Study of injection molding process simulation and mold design of automotive back door panel

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Abstract Numerical simulation of the injection molding process of the outer panel of the automotive plastic rear door and mold design is presented here. Computer aided three-dimensional interactive application (CATIA) is employed to design the original automotive steel structure, and the modal and thermodynamic properties of the plastic back door outer panel are changed by changing the different injection materials of the back door outer panel. In order to efficiently design the panels, finite element analysis is used to verify whether the designed parts meet the mechanical properties requirements such as light weight, low fuel consumption, short production cycle, strong modeling design, high corrosion resistance and good recovery, the above main parameters have been evaluated, and the above main parameters are carried out evaluate. To simulate the injection molding process, computer aided engineering (CAE) software such as ANSYS and HyperWorks are used to analyze the back door of the selected material. After the numerical analysis, suitable material is selected, so that the modal and thermodynamic properties of the product could be satisfied as well as improved. Unigraphics NX (UG) is employed to design the convex and concave mold for the injection molding of the automobile’s plastic back door panel. Combined with the characteristics of the parts and the design requirements of the injection mold, the multi-scheme design of the pouring and cooling system is carried out. By comparing the effects of different gating and cooling systems on injection molding, the best gating and cooling system is selected. The artificial fish swarm algorithm is used to optimize the process parameters of the injection molding process, and the best combination of the injection molding process parameters of the outer panel of the rear door of the automobile is obtained.

1. Introduction

With the tremendous development of the automobile industry, the energy problem in today’s society has become increasingly prominent; which has further resulted in higher public demands of lightweight and low energy consuming automobiles [1]. From Refs. [2-4], it is found that substituting plastic for steel can not only reduce the design and manufacturing costs, but also the weight of the vehicle parts.

The mold market is developing rapidly with stable growth in manufacturing of plastic products where injection molds are used as the main supporting process equipment. At present, more than 90 % of China’s automotive interior and exterior decorative plastic parts are produced by designated plastic molds [5, 6]. The production process mainly involves melt the plastic material by heating to turn it into a high-temperature liquid, and use different methods to send it into the mold, and finally make it into a finished product through the stages of holding pressure and cooling.

There is still a big gap between standards for lightweight vehicles followed by China and other countries. At present, high-strength steel is still used most widely and the lightweight scheme of replacing steel with plastic has not been widely used. The lightweight solution is currently in the promotion and research stage. Judging from the current situation, the choice of
multiple materials will be a major trend in the future [7-11].

This article uses computer aided three-dimensional interactive application (CATIA) to create the three-dimensional model of the outer panel of the automobile all-plastic rear door, and then uses computer aided engineering to analyze its structure. In view of the particularity of the outer panel of the plastic back door, different materials are tried and compared with the best material type. The mold is designed according to the design criteria of the injection mold. Based on the results simulated by Autodesk Moldflow, the pouring and cooling systems of the injection mold will be studied separately [12-16].

2. Design of the outer panel structure of the automobile all-plastic rear door

The main content of the structural design of the outer panel of the all-plastic back door is the selection of materials, the design of the wall thickness of the parts, and the analysis of the mechanical properties of the parts.

2.1 Automobile all-plastic back door outer panel material

The inner panel of the back door mainly plays the role of a bearing; providing strength and stiffness, while the outer panel of the back door mainly realizes the appearance modeling, so that there are great differences found between them during the selection of materials and design analysis stage. The material of choice for automotive plastic rear doors is modified PP (polypropylene), which has the advantages of high specific strength, recyclability, and low cost. The commonly used modified PP (polypropylene) materials include pp-gf-30/40/50 (glass fiber reinforced polypropylene), pp-lgf-30/40/50 (long glass fiber reinforced polypropylene), pp-epdm (ethylene propylene diene monomer) -20/30, etc. The main performance indexes are shown in Table 1.

While selecting materials for the inner and outer panels of the plastic rear door, it should be taken into consideration that the inner panel is mainly used for mechanical load-bearing and the outer panel is mainly for aesthetics. Because the elastic modulus of PP-LGF-30 material is 6502.3 MPa, the shear modulus is 1482.5 MPa, the maximum shear stress is 0.25 MPa, and the elastic modulus of PP-EPDM-T30 material is 2005.3 MPa, the shear modulus is 600 MPa, the maximum shear stress is 0.25 MPa. Comparing the parameters of the two materials and considering the working conditions of the inner and outer panels in actual applications, PP-LGF-30 was finally selected as the material for the inner panel and PP-EPDM-T30 as the material for the outer panel.

2.2 The wall thickness design of the outer panel of the automobile plastic back door

When considering mechanical properties such as the strength, modal and thermal deformation of the outer panel of the plastic back door, the thickness of the plastic part should be controlled within a reasonable range. Therefore, when selecting the material thickness, the calculation is strictly carried out according to the formula for calculating the thickness of the plastic part. The outer panel of the automobile plastic rear door studied in this article is based on the rear door of a domestically-produced vehicle. The structure is shown in Fig. 1.

The material thickness is:

$$S = A / B \times S^* \times (0.8 - 0.95)$$

where $S$ is the original thickness, $B$ is projected area, $S^*$ is average thickness, $A$ is surface area.

This article uses three-dimensional software to analyze the plastic back door in Fig. 1 and finds that the product surface area $A$ is 1024000 mm$^2$, and the product projection area $B$ is 980000 mm$^2$. The thickness of the modified PP (polypropylene) material of automobile parts is usually 1.5 mm-3 mm. Considering the mechanical performance requirements and related design standards of the designed products, $S^*$ in this article is 3 mm. Considering the actual processing situation, the result obtained by the above formula should be multiplied by 0.8-0.95. After calculating using Eq. (1), the thickness of the plastic part can be obtained.

$$S = 1024000/980000 \times 3 \times 0.8 = 2.5 \text{mm}.$$  

Although the plastic back door satisfies the principle of plastic part thickness design, it cannot be well guaranteed whether it can meet the same mechanical performance requirements as the original steel back door. Therefore, this article also com-

Table 1. Performance indexes of thermoplastics.

| Property                        | Value  |
|--------------------------------|--------|
| Glass fiber (%)                | 25-50  |
| Tensile strength (MPa)         | 50-250 |
| Flexural strength (MPa)        | 110-230|
| Impact strength (kJ/m$^2$)      | 15-130 |
| Density (g/cm$^3$)             | 0.98-1.0|

Fig. 1. Automotive plastic back door panel.
bines an equal strength design criterion in the design process. The elastic modulus and moment of inertia of plastic and steel parts should meet the following condition.

\[
\frac{(EI)}{\text{new material}} = \frac{(EI)}{\text{sheet metal material}} = 2
\]

where \(E\) is modulus of elasticity of material and \(I\) is moment of inertia.

Considering the connection and use of the inner and outer panels of the back door, the inner and outer panels are designed as parts of equal thickness. This article uses the principle of equal strength design of the inner plate to check whether the thickness of the designed outer plate is reasonable. According to the design guidelines and related regulations of the automobile industry, the thickness of the sheet metal parts of the automobile four-door and two-cover is generally about 0.8 mm, the elastic modulus of the inner plate material is about 6202.3 MPa, and the modulus of elasticity of steel is 206 GPa. From the above formula, the thickness of the replacement material is found as:

\[
h = H \times \sqrt{\frac{E_{\text{sheet metal part}}}{E_{\text{PP composite material}}}} = 0.8 \times \sqrt{\frac{206000}{6502.3}} = 2.5\text{mm}
\]

where \(h\) is thickness of back door inner panel and \(H\) is thickness of original sheet metal parts.

Through Eqs. (1) and (2), it can be seen that the thickness of the inner and outer panels of the back door is within the error range. Therefore, the thickness of the outer panel of the plastic back door is set at 2.5 mm. The three-dimensional model of the outer panel of the plastic back door is shown in Fig. 2. The plastic back door not only satisfies the principle of plastic thickness design, but can also achieve the same mechanical properties as the original steel back door.

### 2.3 Finite element analysis of the outer panel of automobile plastic rear door

Through modal analysis, the resonance and noise of automobile parts in use can be reduced to a minimum. Since there are countless patterns in component analysis, this article only considers the first six sequences of pattern analysis. When using HyperWorks and ANSYS to analyze the mechanical properties of plastic backdoor, the backdoor mesh is firstly divided. On the basis of mesh division, ANSYS Workbench is employed to conduct a modal analysis on the plastic rear door panel. The sixth mode of plastic back door plate is shown in Fig. 3.

By analyzing the modal cloud diagram, the modal frequencies of the first six orders of the plastic back door are obtained along with the magnitude of the deformation of the plastic back door at the resonance condition i.e., when the frequency of each order of the back door is the same as the frequency of the external excitation. The first six fundamental mode-shapes of vibration of the original steel-back door are compared with the plastic-back door. The modal frequencies associated with the first six modes are listed in Table 2.

| Order | Plastic back-up door model (Hz) | Steel rear door model (Hz) | Difference (Hz) | Percentage difference (%) |
|-------|--------------------------------|---------------------------|-----------------|--------------------------|
| 1     | 45.181                         | 2.445                     | 2.736           | 5.72                     |
| 2     | 55.463                         | 53.924                    | 1.539           | 2.85                     |
| 3     | 101.55                         | 100.63                    | 0.92            | 0.914                    |
| 4     | 149.53                         | 148.4                     | 1.13            | 0.761                    |
| 5     | 159.92                         | 158.04                    | 1.88            | 1.19                     |
| 6     | 199.37                         | 197.22                    | 2.15            | 1.09                     |

Compared to the modes of steel and plastic back doors, the first-order modal value of plastic parts is 5.72 % higher than that of steel, and the second-order modal value of plastic parts is 2.85 % higher than that of steel. The modal values of the first two orders have increased greatly, and the modal values of the last four orders of plastic parts have also increased compared with those made of steel, with an increase of 0.914 %, 0.761 %, 1.19 %, and 1.09 %, respectively.

Because the first six modes of the rear door outer panel made of PP composite plastic all meet the modal requirements of the original steel rear door outer panel. At the same time, the
The low-order mode of the plastic back door outer panel has a greater increase than the high-order mode. The low-order mode of the object has a higher degree of influence on the vibration amplitude than the high-order mode, so the PP composite material is in line with the design and use requirement.

2.4 Analysis of thermal deformation of outer panel of automotive plastic rear door

In the automotive industry, the natural weather temperature and the possible temperature in the actual application process should be taken into consideration. Therefore, the thermal analysis temperature of the plastic back door was set at -23 °C-23 °C and 23 °C-80 °C, respectively [17]. First, this article carried out the pre-processing of the finite element analysis of the designed back door structure, and then carried out the simulation analysis after the completion of the processing operation. The analysis results are shown in Figs. 4 and 5.

As can be seen from Fig. 4, when the temperature changes from 23 °C to 80 °C, the maximum deformation of the plastic back door plate is at the center of the outer plate. At this time, the deformation of the plastic rear door reached 1.861 mm. Fig. 5 shows that when the temperature drops from 23 °C to -23 °C, the gap surface deformation should also be less than 2 mm. Obviously, the analysis results of 1.861 mm and 0.002736 mm are less than 2 mm, so the selection of rear door materials and structural design meet all the requirements.

Through the use of ANSYS to conduct thermal analysis on PP composite parts, the thermal deformations under the two working conditions are 1.86 mm and 0.0027 mm, which are both less than the specified 2 mm. The feasibility of the part design is verified by the above analysis.

3. Design of injection mold for outer panel of automobile all-plastic back door

Injection molding product quality is a direct reflection of injection mold design and is a reasonably important index. The main content of the injection mold design of the back door plate is the choice of injection molding machine and the calculation of the core and cavity of the injection mold of the outer plate.

3.1 Selection of injection molding machine.

The injection mold and machine tool of the plastic back door plate of the automobile are an inseparable hence the choice of injection molding machine is also very important. Performance parameters of injection molding machine include maximum injection volume, maximum injection pressure, clamping force, nozzle and aperture, etc. [18].

(1) Maximum injection volume

The maximum injection volume of the injection machine should be greater than the total injection volume required by the plastic back door plate.

\[
M \leq G_i
\]  

where \(G_i\) is the actual maximum injection volume, \(M\) is the amount of injection required for molding.

\[
M = n \cdot M_{\text{model}} + M_{\text{gating}}
\]  

where \(n\) is the cavity number, \(M_{\text{model}}\) is the weight or volume of plastic parts, \(M_{\text{gating}}\) is the gating system’s weight or volume.

According to the requirements, \(G_i\) should be less than 80 % of the maximum injection volume of the injection molding machine.

\[
M \leq 80\% G_i
\]  

Admissible range for \(M\) is:

\[
20\% G_i \leq M \leq 80\% G_i
\]
The total volume of filling is 700 cm³. The total volume of the gating system is 100-150 cm³. According to Eq. (3), the maximum injection volume range is 875-1500 cm³.

(2) Clamping force

In this article, when designing the mold, it is necessary to set the clamping force reasonably so that it is greater than the thrust caused by melt flow.

\[
T \geq K \cdot F \cdot q / 1000
\]  

(7)

where \( T \) is clamping force, \( F \) is the total projected area of the outer plate and the gating system on the parting plane, \( q \) is pressure in the cavity, \( k \) is safety factor.

The cavity pressure is about 25-50 % of the injection pressure. Generally, the pressure of the die cavity is 200-300 kg/cm². The projection area of the back door plate is 9800 cm² when calculating the thickness of the parts. Considering the projected area of the gating system, \( F \) is 10000 cm². According to Eq. (7), \( T \) can be obtained as 2200 t.

\[
T \geq KF \cdot q / 1000 = 1.1 \times \frac{200}{1000} = 2200 t
\]

The clamping force of the selected injection machine should be greater than 2200 tons. Based on the data analysis and the actual situation of the automobile industry, the maximum injection pressure of the injection molding machine is selected as 60 MPa. After consulting the injection molding machine model manual, the Haitian injection molding machine is finally selected. The model of Haitian injection molding machine is HTF300J/TJ.

3.2 Calculation of core and cavity of injection mold for outer panel of plastic rear door of automobile

(1) The auto plastic back door panel forming shrinkage rate and cavity size manufacturing deviation are averaged. The average value of the size deviation of the plastic back door plate can be obtained as follows:

\[
\begin{align*}
A_i & = \frac{\Delta}{2} \left( A_i + \frac{\delta_i}{2} + \frac{\delta_i}{2} \right) - \left( A_i - \frac{\Delta}{2} \right) S \\
\end{align*}
\]

(8)

where \( \Delta \) is automotive plastic back door plate tolerance/mm, \( S \) is average shrinkage rate of automotive plastic back door panels, \( \delta_i \) is automobile plastic back door plate injection mold wear/mm, \( \delta_i \) is mold manufacturing tolerance/mm.

The radial dimension formula of the cavity is as follows,

\[
M_z = (1 + S) A_z - \left( \Delta + \delta_z + \delta_z \right) / 2.
\]

(9)

(2) The cavity depth dimension is taken as \( \delta_i = \Delta / 3 \). By analogy with the formula of cavity radial dimension, the calculation formula of cavity depth dimension is obtained.

\[
H_{z+b}^{h+} = \left[ (1 + S) H_z - \frac{2}{3} \Delta \right]^{\delta_i}.
\]

(10)

Calculation formula of radial dimension of core is given by,

\[
B_{w-d} = \left[ (1 + S) B_w + x \Delta \right]_{-\Delta}^{+\delta_i}.
\]

(11)

Core height dimension formula is given by,

\[
h_{w-d} = \left[ (1 + S) h_w - \frac{2}{3} \Delta \right]_{-\delta_i}^{+\delta_i}.
\]

(12)

According to the above formula, the radial and axial dimensions of the cavity plastic parts are 1115.42 mm and 462.21 mm, respectively, and the radial and axial dimensions of the core plastic parts are 1115.62 mm and 457.06 mm, respectively. The radial and axial dimensions of the core plastic parts are 1115.62 mm and 457.06 mm, respectively. The working radial and axial dimensions of the cavity are 1126.57 mm and 468.85 mm, respectively. The working radial and axial dimensions of the core are 1126.77 mm and 461.63 mm, respectively. This article uses the UG injection module to model the core and cavity of the outer panel of the plastic rear door of the automobile. The core and cavity are shown in Fig. 6.
3.3 Mold assembly drawing

Before injection molding, the movable and fixed molds are driven by the injection molding machine to complete the closing. The injection molding machine injects the molten plastic in the barrel into the cavity under pressure, and finally obtains the plastic part after a series of molding processes. The mold diagram of the outer plate of the plastic rear door of the automobile is shown in Fig. 7.

4. Results and discussions

The main content of the research on the pouring system and cooling system of the outer panel of the automobile all-plastic rear door is the design and selection of the two major systems of the pouring system and the cooling system during the cooling process. This article determines the pouring location, gate size and cooling system related data, uses Autodesk Moldflow to analyze, select and verify the designed pouring and cooling system, and determine the best pouring and cooling system [19, 20].

4.1 Scheme design of pouring position

This article uses Autodesk Moldflow analysis to obtain a cloud map of gate matching. With the help of actual production experience, analysis is performed (in this work) Autodesk Moldflow gate analysis as an aid to design the gate location and gate quantity. Considering that the plastic back door panel is a large automobile cover, the number of gates is 4, 6 and 8, respectively, by the experience of actual production. This article simulates and analyzes the three gate positions, and the results are shown in Fig. 8.

It can be judged from the above three figures that the blue area in the figure is the place where the flow resistance is the least, so the blue part is the best gate position simulated by the software. In this article, Autodesk Moldflow is employed to simulate the filling and flow state of molten plastic in the mold.

The injection molding process includes pressure, time and temperature, which needs to be simulated in this article. The filling time of the eight gates, the temperature difference and the number of weld marks are relatively high among the three schemes, so the scheme of eight gates is excluded first. Compared with the two schemes of four gates and six gates, the difference between filling time and temperature is not significant, but the schemes of fusion connection and die locking force are relatively larger. Considering the actual production situation, the automobile plastic back door panel is a large automobile panel, and it is difficult to achieve the molding effect if there are few gates. Therefore, the scheme with more gates should be selected as far as possible in the case of little difference. Through the above analysis and comparison, this article finally chooses the pouring plan of six pouring ports.

4.2 Mainstream design

The main channel is the plastic channel established between the nozzle of the injection molding machine and the runner. There are two general design schemes, as shown in Fig. 9. Because the ejection position of the plastic rear door of the automobile is in the center of the mold, the main channel of this article chooses the vertical solution.

From the point of view of pressure transmission, the split channel requires a larger flow channel. Compared with other types of cross sections, the circular cross section is the most ideal, and it is also used more frequently. Therefore, a circular cross-section shunt design scheme is chosen in the structural design of the shunt.

4.3 Cold material well (cavity) design

The cold material well (cavity) is designed to prevent the cold material generated during the injection molding process from entering the cavity, thereby causing damage to the molded part. Cold slug wells are generally distributed at the end of the flow channel, and their location is often at the turning point of the melt flow. The cold material well (cavity) design is shown in Fig. 10.
The size of the cold slug well is usually 1.5 to 2 times the diameter of the runner. According to the actual production experience, the length of the cold slug well of the main runner is 27 mm, and the length of the cold slug well of the branch runner is 17 mm.

4.4 The gate design

For large plastic parts such as the outer panel of the plastic rear door of an automobile, multiple point gates are usually provided to reduce warping deformation. The schematic diagram of point pouring is shown in Fig. 11.

4.5 Research on cooling system of injection mold for outer plate

The straight-through type is suitable for the water transportation of the template and the cooling of large plastic parts. The straight-through cooling water circuit is used for the large plastic parts such as the outer panel of the plastic rear door of the automobile. The straight-through cooling water circuit is shown in Fig. 12.
In mold design, injection molds with relatively high number of cores are often encountered. In this case, cooling water channels with water column channels are required. The water column cooling channel is shown in Fig. 13.

4.6 Layout of cooling pipes

Taking into account the large size of the outer panel of the plastic rear door of the automobile, the number of cooling pipes should be set as many as possible while ensuring reasonable and no waste. This article uses this as the premise to design the water circuit. As shown in Fig. 14, Autodesk Moldflow is used to verify the design scheme after the completion of the scheme design. This article evaluates the temperature, time and other related physical quantities of the waterway layout plan to judge whether the plan is reasonable.

In this article, the process parameters are set in Autodesk Moldflow to analyze the cooling process. The time to reach the ejection temperature is shown in Fig. 15. Through the analysis of the simulation results, this article finally chooses this scheme as the cooling water circuit layout scheme.

5. Simulation and data processing of the injection molding process of the outer panel of the car back door

Now apply the theory to practice to simulate the injection molding process. Firstly, the influence of each process parameter on the evaluation index is analyzed through orthogonal experimental design, and then the test data results are processed and analyzed by the gray correlation degree and Taguchi method.

5.1 Orthogonal experimental design of the injection molding process for the outer panel of the automotive plastic rear door

The basic step of the orthogonal test is to first clarify the value range of each process parameter, and then find a reasonable evaluation index. This paper designs a set of reasonable orthogonal test tables and uses CAE software to simulate the combination of process parameters.

5.2 Influencing factors and evaluation options

There are many factors that affect the injection molding process of the outer panel of the plastic rear door of the automobile. The main factors include: melt temperature, mold temperature, injection pressure, injection time, holding pressure,
holding time, cooling time, etc. This article tries to control the influencing factors to about 5 in the design, and finally chooses the five factors of melt temperature, mold temperature, cooling time, holding pressure, and holding time. This article is based on actual production experience, and selects the level of each factor according to the actual process parameter values, as shown in Table 3.

For the injection molding process, not only the quality of the product is required, but also the size and assembly accuracy must meet the standards. Among them, the amount of product warpage and volume shrinkage are the main factors that affect the surface quality and assembly accuracy of the product. Because each part of the structure shrinks unevenly, the product will shrink in volume, which will cause surface shrinkage marks and affect the assembly of parts. Therefore, this paper selects the two indicators of product warpage and volume shrinkage for research.

Input the selected level value of each influencing factor into the orthogonal table, the system automatically generates 16 sets of process parameter combinations, and use Moldflow to simulate the 16 sets of process. This article first enters the level values of the selected influencing factors into the orthogonal table, and the system will automatically generate 16 sets of process parameter combinations. Then use Moldflow to simulate 16 sets of process parameter combinations, and obtain the index results corresponding to each set of experiments. The index results are shown in Table 4.

### Table 3. Level factor settings.

| Level | A  | B  | C  | D  | E  |
|-------|----|----|----|----|----|
| Mold temperature | Melt temperature | Cooling time | Holding pressure | Compress time |
| 1     | 40 | 185| 20 | 65 | 15 |
| 2     | 50 | 200| 25 | 75 | 20 |
| 3     | 60 | 215| 30 | 85 | 25 |
| 4     | 70 | 230| 35 | 95 | 30 |

### Table 4. Tests and results.

| Serial number | A  | B  | C  | D  | E  | Warpage /mm | Volume shrinkage/% |
|---------------|----|----|----|----|----|-------------|-------------------|
| 1             | 40 | 185| 20 | 65 | 15 | 10.35       | 14.26             |
| 2             | 40 | 200| 25 | 75 | 20 | 10.35       | 15.05             |
| 3             | 40 | 215| 30 | 85 | 25 | 11.35       | 14.86             |
| 4             | 40 | 220| 35 | 95 | 30 | 10.59       | 12.35             |
| 5             | 50 | 185| 25 | 85 | 30 | 10.33       | 14.29             |
| 6             | 50 | 200| 30 | 95 | 25 | 9.10        | 15.05             |
| 7             | 50 | 215| 35 | 65 | 20 | 11.44       | 15.85             |
| 8             | 50 | 220| 20 | 75 | 15 | 10.27       | 16.64             |
| 9             | 60 | 185| 30 | 95 | 20 | 7.84        | 14.24             |
| 10            | 60 | 200| 35 | 85 | 15 | 8.27        | 15.05             |
| 11            | 60 | 215| 20 | 75 | 30 | 12.01       | 15.85             |
| 12            | 60 | 230| 25 | 65 | 25 | 13.52       | 16.63             |
| 13            | 70 | 185| 35 | 75 | 25 | 8.84        | 14.24             |
| 14            | 70 | 200| 20 | 65 | 30 | 11.41       | 15.05             |
| 15            | 70 | 215| 25 | 95 | 15 | 8.61        | 15.86             |
| 16            | 70 | 230| 30 | 85 | 20 | 10.91       | 16.63             |

### Table 5. Range analysis of warpage deformation.

| Level | A  | B  | C  | D  | E  |
|-------|----|----|----|----|----|
| Mean 1| 10.66| 9.34| 11.01| 11.68| 8.826|
| Mean 2| 10.29| 9.79| 10.15| 10.37| 11.04|
| Mean 3| 10.41| 10.30| 9.67| 10.09| 10.71|
| Mean 4| 9.26| 11.19| 9.79| 8.487| 11.09|
| Very bad| 1.4| 1.85| 1.344| 3.2| 2.264|

5.3 Data analysis of orthogonal test table

The range analysis method is used to analyze the test data of a single warpage. The analysis results are shown in Table 5 and Fig. 16.

It can be seen from Tables 5 and 6 that the degree of influence of various factors on warpage deformation is: holding pressure > holding time > melt temperature > mold temperature > cooling time. Through the analysis of the warpage range, this paper obtains a better combination of process parameters. After the combined analysis and verification of this set of process parameters, the final result is shown in Fig. 17. The war-
page deformation is 9.3 mm, and the volume shrinkage rate is 14.3 \%.

This paper also applies the range analysis method to the range analysis of the shrinkage of a single volume. The analysis results are shown in Table 6 and Fig. 17.

It can be seen from Tables 5 and 6 that the degree of influence of various factors on the volume shrinkage rate is: Melt temperature > mold temperature > cooling time > holding pressure > holding time. In this paper, a set of good combination of process parameters can also be obtained through the extreme difference analysis of volume shrinkage. By verifying this group, the final result is shown in Fig. 19. The warpage deformation is 8.38 mm, and the volume shrinkage rate is 15.05 \%.

### 6. Optimization of injection molding process parameters based on least squares and fish school algorithm

The least square method is used to firstly perform numerical fitting on the warpage deformation of a single evaluation index on the obtained orthogonal test data, and then optimize the fitting curve by fish school algorithm.

#### 6.1 Least squares curve fitting

In view of the fact that there are many influencing factors in the process of injection molding process parameter optimization, this paper applies the method of setting weights to combine the five factors into one. First, through the investigation of the company’s injection molding production situation, and then combined with the actual situation in the injection molding process, the weight of each factor is finally set as:

$$\omega = (\omega_1, \omega_2, \omega_3, \omega_4, \omega_5) = (0.4, 0.3, 0.1, 0.1, 0.1) .$$

In this paper, the weighted numerical method is used to weight the 16 sets of process parameter combinations, and the X value in the least square method is obtained. The X values are 81.5, 88, 90, 94, 94.5, 95, 96.5, 97, 97.5, 99.5, 100, 101, 101.5, 104.5, 106.5, 110.5. Since the evaluation index in this chapter is warpage deformation, the Y value during least squares fitting is the value of 16 groups of warpage deformation in the orthogonal test table. The value of warpage can be

### Table 6. Volume shrinkage range analysis.

| Level | A    | B    | C    | D    | E    |
|-------|------|------|------|------|------|
| Mean 1| 14.13| 14.26| 15.45| 15.45| 15.45|
| Mean 2| 15.45| 15.05| 15.46| 15.44| 15.44|
| Mean 3| 15.44| 15.61| 15.20| 15.21| 15.20|
| Mean 4| 15.45| 15.56| 14.37| 14.377| 14.39|
| Very bad| 1.32| 1.35| 1.06| 1.08| 1.06|

Fig. 17. Mean warpage analysis.

Fig. 18. Combination simulation results of A4B1C3D4E1.

Fig. 19. Volume shrinkage mean analysis.
In order to make the curve fitting more accurate, this paper imports the weighted data into Matlab and connects the discrete points as shown in Fig. 20. Fig. 18 is the data distribution obtained after automatic import with Matlab software, and then use the software to simulate the curve of this set of discrete data. After many attempts and optimizations, the final fitting curve is shown in Fig. 21. It can be seen from Fig. 19 that the 16 sets of imported data are basically distributed on the fitted curve. There are individual points that deviate from the fitted curve, because curve fitting itself is an infinitely close process, and there is no guarantee that all discrete points are on the fitted curve. However, the distribution of as many points as possible on the curve is an important evaluation index, so the fitting curve as a whole meets the requirements. The analytical formula and parameter values of the curve equation fitted by the software are shown in the figure below.

General model $\sin 4$:

$$F(x) = a_1 \sin(b_1x + c_1) + a_2 \sin(b_2x + c_2) + a_3 \sin(b_3x + c_3) + a_4 \sin(b_4x + c_4)$$

in

- $a_1 = 11.41; b_1 = 0.0006434; c_1 = 7.279$
- $a_2 = 1.414; b_2 = 0.3507; c_2 = -11.73$
- $a_3 = 2.096; b_3 = 0.8195; c_3 = -18.83$
- $a_4 = 3.388; b_4 = 1.646; c_4 = -12.89$

The above shows in detail the analytical formula of the curve after applying the least squares method. On this basis, the algorithm will be applied to optimize the analytical formula of the curve equation.

6.2 Optimization of injection process parameters based on fish school algorithm

In this paper, the mathematical model obtained by the curve fitting method is written into the artificial fish school algorithm. The programming ideas are as follows:

- $a_1 = 11.41; b_1 = 0.0006434; c_1 = 7.279$
- $a_2 = 1.414; b_2 = 0.3507; c_2 = -11.73$
- $a_3 = 2.096; b_3 = 0.8195; c_3 = -18.83$
- $a_4 = 3.388; b_4 = 1.646; c_4 = -12.89$

figure(1); hold on

eplot([11.41*(\sin(0.0006434*x + 7.279)) + 1.414*(\sin(0.3507*x - 11.73)) + 2.096*(\sin(0.8195*x - 18.83)) + 3.388*(\sin(1.646*x - 12.89))], [0,100]).

According to the specific situation of this article, the number of artificial fish is set to 50. The purpose is to have enough samples without increasing the difficulty of analysis. Second, the maximum number of iterations is set to 50. The reason why the maximum number of trials is set to 50 is based on actual conditions. In this paper, the maximum number of trials is 100, the perception distance is set to 1, the congestion factor is set to 0.618, and finally the optimal step size is set to 0.1. The programming ideas are as follows:

![Warpage deformation](image)

![Volume shrinkage rate](image)

Fig. 20. Combination simulation results of A4B1C4D4E4.

Fig. 21. Data import.
After the initial setup is completed, the algorithm will run. The computer will perform internal calculations according to the set parameters to find the fitness value of the individual fish school. On this basis, the best artificial fish status is selected through comparison and assigned to the bulletin board at the same time.

The following is an individual evaluation of each individual, and selections are made based on the various fish school behaviors described above. Some programming thought steps are as follows:

BestY = -1* ones (1, MAXGEN);
% The optimal function value in each step
BestX = -1* ones (1, MAXGEN);
% The best independent variable in each step
bestY = -100; % Optimal function value
Y = AF_foodconsistence (X)
while gen <= MAXGEN
for i = 1, int(1.5*gen)
for i = fishnum
Xi1, Yi1 = AF_swarm (X, i, visual, step, delta,
try_number, LBUB, Y), % Group behavior
Xi2, Yi2 = AF_follow (X, i, visual, step, delta,
try_number, LBUB, Y), % Rear-end behavior).

Next, iterative optimization is carried out, and this article applies algorithmic procedures to evaluate all individuals. When the result of the individual is better than the result displayed on the bulletin board, replace the individual on the original bulletin board with the individual. Iterative analysis is carried out by analogy, and the iteration stops when the specified error range is reached. The optimization programming ideas are as follows:

**title**('Optimal coordinate movement in the iterative process of fish school algorithm')
**plot**(1: MAXGEN, BestY)
**xlabel**('Number of iterations')
**ylabel**('Optimization value')
**title**('Iterative process of fish school algorithm')
**dispel**(['Optimal solution X : ', num2str (bestx, '%1.5f')])
**dispel**(['Optimal solution Y : ', num2str (besty, '%1.5f')]).

In this paper, the fish school algorithm is used to optimize the weighted parameters of the process parameters that affect the warpage, and the final optimal solution is 92.88298. After 16 sets of data analysis, it is predicted that the weighted value of the optimal process parameter combination is about 93.

**6.3 Optimization of injection process parameters based on fish school algorithm**

When the value is 89.5, the corresponding five process parameters are: mold temperature 50 °C, melt temperature 185 °C, cooling time 25 s, holding pressure 85 Mpa, and holding pressure time 30 s. When the value is 94, the corresponding five process parameters are: mold temperature 60 °C, melt temperature 185 °C, cooling time 30 s, holding pressure 95 Mpa,
Analysis of Table 7 shows that the group with the smallest warpage deformation is the fifth group of the verification test group, and the deformation value is 6.405. The weighted combination of this group of process parameters is 93, which is basically in line with the prediction. At the same time, this paper compares the warpage deformation with the results of the orthogonal test done before, and finds that this group is still the least deformed. Therefore, the best combination of process parameters is the fifth group of the verification test group, and the simulation results are shown in Fig. 22.

From the above analysis results, it can be seen that the artificial fish swarm algorithm used in this paper to optimize the injection process parameters is obviously better than the previous results obtained by the orthogonal test range analysis method, and achieves the goal of optimizing process parameters.

7. Conclusions

In this paper, a numerical finite element analysis is carried out on the outer panel of the plastic rear door of a certain car. ANSYS and modal analysis software are used to verify whether the designed part can meet its mechanical performance requirements and related mold design issues. According to the parting surface design principle, UG injection mold is used to select the parting surface. The parting surface selected after verification is conducive to the parting. This article draws the assembly drawing of the mold through the above design. With the help of Autodesk Moldflow, this paper analyzes and studies the different filling and cooling in the injection molding process, and on this basis, determines the best pouring and cooling system.

This paper analyzes the warpage deformation and volume shrinkage in detail, then uses the least square method to analyze the data of the test group, and then uses Matlab to perform curve fitting on the discrete points. Finally, a reasonable analytical formula of the fitting curve and curve equation was obtained, and the establishment of the mathematical model was completed. In this paper, artificial fish school algorithm is used to optimize the injection molding process parameters, and finally the best process parameter combination is obtained. By comparing with the warpage deformation results of the previous chapters, it is found that the results obtained by applying the artificial fish school algorithm optimization are the best, which shows that the optimization method combining the least square method and the artificial fish school algorithm is reasonable.

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Conflict of interests

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled “Study of Injection Molding Process Simulation and Mold Design of Automotive Back Door Panel”.

Nomenclature

| Symbol | Description |
|--------|-------------|
| $S$    | Original thickness |
| $B$    | Projected area |
| $S^*$  | Average thickness |
| $A$    | Surface area |
| $E$    | Modulus of elasticity of material |
| $I$    | Moment of inertia |
| $h$    | Modulus of elasticity of material |
| $H$    | Thickness of original sheet metal parts |

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