An Analysis of the Formation of Sink Marks in Large Thin-wall Injection Molds

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Abstract

In view of some large thin-wall injection molding parts easy to form internal and external defects such as sink marks, based on the case study of air-conditioning framework, this thesis has analyzed the sink mark formation and evolution mechanism in the mold cavity and has explored the impact rule of variation of heat interchange and the pressure value in vertical mold cavity on sink marks' formation and validates that the greater the pressure difference on both sides of the vertical cavity is, the deeper the sink mark is. and that has provided a guidance on the sink mark defect prevention for injection molding industry.

Keywords

Large Thin-Wall Injection Parts; Sink Mark; Evolution Mechanism; Variation of Heat Interchange.

1. Introduction

To a large extent, the imbalance flow of the melting plastic in the mould can affect the surface quality of plastic parts. The size of the defects is mainly determined by the offset level of the front melting plastic flow. The irregular cooling crystallization of plastic melt in the mould cavity can also lead to the generation of sink marks and other defects.Many scholars at home and abroad have made researches on plastic melt flow in the mold cavity. Yashiro [1] has taken all resin and fiber as a group particle and predicted the interaction between molding fiber and resin during injection with the orientation tensor as a basis. Dray [2] comparing several thermal elastic plastic fiber orientation in the flow, summarizes the features of the flow of plastic fibres. Soukane [3] makes his study on resin flow characteristics to predict deformation characteristics of injection molded parts. Gruber [4] has acquired a new surface quality prediction model which can be applied to samples of machine vision systems to predict the size of the surface shrink marks depression. On researches of Process parameters optimization model, Yin [5] conducts his study by a BP neural network, which can create the relationship among parameters of mold temperature, melt temperature, holding pressure, holding time, and the cycle time and the variables of warpage of plastic parts of the car. Huang [6] created a degradation model in parameters optimization in injection molding process. Thus, on the basis of the above study, this study analyzes the formation of sink marks in rheological characteristics, and forms the theoretical model of sink marks in the mould cavity, and exposes the mechanism of formation of sink marks.

2. Case Study

The air conditioning box cover is made up of thin-walled injection pieces with network grid of box shape. Through three dimensional laser scanner measurement, the air conditioning box cover can be measured as 854.3mmx268.2mmx195.2mm, the minimum thickness of plastic pieces as 3.5mm, and the maximum thickness of plastic pieces as about 13.2mm. Due to the complex structure of air conditioning box cover, sink marks can easily appear in handover regions of thick walls and thin walls, the window bar, the surface angles, the reinforced connection and the inside and outside surface. it can be concluded that sink marks are generally clear when the depth is greater than 0.05mm. In the selection of forming materials, according to the performance requirement of the HVAC box cover, the choice of materials should be (impact polystyrene) Polyrex PH-60 HIPS.

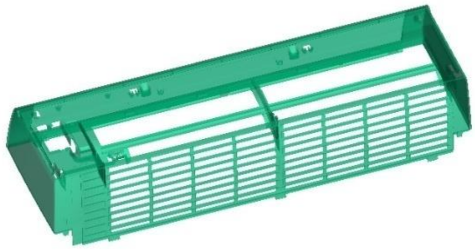

Fig.1 Air-conditioning Plane Frame

3. The Formation Process of Sink Marks of Defects within the Mould Cavity

According to the flow status within plastic melt body in mold type cavity, the plastic melt body has occurred volume contraction in the after cooling curing of process due to the thermal expansion and contraction characteristics. In the end of filling, the melt body surface has solidified after cooling, while the melt body in core layer has just been cooled. If it cannot get enough melt material compensation of holding pressure, the cooling contraction in core layer melt body will pull the surface of melt material, which will make the melt surface layer downward and form shrink marks. In the injection molding process, due to improper setting of process parameters, it is difficult for the surface of injection molded parts to balance the pulling of the core, then resulting in the defects of the surface of the products and other problems. Other factors, like the change of plastics melt temperature, changes of the molecular structure of plastics and the plastic melt molecular orientation and stress can also, to a certain extent, affect the formation sink marks.

4. Modeling Analysis of the Formation Process of Sink Marks

4.1 Modeling of Melt Flow Equations in a Mold Cavity

The conditioning frame of molding process is considered to be a non-isothermal, unsteady and viscoelastic properties of complex processes. In the melt flow in the injection molding process, this thesis applies the infinitesimal method and takes part of the fluid as a reference object and takes a fluid as a particle in plastic melt flow direction, then to set x, y, z three directions, as is shown in Figure 2.

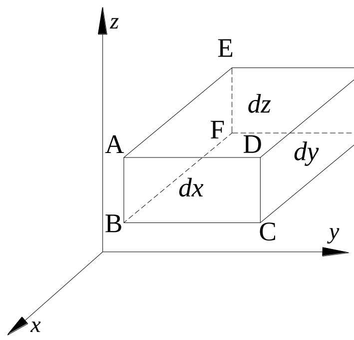

Fig.2 The Flow Rate of the Fluid Particle Group Decomposition

In the same unit of time, the plastic flow in surface EFGH to be $\rho udydz$, thus the plastic flow in the surface ABCD to be $\left[\rho u+\frac{\partial(\rho u)}{\partial x}dx\right]dydz$ in circulation, the other three on surface flow process of plastic melt is similar, so an available equation can be obtained in plastic melt flow in a threedimensional Cartesian coordinate system, and the equation is:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \tag{1}$$

Plastic melt in injection flow processes must comply with conservation of momentum equation, the momentum change in the flow rate formula (2), (3).

$$\frac{\partial P}{\partial x}-\frac{\partial}{\partial z}\left(\eta \frac{\partial u}{\partial z}\right)=0 \tag{2}$$

$$\frac{\partial P}{\partial y}-\frac{\partial}{\partial z}\left(\eta \frac{\partial v}{\partial z}\right)=0 \tag{3}$$

The equation of melt flow in the process of the energy is:

$$\rho C_P\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\beta T\frac{\partial P}{\partial t}+k\frac{\partial^2 T}{\partial z^2}+\eta\dot{\gamma}^2 \tag{4}$$

In the above equation, x, and y is in the coordinates for surface, z is direction coordinates for thick-wall; u, and v, and w respectively representing the component of direction speed of x, y, and z, while η for shear stick degrees, and k, CP, and $\dot{\gamma}$ respectively for density, hot conduction rate, specific heat and shear rate air of the selected plastic melt body (HIPS) of air-conditioning box cover; p for plastic melt body pressure, t for plastic melt temperature degrees, t for plastic melt body of flow time. Thus the plastic melt shear rates can be further expressed as in equation (5).

$$\dot{\gamma}=\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2\right]^{\frac{1}{2}} \tag{5}$$

4.2 Modeling in the Formation of Sink Marks in the Air-conditioning Box Cover

Due to the different temperature of he filling melts and the air conditioning frame cavity wall, heat exchange produces and which will result in heat interchange between plastics melt at different temperatures, and then to form sink marks. This research assumes the thickness of cavity wall of the air-conditioning box to be b, Tb for cavity wall temperature. Similarly, the research assumes that melt in the cavity flow to be neutral plane-symmetric, and assumes the plastic melt temperature and Velocity distributing along the neutral plane to be symmetry.

Air-conditioning on the frame cavity wall Z= ±h/2, satisfies the boundary conditions:

$$u=v=w=0T=T_m \tag{6}$$

In the air box cover on the Center Z=0, satisfies the boundary conditions:

$$\frac{\partial u}{\partial z}=\frac{\partial v}{\partial z}=\frac{\partial w}{\partial z}=0,\ \frac{\partial T}{\partial z}=0 \tag{7}$$

In the equation, h/2 stands for the half thickness of air-conditioning frame mould, T_b for the wall temperature of air-conditioning frame mould .

Assuming that the plastic melt flow through air conditioning frame gate border C_j was the injection flow, and meanwhile the pressure on the inlet was equally distributed, then there are:

$$Q(t_1)=\int_{C_j}\left(-q\frac{\partial P}{\partial n}\right)dl \tag{8}$$

In the equation, the Q(t1) stands for the melt flow of t1, q for the melt flow rate in the air-conditioning box cover, h for the thickness of the wall of injection mold cavity, l for the melt length and n for the normal vector.

Melt flow in the air box cover of the momentum equation (2), (3) double integral in the thickness direction and using no-slip boundary condition can derive:

$$u=-\frac{\partial P}{\partial x}\int_z^{h/2}\frac{z}{\eta}dz \tag{9}$$

$$v = -\frac{\partial P}{\partial y}\int_{z}^{h/2}\frac{z}{\eta}dz \tag{10}$$

If put (9), (10) into equation (5) , it can be gained that:

$$\dot{\gamma} = \frac{z}{\eta}\left[\left(\frac{\partial P}{\partial x}\right)^2 + \left(\frac{\partial P}{\partial y}\right)^2\right]^{\frac{1}{2}} \tag{11}$$

The average velocity of plastic melt in the air box cover in the mold cavity can be obtained from equation (9), (10) :

$$\bar{u} = \frac{-\left(\partial P/\partial x\right)}{h}\times 2q \tag{12}$$

$$\bar{v} = \frac{-\left(\partial P/\partial y\right)}{h}\times 2q \tag{13}$$

In the above formula, q stands for the plastic melt flow rate in air conditioning frame cover, and it can be expressed as in equation (14).

$$q = \int_{0}^{h/2}\rho\varphi dz\ ,\ \varphi = \int_{0}^{h/2}\frac{z}{\eta}dz \tag{14}$$

Now put (12), (13) into equation (1) of plastic melt flow continuity and simplify it as:

$$\frac{\partial P}{\partial t}\int_{0}^{h/2}\frac{\partial \rho}{\partial P}dz - \frac{\partial}{\partial x}\left(q\frac{\partial P}{\partial x}\right) - \frac{\partial}{\partial y}\left(q\frac{\partial P}{\partial y}\right) = -\int_{0}^{h/2}\frac{\partial \rho}{\partial T}dz \tag{15}$$

A summary could be made. As for such complex thin-walled box shaped injection pieces with many network grid window bars, like the air conditioning box cover, pressure border conditions can consider the plastic melt body in poured mouth location to be the given injection pressure $P_E(t)$, the frontier pressure for melt body flow to be zero, and the pressure of air conditioning box cover on wall also meet the conditions of no penetration border. Thus, on formula (15) points and by using air conditioning box cover plastic melt body flow border conditions, we can get the pressure field control equation, which can be simplified as:

$$\frac{\partial}{\partial x}\left(q\frac{\partial P}{\partial x}\right) + \frac{\partial}{\partial y}\left(q\frac{\partial P}{\partial y}\right) = 0 \tag{16}$$

Since sink marks defect are mostly formed by the inner core of plastic melt's pulling the surface of plastic melt and meanwhile the pressure compensation is inadequate, so melts on sink marks defect of normal velocity and pressure should be continuous, i.e. that should met:

$$P^{+} = P^{-} \tag{17}$$

$$\left(q\frac{\partial P}{\partial n}\right)^{+} = -\left(q\frac{\partial P}{\partial n}\right)^{-} \tag{18}$$

P^{+} and P^{-} respectively stands for the pressure value in vertical direction of the mold cavity. $\left(q\frac{\partial P}{\partial n}\right)^{-}$, $\left(q\frac{\partial P}{\partial n}\right)^{+}$ stand respectively for the pressure values on either side of sink marks. The greater pressure difference on both sides is, the deeper the sink marks will be deeper.

5. Conclusion

(1) By taking the inside and outside surface shrink marks defects of the air-conditioning box cover as a case study, the primarily shaped internal and external surfaces of plastic parts measured, the location and size of the sink marks of air-conditioning frame obtained, the formation and evolution mechanism

of sink marks in the mold cavity analyzed in-depth, this thesis concludes the general rule of sink marks' forming.

(2) By building the theoretical model on the formation of sink marks in the mold cavity, this thesis obtains the impact rule of variation of heat interchange and the pressure value in vertical mold cavity on sink marks' formation and validates that the greater the pressure difference on both sides of the vertical cavity is, the deeper the sink mark is.

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