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FILLING SIMULATION OF SILICONE RUBBER MOLD WITH WAX IN CASE OF GRAVITATIONAL CASTING

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Abstract: The present paper expose the benefits of filling and flow process simulation of silicone rubber mold with easily fusible material. Thus, since design stage can minimize defects that can appear on wax patterns if one takes into account the results obtained from simulations with software specialized to solve flow problems.
Key words: *investment casting, wax patterns, fluid dynamics simulation*

1. INTRODUCTION

Complex parts manufacturing with lost wax casting (or investment casting) is a technology with the best results in terms of manufacturing time, complex parts and cost price for small volume production.

The process includes five steps: 1. Master part manufacturing, 2. silicone rubber mold make, 3. casting or injection molding of a wax pattern in silicone rubber mold, 4. make up wax tree and produce ceramic forms, 5. metal casting in ceramic form and obtain metal parts.

The wax pattern is an identical copy of the metal shape that we want to achieve. For this reason, an important role in operating process is obtaining patterns, because by them depends the dimensional accuracy and the metallic shape [1]. Thus, it is useful to study how to fill the mold with wax to control the process better and to get optimal results.

The mold or ceramic form filling is based on the propagation of free surface materialized by melted wax or metal, phenomenon accompanied by phase change, heat transfer and other features. In the management and control of casting process in order to obtain wax patterns or metal parts corresponding to typo-dimensional requirements, process flow simulation is required [2]. Simulation software that is used to analyze and resolve problems that may arise in dynamics fluid process, heat transfer, transfer of state and other thermal properties which require. This can be achieved by using computing techniques, based on finite volumes method (FVM), on finite elements method (FEM) or on other calculation methods like finite difference method (MDF), etc [2].

The simulation purpose is to estimate the possibilities to avoid defects that may occur during mold filling process and easy design for casting process. The data from the simulation can be used to examine critical sections of a casting form at any time of casting process, leading to a drastic reduction of experimental tests.

2. THEORETICAL CONSIDERATIONS

Considering that the material easily fusible (wax) is a viscous fluid, in the simulation stage occur a series of more complex problems in describing physical phenomena that accompany the flow process and filler a silicone rubber mold. Navier-Stokes model is the most general description of the motion of a Newtonian fluid in thermodynamically equilibrium, being formed by continuity equation (1), equations of motion (2) and equation of energy (3), supplemented by equation of state and empirical equations for expression variety in viscosity and heat conductivity depending on flow parameters [3].

$$\frac{\partial \rho}{\partial t} + \nabla(\rho v) = 0 \qquad (1)$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla\left[(\rho v) \otimes v\right] = \rho f - \nabla p + \nabla \overline{\overline{\tau}} \qquad (2)$$

$$\frac{\partial(\rho E)}{\partial t} + \nabla(\rho H v) = \rho f v + q_v + \nabla(k \nabla T) + \nabla\left(\overline{\overline{\tau}} v\right) \qquad (3)$$

where ρ is the density, v is the velocity, p is the pressure, H is the total enthalpy, E is the total energy, q_v are heat sources for unit of mass, T is the absolute temperature, f are exterior forces for unit of volume, $\overline{\overline{\tau}}$ is the viscous stress tensor and it is equal with (4)[3]:

$$\overline{\overline{\tau}} = 2\eta \overline{\overline{d}} - \frac{2}{3}\eta \nabla v \overline{\overline{I}} \qquad (4)$$

where η is the dynamics viscosity, $\overline{\overline{d}}$ is the velocity of deformation tensor and $\overline{\overline{I}}$ is the united second order tensor.

Navier-Stokes model equations that describe fluid flow are difficult to solve for viscous fluids and their resolution lead us to multiple solutions which may be stable or unstable.

The simulation software used was COMSOL Multiphysics. This software includes many modules that are designed to solve some current problems that arise in scientific and technical research. For research, the used software module was Fluid Dynamics.

To solve Navier-Stokes model equations using COMSOL Multiphysics software have been made the following simplifying assumptions:

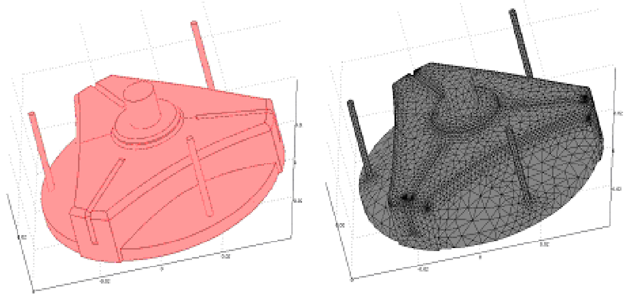
- The flow is 3-D, incompressible and laminar at the entry of wax in the mold;
- The analysis of the turbulent state probability was made using the turbulence coefficient only inside the area filled with fluid, the edge phenomena between liquid phase and solid phase or gaseous phase was overleap;
- The thermal properties of wax are constant, variations within a temperature of 20ºK;
- When wax flow, the wall of silicone rubber mold are fixed;
- The wax frictionless slip on mold wall;
- Wax casting in mold is done at atmospheric pressure.

3. THE FINITE ELEMENT MODEL

The steps for computer simulation of silicone rubber mold filling with wax are as follows [4]:

- importing the CAD model that will be filled from a 3D modeling software in the COMSOL Multiphysics software;
- defining the input variables and specifying the operational characteristics;
- finite elements meshing of the model;

In case of the meshing one must take into account the size of the element. The main factors influencing the accuracy of the numerical solution are the number and the smoothness of the grid used for discretization, time step size and accuracy with which the solution is calculated. The finer the used mesh is, the better the solution accuracy but the computational time increases very rapidly. When using a coarse mesh to shorten the time of calculation there is the possibility that important aspect of the flow are eliminated.



a) b)

Fig. 1. Meshing the model, a) CAD model, b) finite element model

To optimize both computational time and accuracy of the solution one can use a mesh with variable grid. COMSOL Multiphysics software allows this kind of mesh. Fig. 1 shows the CAM model of the piece and it's discretization. One may notice that we have a variable meshing, so simple and flat surfaces have a coarse grid, white a fine grid is used where section variations or fillet radii occur. For the chosen model, the mesh consisted in 74154 finite elements.

4. RESULTS AND DISCUSSION

Simulation of the model filling process involves solving the Navier-Stokes model equations. For this the software is solving both linear and nonlinear equations using different calculation methods and returning values and calculation errors.

The solving method used for nonlinear equations system of flow model is Newton's iterative method. In solving the flow problem in this case was reached a total of 25 iterations and the calculation error is of the order 10^{0}.

BICGSTAB method (BiConjugate Gradient STABilized iterative method) is an iterative method for solving linear equation system used by COMSOL Multiphysics Solver to solve the Navier-Stokes flow model. In our case 350 iterations were made and the calculated accuracy of the solution is 10^{-5}.

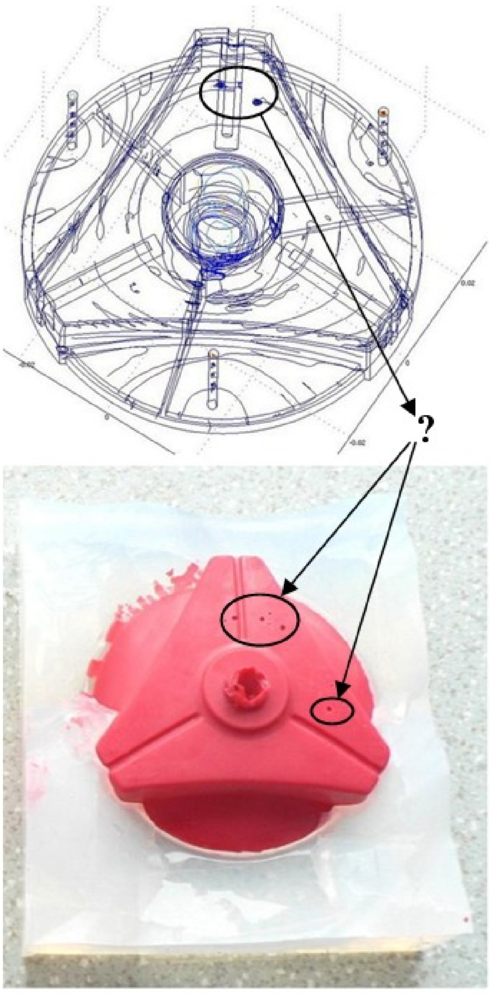


Fig. 2. Vortex field and its effect on the wax pattern

Fig. 2 shows the vortex field resulting from the melt material flow simulation in silicone rubber mold, at gravity die casting where we have as input parameters, wax density, dynamic viscosity, casting pressure and wax velocity of come in mold. It may be noted that the presence of vortex field indicate possible defects to wax pattern surface.

Knowing the area from the surface pattern where there is the possibility of developing vortexes is very important because since the design phase can be avoided a number of problems that can cause defects on the surface of the piece. Flow simulation software provides an optimal design of mold power and casting network pattern so you can avoid a number of flaws.

Fig. 3 represents the velocity vector distribution in the manner of filling the form from the mold.

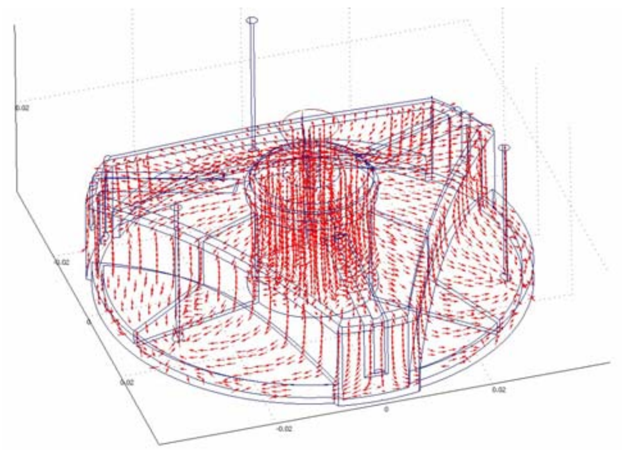


Fig. 3. Velocity vectors distribution in the manner of filling the mold form

Fig. 4 shows the distribution of Reynolds number in the pattern with colors. Thus, for turbulent flow that corresponds to high Reynolds numbers it is used the red color, for laminar flow that corresponds to low Reynolds numbers it is used blue color and for transitional outflows it is used a color palette ranging from blue-green and yellow. This can also be read from the first column on the right of the figure. It is observed that in our case we have turbulent flow only in the middle part of the piece, which does not have a practical importance. Because we have a laminar flow all over the piece surface, where we have thin walls there is no danger that the piece is affected by vortex field. Laminar flow corresponds to a smooth a complete filling of model with melted wax.

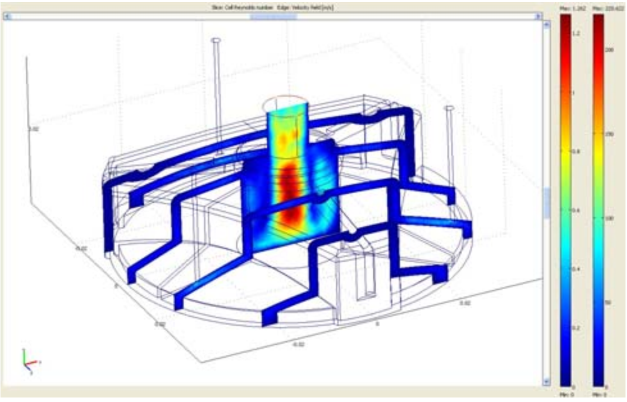


Fig. 4. Reynolds number distribution in the model allong the z axis

5. CONCLUSIONS

Wax models directly influences the quality and dimensional accuracy of metallic parts obtained by investment casting.

This paper highlights the importance of melt material flow simulation in the mold and its filling mode. The experimental results validate the simulation results after which can be established with sufficient precision the model surface areas that are affected by vortex and where they can form bubbles.

After simulations, the runner can be optimized so as to minimize the defects that can occur on wax pattern surface.

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SIMULAREA UMPLERII MATRIȚELOR DIN CAUCIC SILICONIC CU CEARĂ ÎN CAZUL TURNĂRII GRAVITAȚIONALE

Rezumat: Lucrarea de față prezintă aspecte generale referitoare la utilizarea softurilor de simulare pentru a vizualiza modalitatea de curgere şi umplere a matrițelor din cauciuc siliconic cu material fuzibil. Rezultatele experimentale validează rezultatele simulăriilor în urma cărora se poate stabili suficient de exact zonele de pe suprafața modelului care sunt afectate de turbioane şi unde se pot forma bule de aer. Astfel încă din faza de proiectare se pot minimiza defectele care pot apărea la modelele din ceară dacă se ține cont de rezultatele obținute în urma simulărilor cu softuri specializate în rezolvarea problemelor de curgere.

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