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MULTIPLE REGRESSION ANALYSIS USING MINITAB TO DETERMINE THE CORRELATION BETWEEN THE PROCESS PARAMETERS AND THE VOLUMETRIC SHRINKAGE OF WAX PATTERN IN INVESTMENT CASTING

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ABSTRACT

The investment casting process is gaining prominence, especially in the production of complex, high-quality components with near-net shapes, due to its exceptional versatility and adaptability. A major challenge in this process, however, is the shrinkage of wax patterns, which substantially affects the quality of the final product. This shrinkage is influenced by multiple variables, including the wax composition, mold and injection temperatures, pressure, and duration of injection. In this study, the Moldflow simulation software was utilized to evaluate volumetric shrinkage. The resulting data was then used to develop a multiple regression model in minitab that establish a correlation between process parameters and volumetric shrinkage.

Key Words: *Investment casting; volumetric shrinkage; wax pattern*

INTRODUCTION

Investment casting is a specialized manufacturing technique used for producing high quality, net-shape complex parts. It is considered as the most ancient of metal casting arts. Technological advances have also made it the most modern and versatile of all metal casting processes [1]. Difficult to machine metals are best shaped by this process. Excellent surface finish is a major advantage of this process [16]. The steps involved in the investment casting process are as follows: wax injection process, pattern assembly, ceramic shell building, dewaxing, Pre-heating, metal casting, knocking out of the ceramic shell and cutting off the components, and minor finishing operations.

W. Bonilla et al. [17] found that not only the composition of wax blend is affecting the quality of wax patterns, but also there are some other factors such as geometry of the cast part and injection process parameters like injection temperature, injection pressure, die temperature, cycle time etc., which are also plays a significant role in making a good wax pattern. It is necessary to identify the important control factors and then, the optimal combination of selected control factors should be analyzed for improving the quality of the wax patterns. Rahmati et al. [13] presented a rapid wax injection tool of a gearbox shift fork was designed, simulated, and manufactured using rapid prototyping and rapid tooling technology to save time and cost of producing wax models used for the investment casting process. The model of the gearbox shift fork part was analyzed using CAE simulation software such as MoldFlow to investigate the ideal and optimum conditions of tool operation during wax injection molding process. Parameters investigated include filling patterns, temperature profiles, residual stresses, and tool clamping force, the pressure at different time intervals, air trap spots locations, wax model weld lines and freeze time. The results from analysis were compared with conventional wax model production methods and it has not only confirmed the success of such application, but also proves valuable benefits with respect to the common tooling techniques.

S. Pattnaik et al [11] presented the wax blend, to be used in the investment casting process, is prepared by mixing different waxes and starch as filler material to reduce the shrinkage of wax patterns. The effect of the injection process parameters on the dimensional stability of the wax patterns made using silicon rubber mould has been studied and the optimum injection process parameters to reduce the shrinkage of wax patterns have been suggested.

This investigation focuses on four crucial process parameters: mold temperature, injection temperature, injection pressure, and injection time. The researchers evaluate the quality of wax patterns by measuring their volumetric shrinkage as a performance indicator. To validate the efficacy of the proposed methodology, a confirmation analysis is conducted using moldflow simulation software.

MATERIALS AND METHODS

Wax pattern material choice

The wax pattern's accuracy directly affects the final casting's precision. Ideal wax pattern qualities include: high dimensional accuracy, significant hardness, superior surface finish, excellent flowability, easy mold release, and bubble-free injection molding [8]. Cerita wax F30-75 was selected based on Rahmati et al. [16].

Wax injection process parameter selection

The selection of wax injection process parameters for investment casting is based on research by Pattnaik et al. [14] and Bonilla et al. [20].

Process parameter ranges were obtained from industry sources. To design experiments and assess the effects of mold temperature, injection temperature, pressure, and time on wax pattern quality in investment casting, three levels were chosen for each parameter.

Table 1: The level of wax injection process parameters

Symbol	Process parameters	Range	L1	L2	L3
t_m	Mold temperature	14-16(ºC)	14	15	16
t_i	Injection temperature	60-70(ºC)	60	65	70
p_i	Injection pressure	1.0-1.5(MPa)	1.0	1.3	1.5
t_s	Injection time	5-10(S)	5	8	10

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To select an appropriate orthogonal array for conducting the experiments, the degrees of freedom are to be computed. Hence, the total DOF required for three parameters, each at three levels is [4 x (3-1)], i.e. 8. Thus L9orthogonal array was selected to make the present analysis.

WAX PATTERN MODEL

In this study, to analyze the wax injection molding a 3-D model of an industrial part hanger is created in part module of Pro/Engineer wildfire5.0 software shown in Fig 1.

Figure 1: Wax pattern model

Conducting the Analysis for Selected Orthogonal array

Moldflow package was applied to simulate and predict different scenarios and investigate the effect of injection parameters. The 3D model of the hanger part was imported and with the combinations of wax injection process parameters analyses were performed in Moldflow as per selected L9 orthogonal array. The value of volumetric shrinkage at ejection is selected according to H. Oktem (2011) cited in [8] as a response of the analysis. The results obtained from analysis are shown in response table below:

Table 2: Response table for selected orthogonal array L9

Analysis No.	Process parameters				Volumetric shrinkage, V_S (%)
	t_m(°C)	t_i(°C)	p_i(MPa)	t_s(s)	
1	14	60	1.0	5	4.769
2	14	65	1.3	8	5.120
3	14	70	1.5	10	5.477
4	15	60	1.3	10	4.765
5	15	65	1.5	5	5.189
6	15	70	1.0	8	5.515
7	17	60	1.5	8	4.759
8	17	65	1.0	10	5.157
9	17	70	1.3	5	5.578

Regression modeling

A multiple regression analysis using Minitab 17.0 have performed to determine the mathematical relationship between the process parameters and the volumetric shrinkage obtained from the values of the analyses in moldflow based on the wax injection moulding.

The regression equation is as follows:

$$V_S\,(\%) = 0.131 + 0.0116t_m + 0.0757t_i - 0.0110p_i - 0.00927t_s \quad \ldots\ldots\ldots\ldots\ldots \; (1)$$

The above equation shows empirical relationship between independent variables such as mold temperature (t_m), injection temperature (t_i), injection pressure (p_i), injection time (t_s) and dependent variable i.e. volumetric shrinkage (V_S).

RESULTS AND DISCUSSION

Optimum combination of process parameters for minimum volumetric shrinkage

Table 5: Optimum values of process parameters

Symbol	Process parameters	Optimum value
t_m	Mould temperature (^oC)	13
t_i	Injection temperature (^oC)	60.2
p_i	Injection pressure (MPa)	1.47
t_s	Injection time (sec)	9.8

At above optimum value the volumetric shrinkage from regression equation is to be calculated as 4.731 %.

Confirmation analysis

The confirmation analysis were conducted in moldflow simulation software with optimum set of process parameters, i.e. Mould temperature at 13 ^oC, injection temperature at 60.2 ^oC, injection pressure at 1.47 MPa and the injection time at 9.8 seconds. The volumetric shrinkage of the wax pattern was found to be 4.738%, which was closer to the predicated optimal value of volumetric shrinkage shown in figure below.

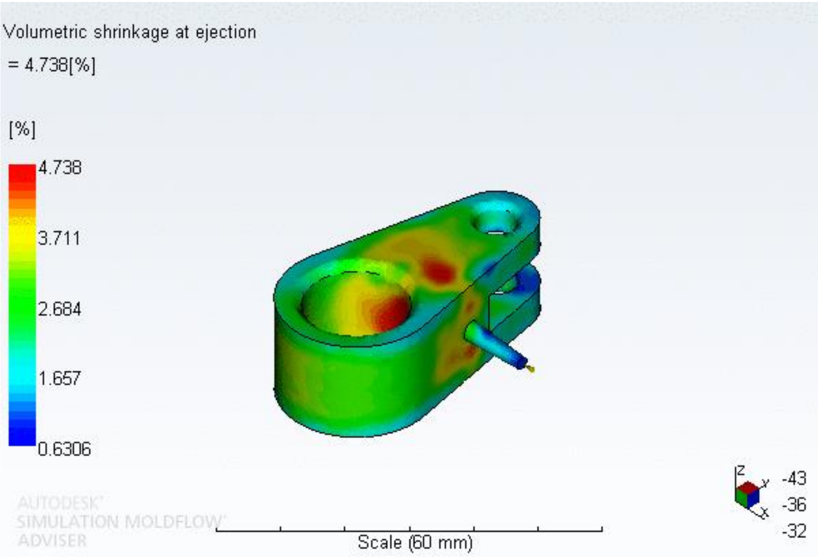

Figure 2: Volumetric shrinkage at Optimum value

CONCLUSION

In the present analysis, Autodesk simulation Moldflow software is used for analyzing wax injection process in investment casting. The predicted optimum volumetric shrinkage from regression equation and moldflow analysis are 4.731% and 4.738% respectively. It is found that the predicted results by the proposed method complied well with the analysis results.

As a result, it is seen that this study is sufficient to model the shrinkage under the process parameters.

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