TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics and Mechanics
Nr. XX, Vol. xx, 20xx

CAE SIMULATION AND RESPONSE SURFACE METHODOLOGY FOR OPTIMIZATION OF VACUUM CASTING PROCESS

Sever-Adrian RADU, Nicolae PANC, Vasile Dănuț LEORDEAN

Abstract: *In this paper CAE Simulation, in particular Autodesk MoldFlow and Response Surface Methodology (RSM) which used in order to optimize the wax vacuum casting process. In the first phase, using the Autodesk MoldFlow program it was found the optimal point of casting and in the same time by simulating it was determined points where it was possible to create air bubble in the cast parts; in that places it was fixed the air vents.*
Key words: *rapid tooling, CAE Simulation, Silicone Rubber Mold, Selective Laser Sintering, Response Surface Methodology.*

1. INTRODUCTION

Vacuum Casting is an alternative technique for the production of prototype castings which mimic injection molded parts such as ABS, PP, PMMA, PA and different grades of rubber. A form of Room Temperature Vulcanizing (RTV) molding known as Vacuum Casting is widely used for producing accurate silicone tools for casting parts with fine details and very thin walls.

On a widely scale, the researchers have studied the optimal location of the inlet and vents. Cai [1] was one of the first who studied these optimal locations and came up wish some useful closed form solutions for the wet length, mold filling time and pressure distribution of rectangular, trapezoidal and circular sections. Jiang et. al [2] used a genetic algorithm to optimize the location of the inlet and vent wish a mesh distance based approach model. Boccard et al. addressed the issue of excessive calculation times and therefore presented a fast geometrically based model to determine the location of the vents on flat RTM molds [3].

In [4] it was proposed an optimization algorithm coupling flow simulation and genetic algorithms. In that case 1% of simulations were necessary for the possible permutations of gates and vents.

2. METHODOLOGY

In this research, first the 3D model of the part was created in SolidWorks software after that it was saved in a STL file. The STL file format has become the Rapid Prototyping industry's standard data transmission format. This format approximates the surfaces of a solid model with triangles, as shown in figure 1 [5].

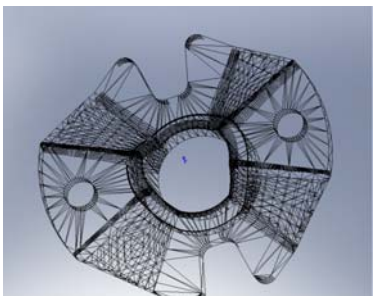

Fig. 1. STL model of the part

This STL file is going to be transferred to the Sintering Laser Sintering (SLS) system which exists in the Department of Manufacturing Technology from Technical University of Cluj-Napoca. The SLS process is one of the most effective and versatile rapid prototyping methods available today [6]. The SLS manufactured part is represented in figure 2.

3. TOOL SIMULATION AND ANALYSIS

Computer-aided engineering (CAE) can reveal model design problems, vacuum casting parameters and difficulties encountered during operation. Autodesk MoldFlow package was applied to simulate and predict different scenarios and investigate the optimum tool design and vacuum casting parameters.

After the part was saved as a file IGS it was imported in the Autodesk MoldFlow, at then it will follow the mesh of the model, it was obtained 33066 nodes, as you can see in fig. 2.

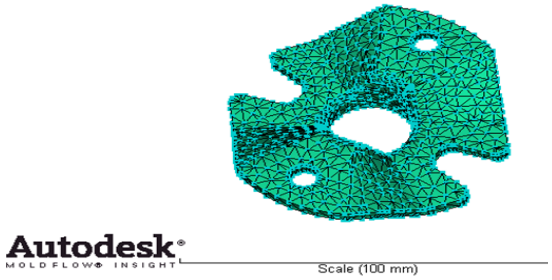

Fig. 2. Meshing the model

In menu Process Settings Wizard it was introduced the characteristics of silicone rubber mold (ESSIL 291 produced by the Axson company from France) according to datasheet [8] like in the fig. 3.

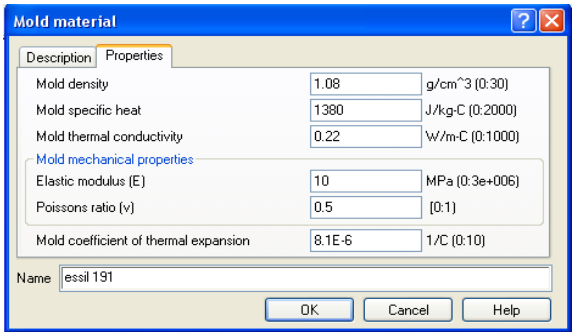

Fig. 3. Meshing the model

The Autodesk MoldFlow software determined the best surface where it might place the pouring gate (the blue zone), as shown in fig. 4.

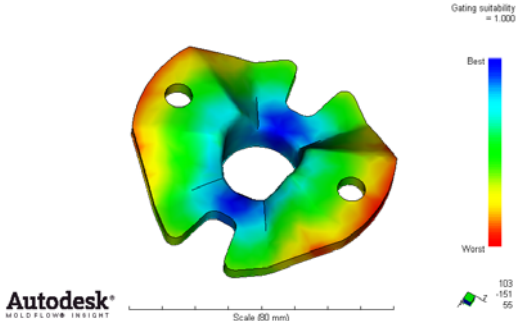

Fig. 4. Optimal gate location

During the vacuum casting process in the part may appear air bubbles, as you can see in the marked zone (fig. 5).

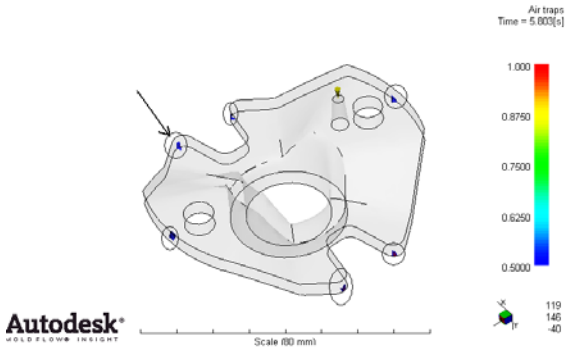

Fig. 5. Air bubbles

4. THE SILICONE RUBBER MOLD PROCESS

Casting is the process of producing a part in a mold. Vacuum casting is ideal for producing small quantities of parts, especially if aesthetics are important. The master part was manufactured by SLS. The process includes next steps:

- preparation of the master model and adjustment inside the casting frame;
- preparation of one or several gates and vents (in our case one gate and 6 vents);

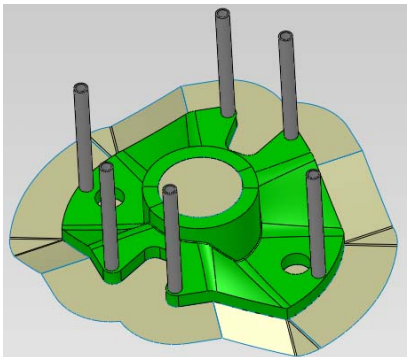

Fig. 6. The part with all 6 vents

- mixing of the two component silicone and pre-evacuation in the vacuum chamber;
- casting the silicon into the mold with subsequent evacuation in the vacuum chamber;
- after the mold has been cured in the oven it is opened and the master model is taken out. Wax casting is a much simpler process. First, the wax heated in the heater cup to 75^0C (above its melting point of 72^0C – 74^0C). The patterns were made using 866 Blue Wax [10], very flexible wax for fragile pieces with low shrinkage and medium flow behavior.

Fig. 7. Wax pattern

5. RESPONSE SURFANCE RESPONSE

The Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [7].
RSM postulates a model of the form:

$$y(x) = f(x) + \varepsilon . \quad (1)$$

where $y(x)$ is the unknown function of interest, $f(x)$ is a known polynomial function of x and ε is random error which is assumed to be normally distributed with mean zero and variance σ^2.The polynomial function $f(x)$, used to approximate $y(x)$ is typically a low order polynomial which in this paper is assumed to be quadratic:

$$\hat{y} = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i} \sum_{j>i} \beta_{ij} x_i x_j \quad (2)$$

The parameters: $\beta_0, \beta_i, \beta_{ii}$ and β_{ij}, of the polynomial in equation 2 are determined through least squares regression which minimizes the sum of the squares of the deviations of the predicted values. In this paper a Central Composite Design (CCD) with two factors was used for experimental design. A good design series of experiment can reduce the number of experiments. Number of vents and silicone rubber mold temperature are independent variables and their values are illustrate in table 1.

Table 1

Factors and their levels

Name	low	high	-alpha	+alpha
Vents	4	8	3.1715	8.8284
Mold temp.	60	75	56.893	78.106

Analysis of the model proposed for the observed data, and calculation of its coefficients, were carried out using the Design Expert software 8.0.4 [9].

Table 2

Experimental plan propose by Design Expert

Run	Independent variables		Response variable
	Vents [number]	Mold temp. [^{0}C]	Air bubbles [g]
1	8	60	-0.0348
2	3	67.5	-0.4526
3	6	56.89	-0.077
4	6	67.5	-0.0291
5	4	60	-0.4408
6	6	78.11	-0.0416
7	6	67.5	0.0451
8	6	67.5	0.077
9	4	75	-0.2659
10	9	67.5	-0.0977
11	6	67.5	0.0291
12	8	75	-0.0785
13	6	67.5	-0.118

6. RESULTS AND DISCUSSION

Starting from experimental data analysis to establish a mathematical model able to describe the dependence of air bubbles of parts and number of vents and mold temperature. The model is based on observed data from the process and is an empirical model:

$$g_b = -6.7101 + 0.7216A + 0.1259B - 0.03429A^2 \quad (3)$$

where g_b is the predicted response in real value, A is the number of vents and B is the mold temperature. Statistical testing of the empirical model has been done by the Fisher's statistical test for Analysis of Variance – ANOVA test applied to the individual coefficients in the model, to test their significance.

The F-value is the ratio of mean square due to regression to the mean square due to residual. The model F-value of 13.72 implies that the model is significant. The 3D response surface given by Equation (3) is shown in figure 8.

7. CONCLUSIONS

In this paper a new approach is proposed for optimization for vacuum casting process using the wax parts. This approach consists in the use of Autodesk MoldFlow simulation and

Response Surface Methodology in order to establish a relationship between the quantity of air bubbles, mold temperature and number of vents.

Table 3

Analysis of the model propose by DOE

Source	SS	DF	MS	F-value	P-value
Model	0.32	5	0.063	13.72	0.0017
A	0.14	1	0.14	29.83	0.0010
B	4.107e-003	1	4.107 e-003	0.89	0.3767
AB	0.012	1	0.012	2.59	0.1515
A^2	0.14	1	0.14	31.16	0.0008
B^2	0.012	1	0.012	2.66	0.1466
Residual	0.032	7	4.61e-003	-	-
Total	0.35	12	-	-	-
SS – sum of square; DF – degree of freedom; MS – Mean Square					

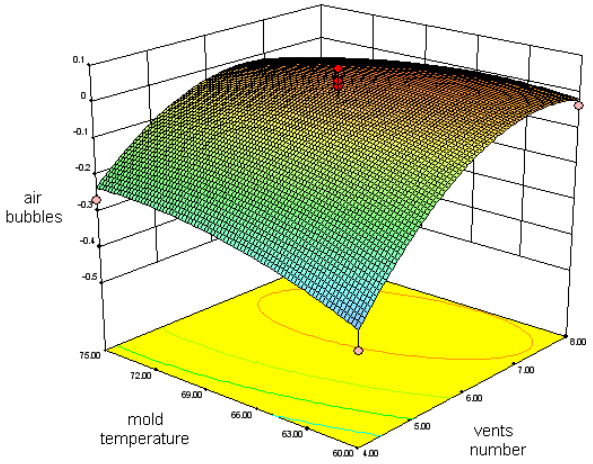

Fig. 8. The 3D response surface

8. REFERENCES

[1] Cai Zhong, *Analysis of mold filling in RTM processes,* J. Compos Mater 26 (9): 1310-38, 1992.

[2] Jiang Shunliang, Zang Chuck, Wang Ben, *Optimum arrangement of gate and vent locations for RTM process design using a mesh distance-based approach.* Applied Science and Manufacturing 33: 471-81, 2002.

[3] Josef F.A Kessels, Attie S. Jonker, Remko Akkerman, *Optimising the flow pipe arrangement for resin infusion under flexible tooling,* Applied Science and Manufacturing, Composites: Part A 38: 2076-2085, 2007.

[4] Montes N., Sanchez F., *A new computational tool for liquid composite molding process design based on configuration spaces,* Composites Part A, 2009, http://www.elsevier.com.

[5] Berce P., Radu S., A., *Precision analysis of wax parts processed by vacuum casting in silicone rubber mold,* XXIII. MicroCAD, International Scientific Conference, Miskolc, 2009.

[6] King D., Tansey T., *Alternative materials for rapid tooling,* Journal of Materials Processing Technology 121: 313-317, 2002.

[7] Montgomery, Douglas C., *Design and Analysis of Experiments: Response surface method and designs,* John Wiley and Sons, Inc., New Jersey, 2005.

[8] www.axson.fr

[9] http://www.statease.com/dx8trial.html

[10]http://www.srs_ltd.co.uk/support/downloads/products_services/injection_waxes/injectio_wax_royalblue.pdf

SIMULAREA ŞI METODOLOGIA SUPRAFEȚEI DE RĂSPUNS PENTRU OPTIMIZAREA PROCESULUI DE TURNARE SUB VID.

Rezumat: În această lucrare, Simularea asistată de calculator, în special programul Autodesk MoldFlow şi metodologia suprafeței de răspuns, tehnologie folosită pentru optimizarea procesului de turnare sub vid a pieselor din ceară. În prima etapă folosind Autodesk MoldFlow a fost identificat punctul optim de turnare şi tot prin simulare au fost determinate zonele în care este posibil să se formeze bule de aer, în aceste zone s-au fixat aerisitoarele

Sever-Adrian Radu, Asist. Eng., Technical University of Cluj-Napoca, Manufacturing Engineering Department, Adrian.Radu@tcm.utcluj.ro, 0264415653, Bd. Muncii, no.103-105, Cluj-Napoca.

Nicolae Panc, Asist. Eng., Technical University of Cluj-Napoca, Manufacturing Engineering Department, Nicolae.Panc@tcm.utcluj.ro, Bd. Muncii, no.103-105, Cluj-Napoca.

Vasile-Dănuț Leordean, Phd.Student., Technical University of Cluj-Napoca, Manufacturing Engineering Department, Danut.Leordean@tcm.utcluj.ro, Bd. Muncii, no.103-105, Cluj-Napoca.