important and difficult phase in the whole material change process, especially, when the change ability is getting lower and lower in the late stage of the material change process. So it is very necessary to do the theoretical research and guide practical production on the basis of the experience in existence.

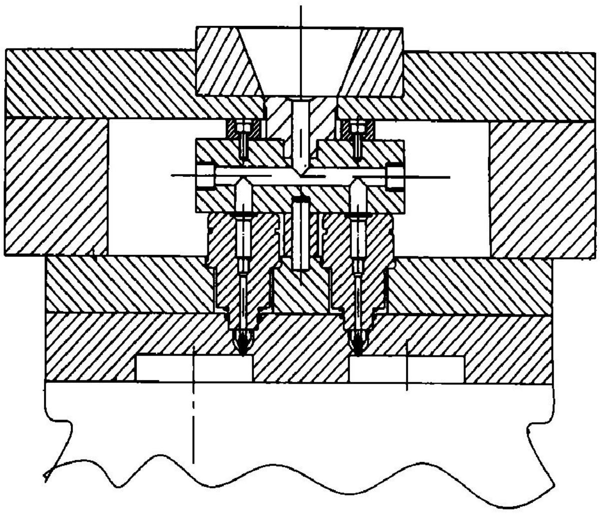

Fig. 1 Hot runner system in double cavity mold

2 DESCRIPTION OF DRAG MATERIAL CHANGE

2.1 Physical model of drag material change technique

Drag material change is named after its working principle. It is a quick material change process, in which the whole hot runner is first heated by its temperature controlling device to make the previous material keep in melt state, and then new material is injected into hot runner mold. The dragging and carrying effect of new material on previous material is used

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to clear out the previous material. The interaction between the new and the previous material is mainly shear stress on the interface of them, and the shear stress of previous material near the interface is the key of whole material change process. In fact, the interface is a very thin mixture layer of new and the previous material melt[2, 3]. Before the material changes, the whole hot runner is full of previous material melt. According to the rheological properties of plastic melt in isosectional pipe, the new material pushes central part of the previous material melt out of hot runner in the early stage, meanwhile the center of previous material is filled with new material. The previous material melt is gradually cleared out by the new material flowing at a speed of v as illustrated in Fig. 2. The process is similar to the drag flow as shown in Fig. 3. The only difference is that the diameter of the new material melt increases with the material change process proceeding, as shown in Fig. 4.

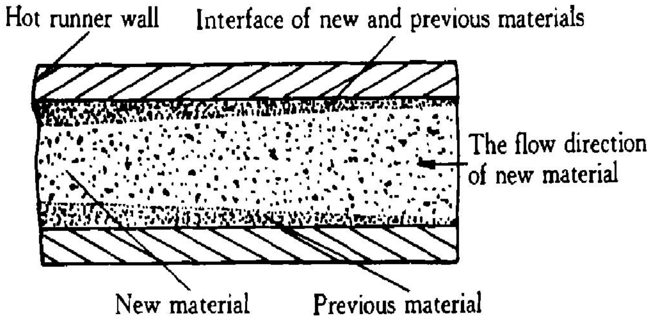

Fig. 2 Distribution of new and previous materials in section of hot runner

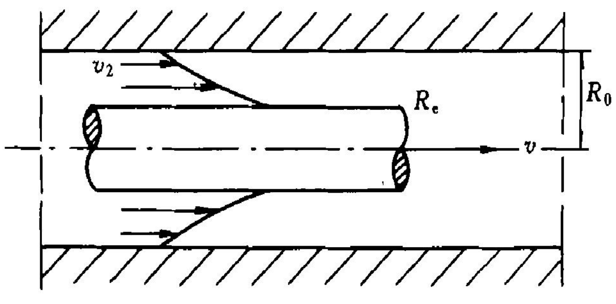

Fig. 3 Model of drag flow in annular channel

2.2 Mathematical model of drag material change process

The section of the hot runner is typically circular. When its center is filled with new material melt, the simultaneous flow of the new and the previous materials can be described as the model of drag flow in annular channel as Fig. 3. But the flow during drag may not be stable. The radius R_e of the new material in the center of hot runner gradually increases and the

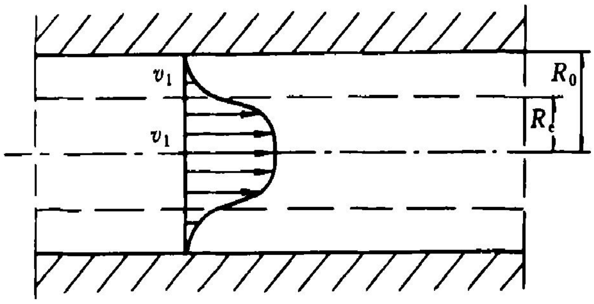

Fig. 4 Model of new and previous material in drag material change

thickness of the previous material becomes thin. The several parameters may vary dynamically as the material change proceeds. Their relation can be described by the average speed of new material in the center of the hot runner given by

$$v = \frac{Q}{\pi R_e^2} = \frac{n_1}{3n_1 + 1}\left[\frac{\Delta p}{2K_1 L}\right]^{\frac{1}{n_1}} R_e^{\frac{n_1+1}{n_1}} \quad (1)$$

where Q is the volume of injection machine, K_1 is the thickness of the new material melt, L is the length of the hot runner, Δp is the pressure drop between the two ends of the new material melt at the moment, n_1 is the non-Newtonian index of the new melt, and R_e is the average radius of the interface of the new and the previous material melt at this time.

At a moment, the previous material melt in annular channel dragged by the new material melt flows in axial (Z) direction at average speed v. At this moment, the momentum equation can be simplified as

$$\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rZ}) = 0 \quad (2)$$

Integrating Eqn. (2), we can get

$$\tau_{rZ} = \frac{C}{r} \quad (3)$$

The constitutive equation of material is based on power law model. At specific time the shear stress τ of the previous material melt at radius r can be given by

$$\tau = K_2\left[-\frac{dv_2}{dr}\right]^{n_2} \quad (4)$$

where K_2 is the thickness of the previous material melt, n_2 is the non-Newtonian index of the previous material melt, and v_2 is the velocity of the previous material at this point.

Supposing the previous material melt satisfies the following boundary conditions: 1) The velocity of the new and the previous material melt at the interface are equal, i. e., $r = R_e$, $v_2 = v$; 2) the velocity of the previous material melt on the inner wall of the hot runner is 0, i. e., $r = R_0$, $v_2 = 0$. Then from Eqns. (3), (4) and the boundary conditions, the velocity distribution of the previous material melt can be deduced as

$$v_2 = \frac{v}{k^q - 1}\left[\left(\frac{r}{R_0}\right)^q - 1\right] \quad (5)$$

where $q=\frac{n_2-1}{n_2}=1-\frac{1}{n_2}$, $k=\frac{R_e}{R_0}$, v is taken as the average speed of new material melt at the moment.

According to Eqns. (1), (3) and (5), it follows that the average speed v of the new material melt is in direct proportion to the injection volume Q and $\Delta p^{1/n}$, in inverse proportion to R_e^2, and that the shear stress τ of the previous material melt is in inverse proportion to radius r, and that the shear stress at the interface of the new and the previous material melt reaches the maximum, and the minimum on the hot runner wall, and that the velocity of the previous material melt is in direct proportion to the average speed v of the new material melt, which decreases with the increase of r. The interaction of various parameters in the material change process lowers the dragging ability of the new material melt to previous ones as the process proceeds. Namely, the volume of the previous material melt cleared out of the hot runner by new material melt per unit time decreases, especially, in the late stage of changing, indicating that the drag material change is becoming more and more difficult.

3 INFLUENCES OF FACTORS ON EFFICIENCY OF DRAG MATERIAL CHANGE

Based on the principle of extrusion at the early stage and drag flow at the later stage as stated above, it is found in the drag material change process that the new material melt does not simply push out the previous material melt. If the operation is improper, the previous material melt will not be cleared out fully even if large volume of new material melt have been injected into the hot runner, which wastes both new material and time, and can not get eligible products. In order to improve the dragging ability of the new melt, the parameters such as injection speed, injection pressure, viscosity difference, temperature and mold structure show the important effects on raising the dragging and carrying ability.

1) Properly increasing the injection speed v of the new material melt is beneficial to improving the efficiency of drag material change. According to Eqn. (5), the higher the injection speed v of the new material melt, the higher the speed of the previous material melt, and the more the volume of the previous material melt carried by the new material melt per unit time.

2) Properly increasing the injection pressure of the new material melt is helpful to improving the efficiency of drag material change. According to Eqns. (1), (3) and (5), the higher the injection pressure of the new material melt, the higher the average speed v of the new material melt, and the higher the flow speed and the shear stress of the previous material. In addition, the plastic materials flowing in hot runner are sensitive to the pressure, so increasing the injection pressure of the new material melt can get good effect. If the molding system is a pulse injection molding system[4,5], we can appropriately adjust the injection pressure to make the new material melt wave slightly, leading to engaging on the interface between the new and the previous material melt to a certain extent[6]. Therefore the extrusion function is added on the basis of shear stress, at the same time the contact area of interface and the effective area of shear stress are increased.

3) Properly controlling the viscosity of the new and the previous material melt can improve the dragging effect in the later stage of the process. It is easier to achieve quick material change with the new melt with higher viscosity carrying the previous material melt with lower viscosity. In contrast, the new material melt with lower viscosity will incline to squeeze out along the center of the previous material melt with higher viscosity, so that the previous material melt remainder near the inner wall of hot runner is difficult to be dragged out by insufficient shear stress. The viscosity difference between the new and the previous material melt must be controlled in a reasonable range, avoiding two extremes of viscosity. In production, because different kinds (even different grades) of polymers or different colored materials used in the single polymer possess correspondingly different viscosity, the attention must especially be paid to controlling viscosity difference between the new and the previous polymers[7]. Because temperature exerts striking influence on the viscosity of plastics, perfect viscosity difference can be obtained by respective temperature control for the different parts[8,9]. Decreasing the barrel temperature of the injection machine can increase the viscosity of the new material melt. The multi-point controlling temperature and district heating along the flow direction of hot runner mold can make the temperature of the previous material melt go up and its viscosity decrease[10]. The method is beneficial to creating the viscosity difference of the new and the previous material melt, to improving the fluidity of the melt, and to enhancing the ability of material change. But it should specially be noted that the plastic used in hot runner is not sensitive to temperature, the change rate of the viscosity with temperature is very small. Although increasing temperature is one of the ways to improve the effect of dragging, it is not necessary to pursue big difference of the melt viscosity too much. Too much high temperature may result in heat fatigue of hot runner parts and too low viscosity of both the new and previous material melt, even more it may cause the materials to be degraded. In addition, increasing the injection pressure of the new material can also increase its viscosi-

ty.

4) Properly planning production process is beneficial to improving the efficiency of drag material change. The plastic parts with lower viscosity and smaller injection volume should be generally given priority to production. That means the new material volume used to clear the previous material will be smaller. The previous material melt with lower viscosity can be dragged out easily by the new material melt with higher viscosity. Because fiber enhanced polymer plastic has higher viscosity and better ability of material change than single polymer plastics, the single polymer plastic should first be used in production.

5) The structure design of the hot runner mold will also influence the efficiency of drag material change. The hot runner should be designed in the style of through-pipe and external-heating hot runner mold. If heaters are installed in the inner of runner, they will block the flow of plastic melt, and cause easily the melt circumfluence area which is not beneficial to drag material change. The sudden change of flow direction should be avoided as far as possible. It is better to use streamlined runner such as cone-shaped or cuneal transition, to make the flow of plastic melt easy and smooth, and "dead area" of flow to be prevented. The dimension of hot runner should be as small as possible. The smaller the volume of hot runner, the smaller the volume of previous material, the less the times of changing. The shorter the runner, the less pressure drop in it, and the shorter flow route of previous material. It is certain that the dimension of section should not be too small, otherwise it will result in considerable pressure drop blocking the flow of plastic melt. In addition, in the case of failing to achieve drag material change, it must ensure that operator can reach the region of solidified previous material to clear out them manually[11~13]. The control system of temperature should be adjusted conveniently and accurately to control the internal temperature of hot runner, forming the viscosity difference between the new and the previous material melt. District heating and multi-point controlling systems of temperature are preferable.

In production, we should synthetically consider all factors and coordinately use the above measures to achieve drag material change successfully to guarantee the quality of products and gain economic benefits.

4 CONCLUSIONS

The mathematical model of drag material change process in this study can well explain the simultaneous flow behavior of the new and the previous material melt in hot runner. The viscosity difference between the new and the previous material melt can be achieved by using district heating and multi-point temperature controlling system. The ability of the material change in the later stage of the process is improved, so the ability of material change in the whole process is enhanced. The design rules of hot runner injection mold are put forward. The further research on the quantitative description of process of the whole drag material change will be of significance to understand the plastic change behavior in hot runner in detail.

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