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MODELING AND GRAPHIC OPTIMIZATION OF VACUUM CASTING PROCESS OF WAX PARTS IN FLEXIBLE MOLDS

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Abstract: The research presented in this paper aims at modeling and optimization of vacuum casting process wax parts in silicone rubber molds based on the response surface method (RSM) and bi-factorial dispersion analysis. In this case of wax parts casting, the dependent variable considered is mold filling time (t_{fill}) and the independent variables are wax temperature (T_w) and mold temperature (T_m).In this particular case, the best combination of process parameters is determined by graphical optimization method. ***Key words:*** *modeling, simulation vacuum casting, response surface methodology.*

1. INTRODUCTION

Design of experiments method (DOE) uses the orthogonal arrays to organize the parameters affecting the processes and also their levels of variance. Thereby, it can be tested a limited set of parameters combinations instead to check all possible combinations like factorial design. This methodology allows saving time and resources by determining with a minimum number of experiments which factors most affect the process results.

1.1 Response Surface Methodology

This method is used in the empirical study of relationships between one or more responses and a group of variables **Error! Reference source not found.**. Most applications of Response Surface Methodology (RSM) are cases where it is assumed that multiple input variables (independent variables) influence the process performance or its quality characteristics, usually named dependent variables or responses [5]. For the practical application of RSM it is necessary to develop a model for the approximation of the real response surface. Mathematical models of approximation are empirical being created on the basis of data collected from the process or from process simulation. Complex models are analyzed most of the times, through the techniques of multiple linear regression. Model development is done in several stages: choosing the regression method, estimation of parameters of regression model and checking model adequacy.

1.2 Dispersional analysis of variance (ANOVA)

ANOVA is used in RSM to verify if a particular variable should or should not be included in the model. Most criterion used for adding or removing a variable is based on partial F test. A few objectives can be determined by unifactorial dispersion analysis. Involvement in the analysis of two factors requires a analyse tool that can differentiate the influence of the first factor, the influence of the second factor and their combined influence (the interaction of those two factors). For this reason, it appeals to bifactorial dispersion analysis.

Originality of this work consists in modeling and optimization of casting processes under vacuum; considering the subject of this work unique and we have a few information about it in the literature. Vacuum casting of wax parts is analyzed by simulation using specific software and experimental research.

2. RESPONSE SURFACE METHOD APPLICATION FOR MODELING AND

OPTIMIZATION OF VACUUMCASTING PROCESS

Vacuum casting is a modern technique that has proved its appropriateness and effectiveness in the development of new products, because the achievement of the parts in small batches and in production of unique items at low prices and a reduced manufacturing time, being one of the most interesting and spectacular applications of the RP models [4] ,[5]. Optimization of any process is based on a mathematical model. Mathematical models can be used in order to find optimal conditions, but also as an important source of information, necessary for the optimal management of technological processes.

The objective of this paper is to develop mathematical models that describe the correlation between different parameters of the vacuum casting process of wax parts in silicone rubber molds. The work has been done in a case study for a complex shaped part illustrated in the figure 1.

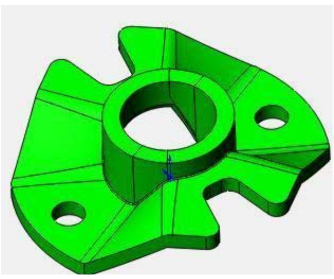

Fig. 1. Part model (case study)

The studies presented in this paper describe the methodology for the development of three mathematical models. The first one establishes the link between mold filling time, the temperature of melted wax and the temperature at which the mold is heated:

$$t_{fill} = f(T_m, T_c). \qquad (1)$$

where:

t_{fill} – mold filling time[s];

T_c – temperature of melted wax [^{0}C];

T_m – temperature of heated mold [^{0}C].

For the optimization of vacuum casting process it was adopted the central compositional planning. For this study we used The Design Expert 8.0.4.

3. MODELING STAGES AND OPTIMIZATION OF VACUUM CASTING PROCESS

First phase of RSM is dedicated to establish the optimization conditions, then the response surface between process variables and objective function is created. Using the response surface and a conventional optimization method, the optimal combination process of parameters is established. It is used a simple function called the response surface, the procedure is very fast (Figure 2). It should be pointed out that the optimal solution accuracy depends on approximation accuracy of response surface. As noted above, in RSM the choice of parameters is generally achieved by designing experiments and numerical analysis and it is repeated many times as are set out in planning experiments.

4. VACUUM CASTING PROCESS MODELING

The responses of the dependent variable, meaning fill time (t_{fill}), has been achieved by virtual experiments, by simulations with Autodesk MoldFlow software.

The part material chosen from software database is the wax 865 Green, produced by Argüeso. Its properties are presented in Table 1.

Table 1

Technical specifications of wax 865 Green

Technical data	Method	Typical value
Color	Visual	Green
Dropping point	ASTM D 3954	70-78^{0}C
Curing point	ASTM D 938	64-68^{0}C
Hardness at 25^{0}C	ASTM D 1321	5-10±0.1mm
Viscosity al 100^{0}C	ASTM D 3236	80-110 mPa.s
Density		1.05g/cm^3

An example of mold filling simulation is shown in Figure 3. To study factors influencing the filling of silicone rubber mold cavity, it compares the groups characterized by temperature of heated mold, the temperature melted wax temperature. The purpose of this study is to determine whether mold filling depends on the temperature of heated mold, melted wax temperature or on the combined effect of these two factors.

For numerical analysis, the values of independent variables were selected according to preliminary tests. Information about the size range of values are presented in Table 2.

In Table 3 is presented central compositional programming array obtained by simultaneous modification of the five levels of the variables.

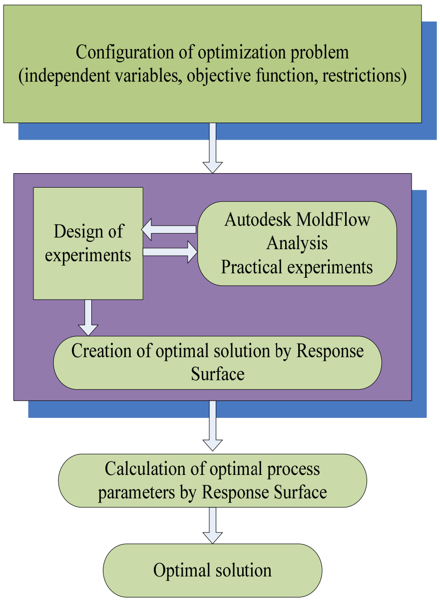

Fig. 2. Optimization using numerical analysis and response surface method [3]

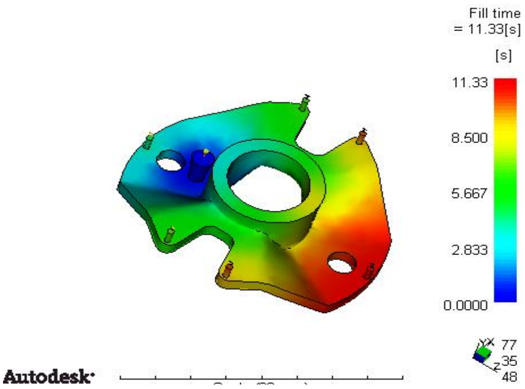

Fig. 3. Simulation of the mold filling

Independent variables (T_m and T_w) are shown both encoded version and with actual values. Response variable values, mold fill time t_{fill}, obtained from the above simulations are shown in the same table. To determine which of the three mathematical models best describes the relationship between the dependent variable and independent variables were used for statistical F (Fischer), the coefficient of determination R^2, adjusted coefficient of determination R^2_{adj}, and predicted residual error sum of squares (PRESS).

Based on these data was selected quadratic model. The value of 7.61 for Fischer statistic implies that the model is significant.

Table 2

Variation range of independent process variables

Process variables	Code	-α	-1	0	+1	+α	Step
Temp. of heated mold [°C]	T_m	13.78	20	35	50	+56.21	6.21
Melted wax temp. [°C]	T_c	56.89	60	67.5	75	+78.1	3.10

Table 3

DOE array for mold filling time t_{fill}

Ex. no.	Encoded variables		Actual values of independent variables		Res-ponse
	T_m	T_w	T_m	T_w	t_{fill} [s]
1	-1	+1	20	75	7.5
2	+1	+1	50	75	20.5
3	+α	0	56.21	67.5	50.6
4	0	+α	35	78.11	11.2
5	0	-α	35	67.5	14.8
6	+1	-1	50	60	20.6
7	-1	-1	20	60	3.4
8	0	0	35	67.5	10.9
9	-α	0	13.78	67.5	5.6

There is a probability of 0.95% of the mean value of the model to be out of the confidence interval. The significant parameters of the model proposed, are identified.

Regression equation of the mold filling time is:

$$t_{fill} = -70.87709 - 0.67994T_m + 2.38687T_w + \\ + 0.029834T_m^{\ 2} - 0.015398T_w^{\ 2} \qquad (2)$$

where:

t_{fill} – response variable, mold filling time[s];
T_m – temperature of heated mold [°C];
T_w – temperature of melted wax [°C];

Based on the mathematical model, in Figure 4 it is presented the dependence of the mold filling time relative to the temperature at which wax is melted and the temperature at which silicon rubber mold is heated. The range of the mold temperature is 20^0C to 50^0C, the temperature at which molten wax is between 60^0C and 75^0C. It can see that the mold filling tome decreases with increasing of mold temperature.

At high mold temperature the filling time decreases slightly with decreasing of melted wax temperature. At low values of mold temperature (20^0C), the phenomenon is the reverse, namely the filling time slightly increases with the wax temperature. In conclusion for shorter mold filling time, it is recommended high mold temperature but not more than 50^0 C.

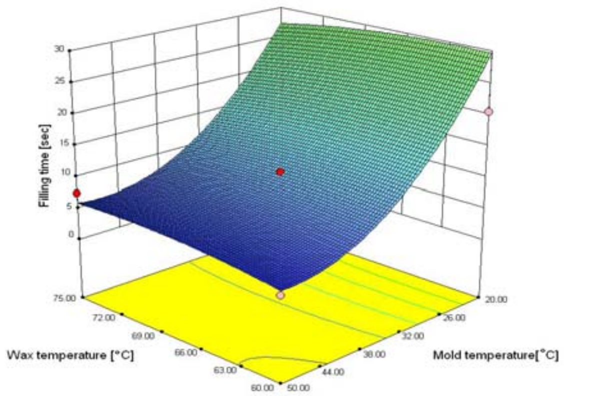

Fig. 4. Variation of mold filling time depending on the independent variables

5. CONCLUSIONS

This paper presents the development methodology of mathematical model describing the relationship between mold filling time, melted wax temperature and temperature of heated mold. The mathematical model was validated through comparison with experimental results both graphical and numerical simulation.

6. REFERENCES

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Modelarea si optimizarea grafica a procesului de turnare sub vid in matrite din cauciuc siliconic a pieselor din ceara

Cercetarile prezentate au ca scop dezvoltarea unui model matematic a timpului de umplere a matritelor din cauciuc siliconic in raport cu temperatura la care este topita ceara, respectiv cu temperatura la care este incalzita matrita. Ecuatia de regresie obtinuta este valabila doar pentru ceara analizata si anume Green 865 produsa de firma SRS.

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