Research on Optimal Parameters for Injection Moulding of Air-conditioner Mask based on Response Surface Model

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Abstract

In order to solve the problem of formation of sink marks on the surface of air-conditionermask during moulding, a 3D (three-dimensional) model, as well as gating and cooling systems, was established on the basis of air-conditioner mask's 3D structure, and an initial analysis on melt filling was made. The research shows that the main moulding parameters have remarkable effect on the formation of sink marks on the surface of mask. Therefore, a response surface model is set up on the basis of melt and mold temperature, dwell pressure and injecting time, besides which a optimal function is set up aimed at obtaining minimum sink mark index. The result is that the minimum sink mark index value and optimal moulding parameter combination are obtained, this research will provide a new way for a design of moulding thin-wall and complicated air-conditioner mask at low cost and with high quality.

Keywords

Air-conditioner mask; Sink mark index; Response surface model; Optimal function.

1. Introduction

In order to solve the problem of formation of sink marks on the surface of air-conditionermask, certain research and analysis have been done and described in this paper. First of all, on the basis of air-conditioner mask's 3D (three-dimensional) structure, a 3D model was established, as well as gating and cooling systems, and an initial analysis on melt filling was made. It is discovered that the quality of the product surface is related greatly to moulding techniques, mold structure and properties of the material. Obviously, sink marks generally appear on the inside and outside surfaces. The main cause is the flowing way of plastic melt. In the moulding process, the mask is not filled fully in the areas of thick and prominent places and reinforcing ribs during cooling, and sink marks appear easily. Domestic and overseas researchers have done much to improve surface quality.Yong and others discovered that during moulding the excessive superficial residual heat stress can cause sink mark [1]. FAN [2] and others verified, from their simulations and experiments on moulding disk with PS material, that residual heat stress has remarkable effect on surface quality. Gruber [3] and others made a model for calculating surface quality. They can also predict sink marks of the product through machine vision system. On the basis of all these researches, this paper has established a response surface model based on injection moulding parameters and surface sink mark index of air-conditioner mask, and also established optimal function aimed at the minimum sink mark index. Through tests, the best parameter combination for high quality air-conditioner mask moulding was obtained.

2. The Product's structure and surface sink mark

Air-conditioner mask is a thin-wall product with grid molded in injection moulding. Laser scanning obtains the mask's dimensions of 854.3mm×268.2mm×195.2mm; the thinnest part of the wall is

3.5mm and the thickest is 13.2mm. Out of the complicated structure of the mask, the areas where sink marks easily appear are those connecting thin and thick walls, rib connections, corners, grid, inside and outside surfaces. See Figure 1.

(a) Outside surface sink marks (b) Inside surface sink marks

Fig 1. Sink marks on the surface of air-conditioner

3. The design of analogue simulation system for air-conditioner mask

Since there are many heaves and reinforcing ribs on the surface and there is grid on the front part of the mask, impact-resistant material of polystyrene (HIPS) is selected, and the runner system is designed to be open and heated to ensure filling evenly to every part of the mold with low residual heat stress on the product after demoulding, so as to have fewer sink marks. To have even flow for melt, 6 hot mouths are established, with a diameter of 3.5mm for each one, In moulding process, cooling time takes up 70-80% of the moulding time, and cooling speed and evenness affect the product quality. Therefore, the number, location and geometric patterns of cooling runners will affect the evenness of melt flow in the mold. So cooling runner is designed to be like a door frame; cooling medium is water; cooling runner's diameter is 10mm. See Figure 2.

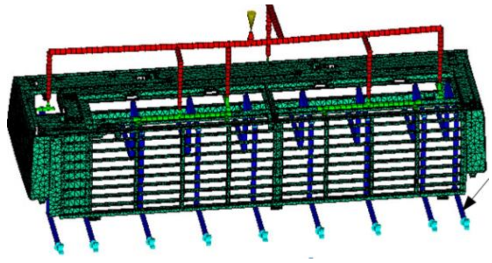
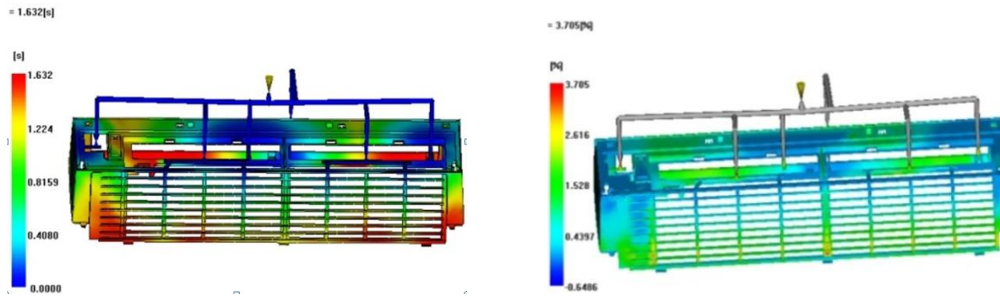


Fig 2. The cooling system of air-conditioner mask

4. The effect of injection moulding parameters on formation of sink mark on product surface

4.1 The initial analysis on filling

Analysis on fast filling can be started once filling and cooling systems and the material are prepared and then the recommended injection moulding parameters, such as melt and mold temperature, filling time and dwell pressure, are obtained. In the process of filling analysis, it is possible to predict the product's defects, therefore to prevent uneven flowing and short shot. From the following Figure 3(a) it is seen that the melt basically reaches all the ends of the mold at the same time and the filling is finished in 1.632s without short shot. Sink mark index is the ratio of sink mark depth to the wall thickness in the relative location, which can be used to judge the possibility of sink mark occurrence to a product. Figure 3(b) shows that this product's biggest sink mark index is 3.705%; its depth is about 0.13mm, clearly seen. Therefore there is need to optimize the moulding parameters.



(a) Filling time for moulding air-conditioner mask (b)Sink mark index of air-conditioner mask

Figure 3 Filling time and sink mark index of air-conditioner mark

4.2 Analysis of effective factors on injection moulding

During injection moulding process, main parameters that may cause sink mark include melt and mold temperature, dwell pressure, filling and dwell time. The effect of parameters on sink mark index is discussed and the data range is decided by moulding process and material quality. Analysis showed indicates that when melt temperature varies from 176℃ to 260℃,sink mark index decreases first and then increases; it reaches the minimum value at about 180℃~200℃. Figure 6 shows that excessive or lower temperature of the mold can both affect the product’s surface smoothness. It is seen from the figure that the sink mark index changes slightly within the range of 21℃~36℃.During dwell process, filling is continued to replenish the mold. Figure 7 presents that when relative dwell pressure remains in the range of 70%--90%, sink mark index decreases first and then increases; at about 85%, the index reaches the minimum value. Figure 8 indicates that when filling time ranges from 1s to 2.6s, sink mark index decreases first and then increases; at about 2.2s, the index reaches the minimum value. Figure 9 shows that when dwell time is from 2s to 6s, the index increases slightly; when dwell time is from 6s to 10s, the index decreases fast; when dwell time is from 10s to 20s, the index keeps at 3.705. This means that at 10s of dwell time, the gate has already clotted, so in optimal parameters for moulding, dwell time is set at 10s.

5. Parameter optimization and experiment on injection moulding

In general cases, for different structures of the products, the relationship between moulding parameters and formation of sink marks is different. So the response surface mold is set up at the aim of obtaining the minimum sink mark index. This model can reduce the number of experiments, and acquire the optimal response value. The response surface model of second order regression mode is represented by Equation (1).

$$y=\beta_0+\sum_{j=1}^{k}\beta_j x_j+\sum_{j=1}^{k}\beta_{jj}x_j^2+\sum_{i=1}^{k-1}\sum_{j=i+1}^{k}\beta_{ij}x_i x_j+\varepsilon \tag{1}$$

5.1 The design of regression orthogonal combination for main moulding parameters

The experiment based on multiple regression orthogonal combination is to actively collect data on the basis of linear regression, and obtain more accurate regression equation. The four main parameters in moulding air-conditioner mask are taken as the second order orthogonal experiment elements. In the analysis of moulding parameters, the four factors of melt temperature, dwell pressure, mold temperature and filling time are controlled parameters in the moulding process. Therefore, quaternary quadratic regression orthogonal combination is used to design the four parameters, in which P1is dwell pressure (The relative dwell pressure is the ratio of dwell pressure to the maximum filling pressure.); T1 is melt temperature; T2 is mold temperature; t1 is filling time. There are four elements, so the quaternary quadratic regression orthogonal combination for air-conditioner mask is composed of 25 test points.

According to the effect of selected material for air-conditioner mask, production efficiency, filling time and data range of single element on the formation of sink mark, and considering the system recommended value from moldflow and practical experience, the four parameters in this quaternary quadratic combination are set up as: dwell pressure P1: 70%--90%; melt temperature T1: 176%--260%; filling time t1: 1--2.6s; mold temperature T2: 21--48℃; γ(from the Table) =1.414; change interval between various parameters is $(x_{max}-x_{min})/\gamma$, that is the ratio of the bound difference value of various parameters to γ. In regression equation response surface model, x_1, x_2, x_3, x_4 represent respectively dwell pressure P1, melt temperature T1, mold temperature T2, and filling time t1. The specific design is represented in Table 1.

Table 1 The coded value at various elements' level

x_j	x_1	x_2	x_3	x_4
$+\gamma$	90	260	48	2.6
+1	87	248	44	2
0	80	218	35	1.8
-1	73	188	25	1.2
$-\gamma$	70	176	21	1

Based on the data obtained fromquaternary quadratic regression combination (not listed here because of the paper length) and the structure matrix and computation sheet from regression orthogonal combination, the quaternary quadratic polynomial regression equation can be established, and represented in Equation (2).

$$\begin{aligned} y &= 3.91724 - 0.149245x_1 + 1.465306x_2 + 0.065817x_3 - 0.07921x_4 + 0.067813x_1x_2 \\ &-0.04844x_1x_3 + 020187x_1x_4 + 0.1455625x_2x_3 + 0.016688x_2x_4 - 0.03506x_3x_4 \\ &+0.040971x_1^{'} + 0.152478x_2^{'} + 0.076723x_3^{'} - 0.01328x_4^{'} \end{aligned} \tag{2}$$

$$\text{s.t. } 70 \le P_1 \le 90 \quad 176 \le T_1 \le 260 \quad 21 \le T_2 \le 48 \quad 1 \le t_1 \le 2.6 \tag{3}$$

According to one-parameter value in mask moulding, or according to the constraint condition of parameters of melt temperature T1, dwell temperature P1, filling time t1 and mold temperature T2, meanwhile according to the optimal model programmed with fminsearch in Matlab in Equation (2), (3), the minimum value of sink mark index F (P1,T1, T2, t1) $_{\text{Min}}$ can be obtained, which is 1.352305.

6. Conclusion

(1) With the established 3D model for air-conditioner mask moulding aimed at solving its sink mark defects, the effect of main moulding parameters on sink mark index is studied based on numerical simulation, with the result of sink mark index decreasing first and then increasing in the melt temperature range of 176℃ to 260℃. Therefore the best mold temperature should be lower than 36℃ and the shortest dwell time should be 10s based on analysis.

(2) With the response surface model based on the four parameters of mold and melt temperature, dwell pressure and filling time and on sink mark index, and with the optimal function aimed at the minimum sink mark index, the best moulding parameters and the minimum sink mark index are obtained.

(3) After experimental verification, the expected goals of the minimum sink mark on the product surface can be achieved with this parameter combination and the moulding requirements in production can be satisfied. This research will provide a new way for a design of moulding thin-wall and complicated air-conditioner mask at low cost and with high quality.

References

[1] LEE Y B , KWON T H , YOON K. Numerical prediction of residual stresses and birefringence in injection/compression molded center-gated disk. Part II: Elfects of processing conditions [J] . Polymer Engineering and Science, 2002, 42(11): 2273-2292.

[2] FAN B, KAZMER D, BUSHKO C.A biref ringence prediction of optical media [J]. Polymer Engineering and Science, 2004, 44(4): 814-824.

[3] Gruber D P, Macher J, Haba D, et al. Measurement of the visual perceptibility of sink marks on injection molding parts by a new fast processing model[J]. Polymer Testing, 2014, 33: 7-12.