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THE SIMULATION OF WAX SOLIDIFICATION PROCESS IN SILICONE RUBER MOLD

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Abstract: *The present paper expose the benefits of wax solidification process simulation in silicone rubber mold. The metal parts defects obtained by investment casting depend, in proportion of 60%, on wax model defects and the study of wax models solidification is a practical utility. The possibility to control and to conduct the cast wax solidification leads to obtaining high quality wax models.*

Key words: *silicone rubber mold, heat transfer simulation, wax pattern.*

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 [1].

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.

The wax patterns defects are due to the filling method of the mold with wax and due to solidification and cooling method in the mold.

Due to a defective fill, the mold is not filled completely or it appears vortex that lead to obtaining improper models [2].

Due to different solidification and cooling of the pattern that presents section variations, different contractions appear which leads to dimensional deviations from the designed dimensions. Also due to variation in model section, there are parts of the model that are cooled faster than other areas which lead to shrinkage holes.

An important issue that rises in the production of wax models is the knowledge of the solidification and cooling process of the model in the mold. If the model solidification is known then we can efficiently design the casting process so that it can be avoided a number of defects [3].

The simulation of wax solidification process in silicone rubber mold

2. THEORETICAL CONSIDERATION

Knowing the temperature field in the part walls, in the mold is of great practical importance because it allows intervening in correcting and guiding the solidification and cooling process of the fusible material in favor of cast models quality. Also, knowing the temperature field helps to optimize the extraction time of the wax model from the mold and the mold preparation for a new casting [4].

2.1 Mathematical formulation of heat transfer process

From the moment when in the mold enter first amounts of fusible material, between mold and fusible material starts a thermal interaction process, which is a heat exchange process. Heat exchange process is complex and occurs by conduction, convection and radiation [5].

Heat transmission through conductivity is made by Fourier's law, namely [6]:

$$\frac{dQ}{dt} = -\lambda \cdot S \cdot \left(\frac{\partial T}{\partial x}\right) \tag{1}$$

Heat transmission through convection is made by law (2), namely [6]:

$$dQ = \alpha_c \left(T_p - T_f \right) dS \tag{2}$$

The amount of heat transmitted by radiation results from Stefan-Boltzmann's law applied to gray corps (3), namely [6]:

$$Q = \varepsilon_{p-f} \cdot C \cdot \left[\left(\frac{T_p}{100} \right)^4 - \left(\frac{T_f}{100} \right)^4 \right] \quad \left[J/m^2 \right] \tag{3}$$

Temperature field equation is given by relation (4) and the equation determines the temperature distribution at any point in a corp [6].

$$\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \tag{4}$$

The temperature field of the wax model and of the CS mold is non-stationary and is given by the equation:

$$T_x = f(x, y, z, t) \tag{5}$$

Dependent variable T_x is called solidified fraction volume and is defined by [7]:

$$T_x = \begin{cases} 1 & |T_x \le T\_CR \\ \dfrac{T_x - T\_CR}{T\_C - T\_CR} & |T\_CR \le T_x \le T\_C \\ 0 & |T_x \ge T\_C \end{cases} \tag{6}$$

From relations (6) is established that T_x has value zero when the wax is in a solid state and has the value one when the wax is solidified. At temperatures between casting and solidification temperatures, T_x takes values between zero and one.

2.2 The formulation of the initial and to limit conditions

Solving equation (4) starts from a series of simplifying assumptions [3], [7]:

- Piece temperature at the initial moment $t_{initial}$ is uniform and equal with T_C;
- The mold temperature at the moment $t_{initial}$ is uniform and equal with T_MCS;
- The temperature at the fusible material - mold interface at the moment $t_{initial}$ is constant and equal to $T^{"}$;
- At the temperature $T_x (T\_MCS < T_x < T\_C)$ piece solidification occurs due to the disposal of crystalization latent heat;
- Thermophysical characteristics (c, λ, ρ) do not vary over time;
- The heat transfer in the liquid and in the solidified alloy occurs by conduction, by Fourier's equation;
- The heat transfer by convection between molten wax – CS mold is neglected;
- The heat transfer is unidirectional (in one direction), from the warmer body to the colder one;
- The heat transfer is made by free convection and radiation outside of CS mold or of ceramic form.

3. EXPERIMENT DESIGN

We consider that at the moment $t_{initial}$ in the mold we have wax melted at a temperature *T_C* constant through the mass and also the silicon rubber mold is preheated at a temperature *T_MCS* that is constant throughtout the mass.

At the moment t_0 starts the process of heat transfer that will have as result the solidification and the cooling of the wax model at a moment t_x that will be determined by simulation.

The used simulation software was Comsol Multiphysics. From the Comsol Multiphysics software, for simulation of heat transfer process that occur between melted wax, silicone rubber mold and the environment, we used the *General Heat Transfer* module and from here we used the *Transient analysis* option.

The input data used in this study are presented in Table 1.

To resolve the equations that describe the heat transfer, using Comsol Multiphysics software, simplifying assumptions, described above, were made.

Boundary conditions are made both at domain level (Fig.1) and at the border level, after which passing to mold discretization as in Figure 2.

Figure 2 shows that we have a variable discretization, so on simple and flat surfaces we have a rough grid, and where section variations or connecting rays occur, a fine grid is used.

Table 1

Model parameter values for simulation

Symbol	*Units*	*Material properties*
T_amb	291.15 [K]	Ambient temperature
T_MCS	323.15 [K]	Preheating temperature of the mold
T_C	361.15 [K]	Casting temperature of the wax
T_CR	328.15	Solidification temperature of the wax
k_CS	3.4 [W/(m*K)	Thermal conductivity of the silicone rubber
k_C	0.27 [W/(m*K)	Thermal conductivity of the wax
Cp_C	2260[(J/kg*K)]	Specific heat of the wax
Cp_CS	1460[(J/kg*K)]	Specific heat of the silicone rubber
H_aer	15[W/(m^2*K)]	Heat transfer coefficient through surface
Eps_CS	0.94	Emissivity coefficient for silicone rubber
S_mod el	0.0240[m^2]	The surface of the wax model
S_matr	0.1633[m^2]	The surface of the mold

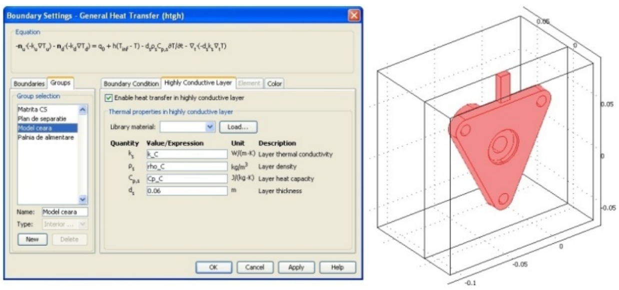

Fig.1. Boundary conditions on the domain, for wax model

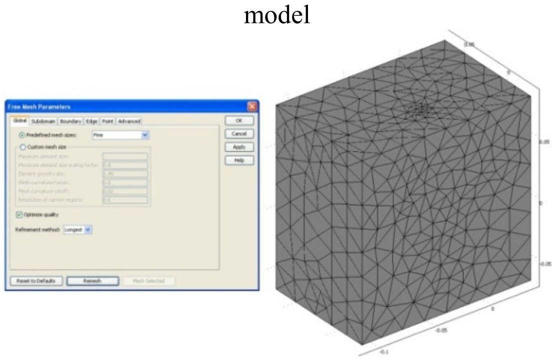

Fig.2. Discretized CAD model

4. RESULTS AND DISCUSSION

Figure 3 - 6 presents the thermal field resulting from the heat transfer simulation process. The graphics present both a general view (position a)) and in section (position b)) the thermal field evolution that occurs at heat transfer between the wax model, silicone rubber mold and the environment.

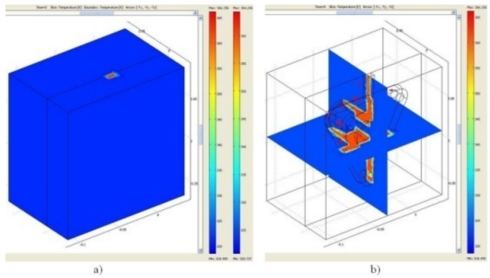

Fig.3. The simulation t0 moment when the heat transfer phenomenon begins

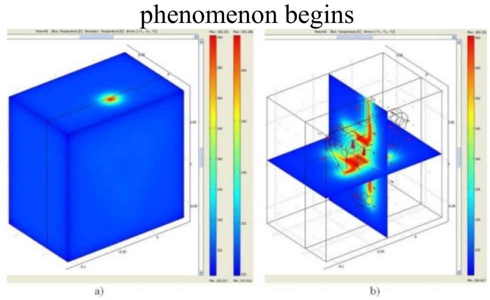

Fig.4. The evolution of the thermal field after one minute

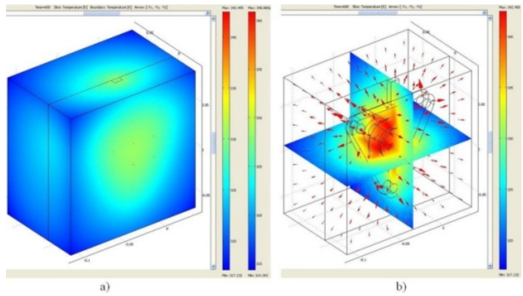

Fig.5. The evolution of the thermal field after ten minutes

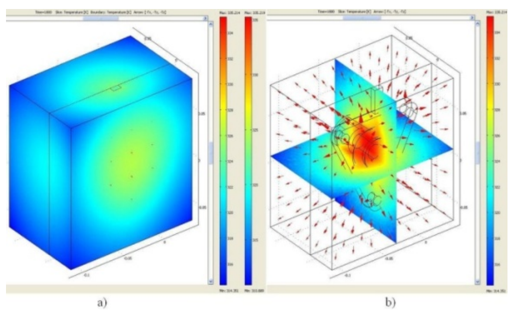

Fig.6. The evolution of the thermal field after 30 minutes

Simultaneously with the heat transfer phenomenon that occurs within the mold, and outside the mold the phenomenon of heat transmission occurs from the preheated mold to environment through free convection and radiaton phenomen. From figures 3-6 it can be seen the heat transfer evolution highlighted by the temperature evolution in the mold and at the surface of the mold.

Figure 7 shows the evolution in time of the thermal field during solidification and cooling for different points of silicone rubber mold.

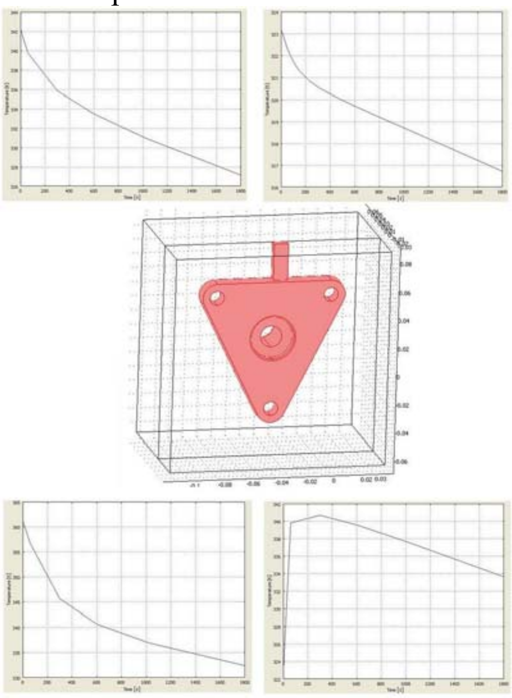

Fig.7. The evolution of the thermal field in different points of the mold

Were choosen as representatives points a point from power supply, a central point of the was model, a point from the silicone rubber core that is limited by the wax model and a point at the surface of the silicone rubber mold.

5. CONCLUSION

The simulation software enables to know the evolution in time of temperature field in the mold, which is a significant advantage in the design of the mold. The advantage is the ability to control the solidification mode by directing the solidification.

The possibility to use a directed solidification lead to casting of high quality parts by obtaining a structure which provides desired mechanical and physical characteristics to the piece.

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Simularea procesului de solidificare a modelelor din ceară în matrițele de cauciuc siliconic

Abstract: Acest articol prezintă avantajele pe care le aduce simularea procesului de solidificare a modelelor din ceara în matrițele din cauciuc siliconic. Defectele pieselor metalice obținute prin turnare utilizând modele uşor fuzibile depind în proporție de 60% de defectele modelului din ceară iar studiul solidificării modelelor din ceară este o utilitate practică. Posibilitatea de control şi dirijare a solidificării cerii turnate dă posibilitatea obținerii de modele din ceară superioare calitativ.

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