Simulation Analysis to Optimize the Parameters of Injection Molding Process to Improve the Residual Stress of Sprinkler Body

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Abstract. Aiming at the residual stress of sprinkler body, simulation analysis of injection molding was carried out by using Moldex3D software. The process parameters in the molding process are taken as the control variables, and the 5 factors and 4 levels of process parameters are matched based on the orthogonal experimental method. The simulation data are processed, and the influence data of each factor on the residual stress are plotted. According to the influence of each factor on the residual stress, two times optimization, and finally get the best combination of process parameters. The calculated results show that the average flow residual stress is 0.141MPa, the average thermal residual stress is 0.276MPa. In actual production, the products formed by the combination of the process parameters have good quality after electroplating, which shows the practicability of the simulation analysis.

Introduction

The residual stress inevitably appears in the injection molding products[1], too large residual stress will not only affect the quality of the product, shorten the service life of the product, but also affect its subsequent processes, such as electroplating, spraying and so on. In the traditional product development process, it is sometimes difficult to consider and avoid the residual stress problem by experience, and the repeated verification and repair process also make the product development cycle longer and lower efficiency.

In recent years, due to the continuous development of computer aided engineering analysis technology, more and more cases also verify the correctness of the injection molding simulation analysis and the effectiveness of solving the problem[2-6]. Therefore, this paper carries on the simulation analysis to the residual stress of the sprinkler body in the production process. Orthogonal experimental method was used to select the technological conditions which had obvious influence on the residual stress of injection molding products, the orthogonal experimental matrix was constructed, and the process combination was simulated and analyzed. The injection molding process simulation and process optimization were carried out by using the flow analysis software Moldex3D, and the optimal process parameters combination was obtained.

Modeling

The sprinkler body model is shown in Figure 1.it’s size is 247 mm long, 46 mm wide and 101 mm high. It’s material grade is ABS727. It’s average thickness is 2.637mm. The entry way is head column, horn gate. one mold with two cavities.
The 3D mesh is chosen as the entity grid, and the grid with enough layers in the thickness direction is guaranteed by using BLM technology. The mesh is shown in Figure 2, and the number of meshes is 604264.

**Optimization**

Taking the residual stress of plastic parts as the goal, 5 parameters, such as filling speed, filling pressure, packing time, packing pressure and melt temperature, are selected as the factors, and 4 levels are set respectively. The factors and levels are shown in table 1. The orthogonal experimental matrix L16 is constructed, and the process combination is simulated. The L16 orthogonal test matrix is shown in table 2. In the other process parameters, the cooling time is set to 40s, the water temperature is set at the surface and handle core pulling is 70 degrees, and the head core pulling is 55 degrees. The calculation mode is the injection molding machine mode, and the injection machine adopts Haitian 250T.

| Process parameters | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|--------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
| A                  | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 3  | 4  | 4  | 4  | 4  | 4  | 4  |
| B                  | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2  | 3  | 4  | 1  | 2  | 3  | 4  |
| C                  | 1 | 2 | 3 | 4 | 2 | 1 | 4 | 3 | 3 | 1  | 4  | 2  | 4  | 3  | 2  | 1  |
| D                  | 1 | 2 | 3 | 4 | 3 | 4 | 1 | 2 | 4 | 3  | 2  | 1  | 2  | 1  | 4  | 3  |
| E                  | 1 | 2 | 3 | 4 | 4 | 3 | 2 | 1 | 2 | 1  | 4  | 3  | 3  | 4  | 1  | 2  |

Table 2. Orthogonal experimental matrix.
The flow pattern analysis was carried out by using Moldex3D software, the average value of flow residual stress and thermal residual stress were selected. The results are shown in figure 3 and table 3.

![Flow residual stress](image1.png)  
![Thermal residual stress](image2.png)  

**Figure 3. Residual stress diagram.**

**Table 3. The analysis results of residual stress.**

| Number | Average value of flow residual stress [Mpa] | Average value of thermal residual stress [Mpa] |
|--------|-------------------------------------------|-----------------------------------------------|
| 1      | 0.150                                     | 0.295                                         |
| 2      | 0.158                                     | 0.313                                         |
| 3      | 0.169                                     | 0.335                                         |
| 4      | 0.185                                     | 0.365                                         |
| 5      | 0.168                                     | 0.340                                         |
| 6      | 0.148                                     | 0.372                                         |
| 7      | 0.188                                     | 0.320                                         |
| 8      | 0.215                                     | 0.339                                         |
| 9      | 0.182                                     | 0.350                                         |
| 10     | 0.198                                     | 0.337                                         |
| 11     | 0.191                                     | 0.342                                         |
| 12     | 0.231                                     | 0.353                                         |
| 13     | 0.202                                     | 0.340                                         |
| 14     | 0.207                                     | 0.341                                         |
| 15     | 0.225                                     | 0.362                                         |
| 16     | 0.256                                     | 0.378                                         |

By calculating the results, we draw the trend line chart of each factor, as shown in figure 4. It can be seen from the trend diagram that the melt temperature and filling speed have a great influence on the residual stress. Increasing the melt temperature and filling speed can effectively reduce the value of flow residual stress, while the other three parameters do not have much influence on the flow residual stress. For the thermal residual stress, increasing the melt temperature and injection speed, increasing the packing pressure and packing time can effectively reduce the value of the results, the filling pressure decreased first and then increased, and the lowest value was about 95Mpa. From the trend chart, the influence of the parameters on the residual stress is as follows: melt temperature > filling speed > packing time > packing pressure > filling pressure. The three parameters of melt temperature, filling speed and packing time have significant influence.
Two Times Optimization

The results of above data analysis show that the three parameters of melt temperature, filling speed and packing time have significant influence on the residual stress. According to the results of the first optimization, two optimizations are carried out on the basis of the optimization results. The packing pressure is 80Mpa, and the filling pressure is 95Mpa. Melt temperature, filling velocity and pressure are selected from three levels at 235 C, 50mm/s and 11S respectively near, as shown in 4. The orthogonal experimental matrix L9 is constructed and numerically simulated. The calculation results of residual stress of plastic parts are shown in table 5.

Table 4. Factors and levels.

| Levels | Melt temperature (°C) | Filling speed (mm/s) | Packing time (s) |
|--------|-----------------------|---------------------|-----------------|
| 1      | 233                   | 48                  | 11              |
| 2      | 235                   | 50                  | 12              |
| 3      | 237                   | 52                  | 13              |

Table 5. The analysis results of residual stress.

| Number | Average value of flow residual stress [Mpa] | Average value of thermal residual stress [Mpa] |
|--------|--------------------------------------------|----------------------------------------------|
| 1      | 0.161                                      | 0.299                                        |
| 2      | 0.156                                      | 0.290                                        |
| 3      | 0.155                                      | 0.283                                        |
| 4      | 0.152                                      | 0.288                                        |
| 5      | 0.152                                      | 0.281                                        |
| 6      | 0.145                                      | 0.292                                        |
| 7      | 0.148                                      | 0.279                                        |
| 8      | 0.139                                      | 0.291                                        |
| 9      | 0.139                                      | 0.282                                        |

The calculation results of table 5 are processed and the trend line chart is drawn, as shown in figure 4. According to the trend line diagram, it can be seen that increasing the melt temperature and filling speed can effectively reduce the value of residual stress, while increasing the packing time can increase the value of residual stress on the one hand, but also reduce the value of thermal residual stress. Therefore, it can be concluded that the combination of A3B3D3 process is the optimal combination in table 5. Because the combination does not appear in the L9 orthogonal test matrix, the combination is simulated and analyzed. The average value of residual stress of flow is 0.141Mpa, and the average value of thermal residual stress is 0.276Mpa, which is lower than all stress values in the above table.
Validation

In order to verify the rationality of the analysis process and the accuracy of the results, the residual stress of the sprinkler body was quantitatively detected. The injection machine is Haitian 250W2/J1, and the screw diameter is 50mm. The optimized process combination was used for injection molding, and the acetic acid stress test and the plating adhesion force test were carried out. The test results were qualified, Samples after electroplating were shown in figure 5.

Conclusion

(1) in the process parameters, the melt temperature, filling speed and packing time have great influence on the residual stress.
(2) the optimum process parameters obtained by orthogonal experiment have the lowest average value of residual stress.
(3) in the actual production, the above analysis can provide certain basis for the process parameter setting, save time and cost.

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