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Injection molding design of wholly plastic pump body and research on its best casting process parameters

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ABSTRACT

To quickly get the all plastic injection parts, this article took advantage of the Mold flow Software to do a numerical simulation of all type plastic pump's injection molding process ,determined the best gate location, designed the injection molding L9(33) orthogonal test table, chose mold temperature, melt temperature, injection pressure as the factors, conformed the shrink mark index, volume shrinkage ratio, maximum warping deformation and cavity residual stress for the parts's quality evaluation index, the orthogonal experiment was completed, and formulated the comprehensive quality evaluation indicators parts, utilized the modified simplex method to optimize transform function optimization into injection molding CAE optimization process, the injection molding process was optimized, which could obtain the injection molding optimum process parameters shown as follows: The mold temperature was 28.49 ℃, The melt temperature was 212.4 ℃,The injection pressure was 80.09MPa. The parts' comprehensive quality was that the shrink mark index was 0.0191%, volume shrinkage rate was 16.33%, maximum warping deformation was 1.516mm, and main direction's cavity residual stress value was 31.65MPa. It could obtain the wholly plastic pump by injection molding according to the optimum process parameters, and the parts met the requirement.

Keywords: Injection molding, CAE, Orthogonal Experiment, Process parameters, Optimization

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INTRODUCTION

Wholly plastic type engineering plastic pump is widely used in non-ferrous metal smelting industry, chlor-alkali industry, water treatment industry, iron and steel enterprises and various corrosive slurry of smelting industry and the chemical industry. Wholly plastic type pump parts are made from a mold injection molding, As a result, the mould design and injection molding process parameters have an important effect on the wholly plastic type pump. In the injection mould system, the forming parts is the key parts of deciding the plastic parts' geometric shape and size. When modern mold design method is in application, the first step is to use 3 d software to take a structure design for the plastic parts , and then to design the molding parts. The parts designed by the modem design method have high precision, save the stamping product's development cycle and save the production cost for the enterprise. Injection molding process simulation is to predict the flow status of plastic melt flowing into injection mold cavity ,which can determine the effects of melt flow on the quality of injection molded parts[1-2]. Molding orthogonal experiment can greatly reduce the number of experiment[3-5], analyze the test data, the trend of process parameters' influence on the evaluation index can be obtained, but this method have not got the best process parameters. Literature[6] using TOPSIS to carry on a good or bad scheduling for the internal table's every testing scheme and select the robust optimal injection molding process parameters to design a scheme.

By means of injection molding process simulation and orthogonal experiment for the wholly plastic type engineering pump body, this paper formulated the comprehensive quality evaluation indicators parts, transformed the function optimization problem into a process of injection molding CAE optimization problem based on the robust optimization method, optimized the injection molding process parameters, and the optimum process parameters of injection molding parts were obtained, the injection scheme could quickly produced a qualified product.

INJECTION MOLDING PROCESS SIMULATION OF WHOLLY PLASTIC PUMP BASED ON MOLDFLOW

GATING SYSTEM LAYOUT AND OPTIMIZATION

Researchers should set the injection molding process parameters for plastic type pump body parts in Moldflow firstly, then simulated and analysed the theoretic best gate location , whose analysis diagram would be obtained, the experimental simulation results of the analysis was shown in Fig. 1.

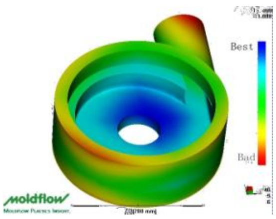

Fig. 1: Layout diagram of gate system

Figure 1 showed the best gate location was on the working plane of pump body (the blue part of the center position in the graph),where required for high smooth finish. If the best gate location was chosen as the actual gate location, the plane precision would be reduced after pump body molding, the service life would fall down, so the theoretic best gate location was not desirable.

GATE LOCATION SELECTION

Fig. 2(a): Gating system scheme one

Fig. 2(b): Gating system scheme two

Fig. 2(c): Gating system scheme three

Fig. 2(d): Gating system scheme four

It could be seen from the Fig. 2: the gate location avoided the working plane of wholly type pump body parts, and the gate location of various schemes was close to the recommended optimal theoretic gate location. these four schemes were all ok. Modeling the four gating system respectively in the Moldflow, then simulating it, parts of the gating system flow analysis results could be known, which were shown in Tab. 1:

Tab. 1: Flow analysis result table of four gating system scheme

	Filling time(s)	Temperature range of flow frontier(℃)	ıvity pressure (MPa)	Clamp force (tonne)
Scheme one	2.283	229.9~231.4	78.87	452.08
Scheme two	2.404	229.9~232.0	81.88	521.29
Scheme three	2.410	229.9~232.0	82.92	516.91
Scheme four	2.524	229.9~231.8	80.02	508.93

It can be seen from Tab. 1, when considering the filling time and the temperature range of flow frontier, scheme one was the best.

INJECTION MOLDING SIMULATION TEST

This paper utilized orthogonal experiment to analyze the factors affecting the quality of injection molded parts[7-8], chose mold temperature, melt temperature and injection pressure as the three factors, respectively from three levels, that was what people called three factors and three levels orthogonal experiment. Various factors level were shown in Tab. 2.

Tab. 2: Orthogonal experiment factors and level settings

factor / level	Mold temperature A(℃)	Melt temperature B(℃)	Injection pressure C(MPa)
1	30	200	78.7
2	40	220	80
3	50	230	83

This experiment chose the L9(33) orthogonal test table and selected plastic shrink mark index, volume shrinkage rate and maximum warping deformation as evaluation index, used Moldflow to simulate the injection molding for wholly plastic pump body , the recorded results were shown in Tab. 3.

Tab. 3: 9Group orthogonal simulation experiment results

Test number	Factor-level setting			Result y			
	A	B	C	Shrink mark index (%)	Volume shrinkage rate (%)	Maximum warping deformation (mm)	First main direction's cavity residual stress（MPa）
1	15	200	78.7	1.100	15.6	1.41	32.64
2	15	230	83	2.386	17.59	1.396	30.66
3	15	250	80	0.7291	18.82	1.473	29.84
4	30	200	83	1.168	15.62	1.407	32.87
5	30	230	80	2.422	17.57	1.425	30.31
6	30	250	78.7	3.417	18.82	1.427	29.74
7	40	200	80	0.000	15.58	1.536	32.18
8	40	230	78.7	0.4371	17.58	1.527	30.61
9	40	250	83	1.984	18.84	1.498	30.93

ANALYSIS OF TEST RESULTS

According to Tab. 3, respectively took the shrink mark index, volume shrinkage ratio, maximum warping deformation and cavity residual stress as optimize direction and conducted a range analysis for the experiment results, Every factor's influences on the targets were shown in Tab. 4, Tab. 5, Tab. 6 and Tab. 7.

Tab. 4: Data analysis of the influence of process parameters on shrink mark index

	A	B	C
K_1	3.2506	2.925	3.25
K_2	3.2506	3.2963	3.2531
K_3	3.25	3.53	3.2481
k_1	1.0843	0.975	1.0833
k_2	1.0843	1.0988	1.0827
k_3	1.0833	1.1967	1.0827
R	0.0002	0.2017	0.0017
Sort	1	2	3

Tab. 5: Data analysis of the influence of process parameters on the volumetric shrinkage

	A	B	C
K_1	7.010	5.242	5.536
K_2	7.007	5.2451	5.538
K_3	2.4211	6.1301	3.1511
k_1	1.4050	0.756	1.6514
k_2	2.3357	1.7484	1.846
k_3	0.8070	2.0434	1.0504
R	1.5287	1.2874	0.7956
Sort	1	2	3

Tab. 6: Data analysis of the influence of process parameters on warping deformation

	A	B	C
K_1	4.279	4.353	4.364
K_2	4.259	4.348	4.301
K_3	4.561	4.398	4.434
k_1	1.426	1.451	1.454
k_2	1.419	1.449	1.433
k_3	1.520	1.466	1.478
R	0.100	0.016	0.044
Sort	1	2	3

Tab. 7: Data analysis of the influence of process parameters on cavity residual stress

	A	B	C
K_1	15.5233	16.282	15.498
K_2	15.4867	15.263	15.743
K_3	15.62	15.085	15.388
k_1	5.17445	5.4272	5.1661
k_2	5.16222	5.0878	5.2478
k_3	5.20667	5.0283	5.1295
R	0.04445	0.3989	0.1183
Sort	1	2	3

In the above four tables, under three different levels of 1,2,3. Kl, K2, K3 respectively stand for various factors' sum of every index and k1,k2,k3 respectively represent various factors' average of every index various factors 1, 2, 3, the size of range R reflects the influence degree of each factor on the index.

Tab. 4 showed every factor's influence on shrink mark index, which was mold temperature > melt temperature > injection pressure. According to the evaluation index combined with Moldflow, which could be concluded that the optimum combination is A3B1C3, namely, when the mold temperature was 50 ℃, the melt temperature was 200 ℃, the injection pressure was 83Mpa,the smallest shrink mark index value could be obtained.

Tab. 5 showed every factor's influence on volume shrinkage ratio, which was melt temperature > injection pressure >mold temperature. According to the evaluation index combined with Moldflow, which could be concluded that the optimum combination is A3B1C3, namely, when the mold temperature was 40 ℃, the melt temperature was 200 ℃, the injection pressure was 83Mpa,the smallest volume shrinkage ratio value could be obtained.

Tab. 6 showed every factor's influence on maximum warping deformation, which was mold temperature > injection pressure >melt temperature. According to the evaluation index combined with Moldflow, which could be concluded that the optimum combination is A2B2C2, namely, when the mold temperature was 40 ℃, the melt temperature was 200 ℃, the injection pressure was 83Mpa, the smallest maximum warping deformation value could be obtained.

Tab. 7 showed every factor's influence on cavity residual stress, which was mold temperature > injection pressure >melt temperature. According to the evaluation index combined with Moldflow, which could be concluded that the optimum combination is A2B3C3, namely, when the mold temperature was 40 ℃, the melt temperature was 200 ℃, the injection pressure was 83Mpa,the smallest cavity residual stress value could be obtained.

PROCESS PARAMETERS OPTIMIZATION OF WHOLLY PLASTIC PUMP BODY INJECTION MOLDING

This paper used the modified simplex method to optimize the result of the orthogonal experiment, combining comprehensive weighted score to evaluate the injection molding, transformed function optimization into process injection molding optimization. One optimization iteration step with one injection molding simulation.

TEST INDEX WEIGHT AND COMPREHENSIVE WEIGHTED EVALUATION

Residual stress was one of the factors resulting in plastic deformation, therefore took the plastic parts quality into consideration and set its weight as 0.4. Considered the plastic parts quality and material performance, control cost and the molding cycle factors, the importance of shrink mark index, volume shrinkage rate and maximum warping deformation were near to each other. So each weight index was set to be 0.2.

First of all, Compared the test index score of each test number, Y(I) stood for the score, i for the test number i. Calculated them according to centesimal system, the maximum test index Aimax for 60 points, the lowest Aimin for 100 points, arranged various number according to their size , the adjacent two varied by five points[9-10]. According to the plastic molding quality, production efficiency and manufacturing cost, each index test should be as small as possible.

$$Y_i^* = \sum_{i=1}^{4} \left[Y(i) \times W_j \right] \quad (1)$$

Orthogonal experiment results and comprehensive weighted score were shown in Tab. 8(Y*stands for comprehensive weighted score),of the 9 tests,No.3 had the highest comprehensive weighted score, which was 85, the process parameters combination was A1B3C2.In addition to the volume shrinkage rate index in that group, the rest of the observational test index in 9 groups tests were relatively close to the minimum. In order to get the optimum process parameters combination under multiple indicators, a statistical analysis of every experiment's comprehensive weighted score was still needed.

Tab. 8: 9Group orthogonal experiment results and comprehensive weighted score

NO	Shrink mark index (%)		Volume shrinkage rate (%)		Maximum warping deformation (mm)		Cavity residual stress(MPa)		Y^*
	value	evaluation	value	evaluation	value	evaluation	value	evaluation	
1	1.100	85	0.975	95	1.41	90	5.44	65	80
2	2.386	70	1.0994	75	1.396	100	5.11	80	81
3	0.7291	90	1.1638	70	1.473	75	4.9733	95	85
4	1.168	80	0.9763	90	1.407	95	5.4783	60	77
5	2.422	65	1.0982	85	1.425	85	5.0517	90	83
6	3.417	60	1.1763	65	1.427	80	4.9567	100	81
7	0.000	100	0.9738	100	1.536	60	5.3633	70	80
8	0.4371	95	1.0988	80	1.527	65	5.1017	85	82
9	72.72	10	0.9993	90	58.17	10	5.155	75	71

Tab. 9:Modified simplex method for wholly plastic pump body parts' comprehensive weighted score test processes and results

No	Point name	Keep vertices	A(℃)	B(℃)	C(MPa)	D (%)	E(%)	F(mm)	G(MPa)	H(Y)
1	vertex		15	200	78.7	1.1	15.6	1.41	32.64	67.04
2	vertex		15	230	83	2.386	17.59	1.396	30.66	82.23
3	vertex		15	250	80	0.7291	18.82	1.473	29.84	67.19
4	vertex		30	200	83	1.168	15.62	1.407	32.87	67.48
5	vertex		30	230	80	2.422	17.57	1.425	30.31	70.46
6	vertex		30	250	78.7	3.417	18.82	1.427	29.74	74.04
7	vertex		40	200	80	0	15.58	1.536	32.18	85.7
8	vertex		40	230	78.7	0.4371	17.58	1.527	30.61	77.02
9	vertex		40	250	83	1.984	18.84	1.498	30.93	72.7
	core	1,2,3,4,5,7,8,9	28.13	223.75	80.8					
10	apex		26.25	223.75	82.9	2.135	17.16	1.419	30.8	79.66
	core	1,2,3,4,5,7,8,10	26.41	220.47	80.79					
11	apex		26.41	220.47	80.79	1.993	16.95	1.414	30.97	79.13
	core	1,2,3,4,7,8,10,11	25.96	219.28	80.89					
12	apex		21.92	208.56	81.78	1.495	16.18	1.4	32.07	77.92
	core	1,3,4,7,8,10,11,12	26.82	216.6	80.73					
13	apex		38.64	203.19	80.73	1.399	15.84	1.408	32.1	77.47
	core	1,3,4,7,8,11,12,13	28.37	214.03	80.46					
14	apex		30.49	204.3	80.46	1.346	15.88	1.39	32.37	77.34
	core	1,3,4,7,8,12,13,14	28.88	212.01	80.42					
15	apex		31.35	203.54	80.05	1.319	15.84	1.407	32.43	87.62
	core	1,3,4,7,8,13,14,15	30.06	211.38	80.21					
16	apex		38.21	214.21	80.21	1.853	16.53	1.442	31.18	89.08
17	Shrink		25.99	209.97	80.99	0.0045	16.27	1.516	31.89	85.7
	core	1,3,4,7,8,13,14,17	29.39	212.18	80.32					
18	apex		27.43	220.82	80.59	2.012	16.96	1.417	30.96	89.24
19	Shrink 1		30.37	207.86	80.19	1.495	16.12	1.412	31.94	87.93
20	Shrink 2		29.88	210.02	80.25	1.58	16.26	1.402	31.7	87.84
21	Shrink 3		29.64	211.1	80.29	0.0191	16.33	1.516	31.65	85.52
	core	1,3,7,8,13,14,17,21	29.34	213.57	79.98					
22	apex		28.69	227.14	79.98	0.1529	17.39	1.513	30.87	86.03
	core	1,3,7,8,14,17,21,22	28.1	216.56	79.89					
23	apex		17.56	229.94	79.05	0.1955	17.59	1.491	30.97	86.05
	core	1,3,7,8,17,21,22,23	26.48	219.77	79.71					
24	apex		22.48	235.23	78.97	2.659	17.91	1.413	30.11	91.03
25	Shrink 1		28.49	212.04	80.09	1.659	16.41	1.402	31.66	91.19
26	Shrink 2		27.49	215.9	79.9	1.701	16.21	1.408	30.75	87.11

OPTIMIZATION OF MODIFIED SIMPLEX METHOD

According to the basic principle of modified simplex method, Researchers optimized the maximum warping deformation of wholly plastic pump body parts, promoted the injection molding orthogonal experiment steps of wholly plastic pump body parts , and recorded the processes and results in Tab. 9(A for Mold temperature, B for melt temperature, C for injection pressure, D for shrink mark index, E for volume shrinkage rate, F for maximum warping deformation, G for first main direction's cavity residual stress, H for comprehensive weighted score).

In Tab. 9, It could be seen that along with started from the 17th sites ,the comprehensive weighted score values of wholly plastic pump body parts had already close to the minimum, namely the injection molding process parameters were beginning to the be close to the optimal process parameters. When the injection molding process parameters range were as follows: mold temperature was 25.99 ~ 40℃, melt temperature was 200 ~ 211.1℃, injection pressure was 80 ~ 81Mpa, then most comprehensive weighted score values were small. Which Suggested that the best response value of comprehensive weighted score of wholly plastic pump body parts' injection molding process parameters were relatively stable in that area. In the practical work if people could combine these two methods, it would achieve better effect for the optimization of plastic parts molding process . In this test, researchers chose the best response value's (No.25) injection molding process parameters as wholly plastic pump body parts' optimum parameters of injection molding conditions. The wholly plastic pump body parts' injection molding process parameters were as follows: Mold temperature was 28.49℃; Melt temperature was 212.4℃;Injection pressure was 80.09MPa. At this time, wholly plastic type of pump body parts' comprehensive weighted score value was 91.19 and results of the test evaluation index were respectively as follow: plastic shrink mark index was 0.0191%, volume shrinkage rate was 0.0191%, maximum warping deformation was 1.516mm, and the first main direction's cavity residual stress was 31.65MPa,which could be concluded from the experiment simulation results that every evaluation indexes basically reached its optimum value.

PRODUCTION APPLICATION

Applying the best simulation test process parameters and model design scheme to the practical production of a pump factory, used the optimum process parameters to do the trying die,which could produce the products meeting the accuracy requirement. The parts' material was PP+T20, belonging to the linear alkenes polymers. The gating system chose figure 2a, whose main channel inlet diameter was 15mm,length was 170mm,draft Angle was 3°, runner diameter was 11mm, and the side gate inlet diameter was 4 mm, draft Angle for 15°,length for 14 mm. Injection molding process parameters were mold temperature for 28.49℃ and 212.4℃,Injection pressure for 80.09MPa,filling time for 3.213 s, clamping force for 2812.9 t . The injection mold and its part were shown in Fig. 3.

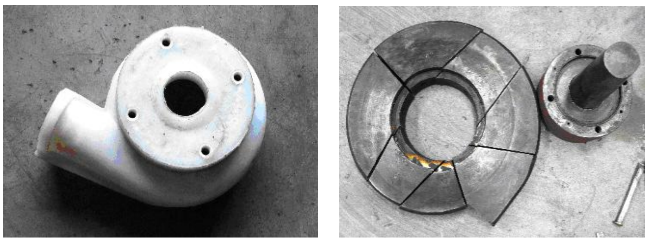

Fig. 3: Molding part and product

CONCLUSION

Obtained the best molding gating system of wholly plastic pump injection, Parts chose the one module and two cavities, gate location closing to the parts' big end scheme, and its main channel inlet diameter was 15mm,length was 170mm,draft Angle was 3°, runner diameter was 11mm,and the side gate inlet diameter was 4 mm, draft Angle for 15°,length for 14mm.The length of main channel, runner and side channel was determined by the die. Designed the L9(33) Orthogonal Experiment table, acquired the best process parameters of wholly plastic pump injection by using Modified Simplex Method and Comprehensive Weighted Score, which were shown as follows: mold temperature was 28.49℃,melt temperature was 212.4℃;injection pressure was 80.09MPa. shrink mark index was 0.0191%、volume shrinkage rate was 16.33%,maximum warping deformation was 1.516mm and first main direction's cavity residual stress was 31.65MPa.Applied the design scheme of die to practical production, produced wholly plastic pump's mould, obtained the wholly plastic pump according to the optimum process parameters, and the parts met the requirement.

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