Manufacturing Process of Packaging Products by Orthogonal Test

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Abstract. For most plastic packaging products, injection molding is the most convenient, simple, widely applicable, especially for those thin, complex structure, smooth surface, and small moulds. Overdependence on experience, it is difficult to quickly design excellent products with short production cycle. In this paper, a common thin CD packaging mould was taken as a research object. By orthogonal experiment method and MPI software obtain the amount of warping deformation and a better group of process parameters. Within the range of orthogonal test, we explore the influence of various process parameters on warpage of injection. Besides, according to variance analysis that it is different from visual analysis to explore the main factors significantly, so that we obtain the most reliable and the best group of process parameters.

Introduction

Now, in the field of packaging materials, plastic packaging products occupy a large proportion. For most plastic packaging products, injection molding is the most convenient, simple, widely applicable, especially for those thin, complex structure, smooth surface, and small moulds. According to statistics, 90 percent of the total of plastic mold are used for injection molding [1]. To obtain the optimal process parameters, technical staff with experience or expertise continue to trial-and-error method, however, which is not only time-consuming but also high cost. Overdependence on experience, it is difficult to quickly design excellent products with short production cycle.

As a novel tool, the orthogonal test can take fewer number of repeatable trials and gain all the factors by analyzing the result of some experimental dates to achieve the best group of process parameters [2]. Therefore, most researchers had done some research on the field of the best group of process parameters, the lower defects of injection molding and the better quality of molding that is simulated under various technological conditions by using analysis software of Moldflow and orthogonal experiment method, yet, most of them taken visual analysis as analysis methods to discuss the result of experiment.

Because of easily understands to be used, the visual analysis occupies a large proportion. But it can’t be distinguished from the change of date that caused by the experimental addition or the experimental error in the experiment, and it cannot be accurately estimated from the size of the influence of various factors on the results of the experiment. This study combined the orthogonal experiment and simulation method both for injection molding to explore the best group of process parameters and proves that it was reliable for the orthogonal experiment to obtain a better group of process parameters. To make up for the defects of visual analysis, we adopted variance analysis that it is different from visual analysis to explore the main factors significantly to obtain the most reliable and the best group of process parameters, which will provide a strong theoretical basis for the actual production of packaging products.
Pretreatment of the Packaging Mould

In this paper, a common thin-wall CD packaging mould was taken as research object, its size is 145mm x 7mm x 125mm, its thickness is relatively uniformity, about 2.5mm, the thinnest place of the mould is 1mm, we adopted the material of polystyrene to fill in the mould. The mould was meshed by the software of Moldflow (Fig. 1), its each ratio was up to 92.8%. Runner system and cooling system were established by MPI software (Fig. 2) [3, 4].

Method Statements for the Mould by Orthogonal Experiment

Warpage can be defined as a dimensional distortion in a molded product after it is ejected from the mold at the end of the injection molding process, and it is almost impossible to completely eliminate the common deficiencies of injection molding, such as warping deformation, shrinkage, flash, weld mark and size change etc.[5]. Thus, in this paper, the maximum deformation of warpage was taken as the test object, we would obtain the most reliable and the best group of process parameters.

Process Parameters of the Orthogonal Experiment. Based on the result of the currently research [5, 6], we drew a conclusion that there were followed mainly factors to result in the kinds of flaws in the process parameters of injection molding: Melt Temperature A, Mold Temperature B, Fill Time C, Part 1: Holding Pressure Process (Percentage filling pressure and packing time) D, Part 2: Holding Pressure Process (Percentage filling pressure and packing time) E, Part 3: Holding Pressure Process (The holding pressure decrease to 0 MPa) F, Cooling Time G. However, the holding pressure process D, E and F decide the curve of holding pressure in molding production process, So the pressure curve is set reasonability or not, which will affect product quality indexes of the thin-wall mould, such as warpage, residual stress, etc. Value ranges of various factors and levels were determined by the preliminary analysis of data and predecessors' research results [7-8], then the best compound condition was designed by seven factors and three levels orthogonal experiment, which was given Tab.1.

| Levels | Factors |
|--------|---------|
| A[℃]   | B[℃]   | C[s] | D[%-s] | E[%-s] | F[%-s] | G[s] |
| 1      | 205    | 35   | 0.6   | 75 0  | 65 10 | 0 1  | 15   |
| 2      | 230    | 50   | 1.0   | 80 0  | 70 10 | 0 2  | 20   |
| 3      | 255    | 65   | 1.3   | 85 0  | 75 10 | 0 3  | 25   |

Study and Discussion of Simulation Experiment of the Thin-Wall Mould by MPI Software. Because of the orthogonal test had seven factors, and each of which has three level values, thus, the orthogonal Tab L18 (37) was selected to set the parameters of the various factors, then the data that were got from the simulation experiment of the thin-wall mould by MPI software would be recorded to be studied and discussed further. Test Tab L18 (37) and the orthogonal experiment results were given Tab.2 and Tab.3. In the factor and levels change trend chart, the abscissa denotes the value of factors and levels, and the ordinate denotes the amount of warp with optimal process parameters (Fig. 3).
Tab. 2 Orthogonal Tab L_{18} (3^3) and datas of simulation test

| No. | Primary effect factors and the level conditions were determined. | Test results |
|-----|---------------------------------------------------------------|--------------|
|     | A | B | C | D | E | F | G | Maximum deformation of warpage [mm] |
| 1   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5793 |
| 2   | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 0.4600 |
| 3   | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 0.3994 |
| 4   | 2 | 1 | 1 | 2 | 2 | 3 | 3 | 0.5597 |
| 5   | 2 | 2 | 2 | 3 | 3 | 1 | 1 | 0.4416 |
| 6   | 2 | 3 | 3 | 1 | 1 | 2 | 2 | 0.4311 |
| 7   | 3 | 1 | 2 | 1 | 3 | 2 | 3 | 0.4530 |
| 8   | 3 | 2 | 3 | 2 | 1 | 3 | 1 | 0.3820 |
| 9   | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 0.5438 |
| 10  | 1 | 1 | 3 | 3 | 2 | 2 | 1 | 0.3518 |
| 11  | 1 | 2 | 1 | 1 | 3 | 3 | 2 | 0.6032 |
| 12  | 1 | 3 | 2 | 2 | 1 | 1 | 3 | 0.4864 |
| 13  | 2 | 1 | 2 | 3 | 1 | 3 | 2 | 0.4161 |
| 14  | 2 | 2 | 3 | 1 | 2 | 1 | 3 | 0.4135 |
| 15  | 2 | 3 | 1 | 2 | 3 | 2 | 1 | 0.5532 |
| 16  | 3 | 1 | 3 | 2 | 3 | 1 | 2 | 0.3535 |
| 17  | 3 | 2 | 1 | 3 | 1 | 2 | 3 | 0.5183 |
| 18  | 3 | 3 | 2 | 1 | 2 | 3 | 1 | 0.4951 |

| K1  | 0.480 | 0.452 | 0.560 | 0.496 | 0.469 | 0.470 | 0.467 |
| K2  | 0.469 | 0.470 | 0.459 | 0.466 | 0.471 | 0.461 | 0.468 |
| K3  | 0.458 | 0.485 | 0.389 | 0.445 | 0.467 | 0.476 | 0.472 |
| Range R | 0.022 | 0.033 | 0.171 | 0.051 | 0.004 | 0.015 | 0.005 |

Optimal levels
A1, B3, C1, D1, E2, F3, G3

Optimal groups
C1D1B3A1F3G3E2

1- Melt Temperature, 2- Mold Temperature, 3- Fill Time, 4- Part 1: Holding Pressure Process, 5- Part 2: Holding Pressure Process, 6- Part 3: Holding Pressure Process, 7- Cooling Time.

Fig. 3 Factors and levels change trend

Tab. 3 Variance analysis of factors and levels

| Sources of variation | Sum of quadratic | Degree of freedom | Mean squared | F Value | Fa Critical value* | Significant test |
|----------------------|------------------|-------------------|-------------|---------|-------------------|-----------------|
| A                    | 0.002            | 2                 | 0.001       | 0.136   | 3.740             |                 |
| B                    | 0.003            | 2                 | 0.002       | 0.204   | 3.740             |                 |
| C                    | 0.089            | 2                 | 0.045       | 6.049   | 3.740             |                 |
| D                    | 0.008            | 2                 | 0.004       | 0.544   | 3.740             |                 |
| E                    | 0.000            | 2                 | 0.000       | 0.000   | 3.740             |                 |
Sources of variation | Sum of quadratic | Degree of freedom | Mean squared | F Value | Fa Critical value | Significant test
--- | --- | --- | --- | --- | --- | ---
F | 0.001 | 2 | 0.001 | 0.068 | 3.740 |*
G | 0.000 | 2 | 0.000 | 0.000 | 3.740 |*
Error | 0.100 | 14 | 0.007 | | |*
SUM | 0.203 | 28 | | | |*

Notice: * α = 0.05

Without considering the interaction between the various parameters, and according to the F value significant test, we can say that the most factors that affect the maximum deformation of warpage are Fill Time C in the chart of range analysis of factors and levels (Tab.2 & Fig.3), other that are Part 1: Holding Pressure Process D, Mold Temperature B, Melt Temperature A, Part 3: Holding Pressure Process F, Cooling Time G, and Part 2: Holding Pressure Process E. However, we had achieved the result of significance test that were given in Tab 3 showed that the main factor C had a significant effect, for another were not. Therefore, shorting appropriate the filling time in plastic molding, it would solve the problem of warping in some extent.

Above, the most reliable and the best group of process parameters is Melt Temperature at 205℃, Mold Temperature at 65℃, Fill Time is 0.6s, Part 1: Holding Pressure Process is 75%-0s, Part 2: Holding Pressure Process is 70%-10s, Part 3: Holding Pressure Process is 0~3s, Cooling Time is 25s.

Summary

(1) From the Variance analysis Tab of simulation experiment by MPI software, we can see clearly that the main factor C had a significant effect and for another are Part 1: Holding Pressure Process D, Mold Temperature B, Melt Temperature A, Part 3: Holding Pressure Process F, Cooling Time G, and Part 2: Holding Pressure Process E.

(2) After using the traditional range visual analysis, we were unable to obtain the most reliable and the best group of process parameters because of the best match was only relative to the factors and levels that had selected, which was not absolute “best group”, for this reason, we usually need to use variance analysis for further discussion. However, we introduced the thought of variance analysis that is easily ignored by researchers, we hope that it will provide a new thinking clue for researchers who combined the orthogonal experiment and simulation method both for injection molding to explore the best group of process parameters, then we also hope that it will provide a strong theoretical basis for the actual production of packaging products.

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