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DIMENSIONAL ACCURACY ANALYSIS IN CASTING USING EASILY FUSIBLE MODELS

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Abstract: *Investment Casting (IC) technology is a fast and efficient way of fabricating metal parts with complex shapes, in small volume production. The objective of the paper is to study the accuracy of the wax patters, cast in different temperature conditions and to optimize the gating system for the wax tree. The accuracy of silicone rubber mold and wax models is the most important element for obtaining tight casting tolerances. Also the size, position and orientation of the wax models onto the sprue, play an important role in providing a high quality of the cast part. Measurements were made within regular conditions, considering the parameters that influence the process such as: temperature of melting wax, silicone rubber mold temperature and the diameter of the funnel.*
Key words: *accuracy, shrinkage, RSM, wax patterns*

1. INTRODUCTION

One of the most used technology for prototypes or small series parts production is investment casting (IC) or lost wax casting (LWC) process. The process involves the use of wax, ceramic powder and molten metal, to produce precisely replicated parts in an economical way. A wax model is a precise wax design that contains all the details that are desired in the final product. Undesirable details, such as scratch, will also be perfectly reproduced, because lost wax casting produces an extremely precise reproduction of the model. The IC process allows for a variety of component features that are not accessible through other manufacturing techniques.

IC is considered to be one of the more accurate casting processes in terms of shape and dimensions (Ramos, 2009). To increase the dimensional accuracy of investment cast prototypes, the investment casting process needs to be better understood and improved. The influence of the pattern geometry is difficult to capture in predicting dimensional changes caused by wax solidification.

The purpose of this paper is to optimize the wax casting parameters so as to obtain pieces of good dimensional accuracy. Using response surface method we propose a mathematical model for predicting contractions of wax patterns depending on process parameters.

2. RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes (Myers, 2009). The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response.

Design of Experiment (DoE) is a method used to determine the relationship between the different factors affecting a process and the output of that process. DoE involves designing a set of experiments, in wich all relevant factors are varied systematically. Analyzing the results of experiments, these helps to identify optimal conditions, the factors that most influence or not the results (Owens, 1997).

3. EXPERIMENTAL DESIGN

To achieve the experiments we used a pyramid as a master model (Fig. 1). Aim of the study is to highlight changes and dimensional accuracy of wax patterns (Fig. 2) cast in silicone rubber mold (Balc, 2001).

Fig. 1. Master model, TUCN

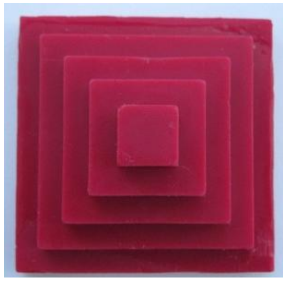

Fig. 2. Wax pattern, TUCN

In this paper a central composite design (CCD) with two factors was used for experimental design. A good designed series of experiments can reduce the number of experiments. Wax temperature (Tc) and silicone rubber mould temperature (Tm) are independent variables and their values are in the table 1.

Factors	Levels				
Wax Temperature (° C)	72	73.9	78.5	83.1	85
Mould Temperature (° C)	25	29.39	40	50.61	55

Tab. 1. Factors and their levels

The wax patterns were made using 864 Red Wax with the injection temperature of 72°C - 74°C. The sprue diameter should be as large as possible and the distance of the sprue should be as short as possible. From the planning of experiment a number of 13 models was necessary. The wax was injected in the mould and allowed to cool and solidify for two hours before the mould was opened and the wax was removed from the mould. After the wax patterns were removed from the mould their dimensions were measured using high precission equipment.

The experimental data were processed using Design Expert software.

4. RESULTS AND DISCUSSIONS

Following the analysis performed using Design Expert software, the influence of wax temperature and mould temperature, concerning the dimensional accuracy of wax patterns we got the next results.

Wax casting temperature (Tc) is the parameter that has a major influence on dimensional accuracy of wax patterns. With increasing temperature also increases wax pattern contractions (Fig. 3). In the experiment the wax temperature varies from 74 °C to 85°C, resulting a contraction variation from 2.5% to 3.1%, so a contraction variation of 0.6%.

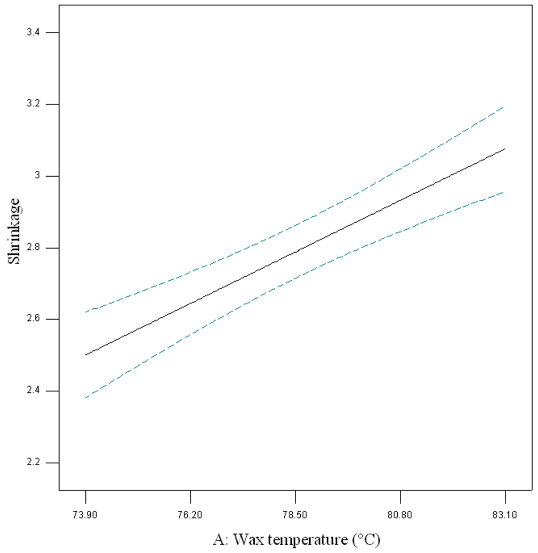

Fig. 3. Shrinkage variation as a function of wax temperature

The silicone rubber mold temperature (Tm) is another important parameter of the casting process. With increasing the silicone rubber mold temperature also shrinkage increases. Mold temperature is varied in the experiment from approximately 30°C to 50°C (Fig. 4), the contractions resulting in a variation from 2.7% to 2.9%, so a contraction variation of 0.2%.

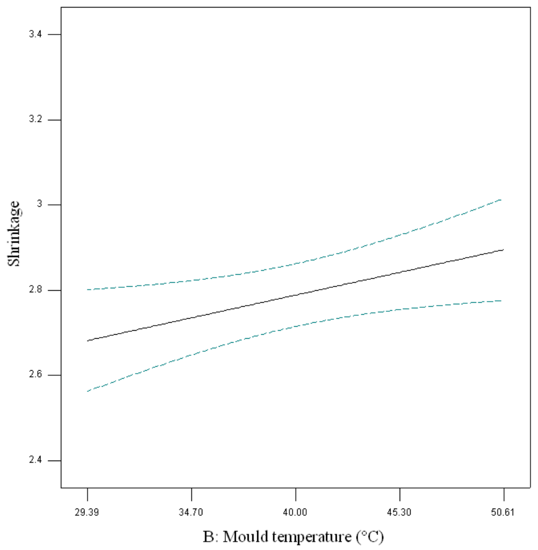

Fig. 4. Shrinkage variation as a function of mould temperature

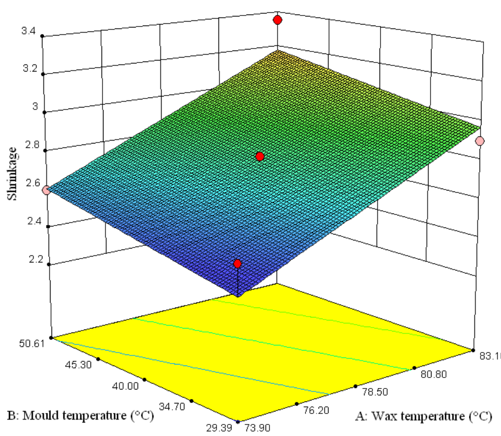

Fig. 5. Wax temperature and mould temperature influence on shrinkage variation

Analyzing the response surface graphic (Fig. 5) we conclude that to achieve a good dimensional accuracy and low contraction of the wax pattern, it is recommended a casting temperature as close to the melting point temperature and also a mould preheating temperature as low. But using too low temperatures to fill mold appear some problems: incomplete fill, ripple and knit lines, surface defects.

To achieve a wax pattern as high dimensional accuracy is important to accomplish an optimization of casting temperatures. Thus we recommend using a wax casting temperature with 8°C higher than flow temperature and a mold temperature between 30-35 °C. To make a wax pattern to a better dimensional accuracy, we take account of the contraction that occurs during the process. Thus the master model size should be increased to compensate the shrinkage of wax (Rahmati, et al., 2009).

In general, dimensional deviations of wax models are influenced by the master model, silicone rubber mold and wax injection. Dimensional deviation of silicone rubber mould is insignificant and can be neglected.

5. MATEMATICAL MODEL

Starting from experimental data analysis to establish a mathematical model able to describe the dependence of dimensional accuracy of parts and temperature respectively wax casting mold temperatures.

The model is based on observed data from the process and is an empirical model:

$$A = -2.528 + 0.062 \times Tc + 0.01 \times Tm \qquad \textbf{(1)}$$

Where: *A* is the predicted response in real value, *Tc* is the wax temperature and *Tm* silicone rubber mould temperature.

Statistical testing of the empirical model has been done with the Fisher's statistical test for Analysis Of Variance – ANOVA. The ANOVA test applied to the individual coefficients of the model, shown their significance. In this case the wax temperature and silicone rubber mould temperature are both significant model terms.

6. CONCLUSIONS

The objective of the paper is to study the accuracy of the wax patters, cast in different temperature conditions and to optimize the gating system for the wax tree. Investment casting tolerances are determined by the size and shape of the casting, as well as by different process factors.

When casting wax patterns, we recomand a wax temperature with 8°C higher than the injection temperature and a mould temperature between 30-35°C. Using those parameters we have obtained patterns in good dimensional accuracy, also taking account of the contractions that occurs during process.

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