

Integration of Computer Tomography and Simulation Analysis in Evaluation of Quality of Ceramic-Carbon Bonded Foam Filter

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Abstract

Filtration of liquid casting alloys is used in casting technologies for long time. The large quantity of available casting filters allows using them depending on casting technology, dimensions of casting and used alloys. Technological progress of material science allows of using new materials in production of ceramic filters. In this article the Computed Tomography (CT) technique was used in order to evaluate the thickness of branch in cross section of 20ppi ceramic-carbon bonded foam filter. Then the 3D image of foam filter was used in computer simulation of flow of liquid metal thru the running system.

Keywords: Ceramic-carbon bonded foam filter, Computer simulation, Computer tomography

1. Introduction

In order to produce high quality of castings there is a need to ensure high quality of molten metal. Metallurgical regime should be maintenance with all alloys used in foundries. During the melting treatment for example on the surface of liquid steel, the slag is creating. This slag can be transported during casting inside the mould [1]. Different inclusions can be oxides that can form during the flow of liquid metal thru the running system. Also during the flow the particles of mould can be transported to the casting and form non-metallic inclusions [2]. Using different types of filters foam filters, cellular filters, mesh filters foundrymen can prevent the inclusions to be located in casting [3]. In this paper the Computer Tomography (CT) was used in evaluation process of quality of foam filters is presented. The CT image of base polyurethane foam that in production process is

impregnated with slurry [4] was compared to final ceramic filter. The CT image of foam filter was used in computer simulation of flow of liquid metal thru the running system. The flow velocities, turbulence intensity, dynamic viscosity and time of filling the modeled geometry was analyzed.

2. Computer tomography

The X-Ray Computer Tomography is perfect diagnostic tool, widely used in material science, micro-mechanics, electronics, geology and biology. Especially in structural defects analysis of responsible castings and internal dimensions measurements. Basic parts of CT are: X-ray lamp (1), detector (2), handles used for holding detail (3). All elements are mounted on granite platform

that is equipped with anti-vibrate system (4). The fig. 1 presents the CT.

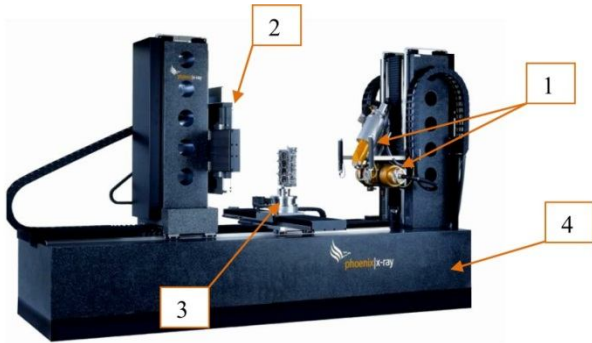


Fig. 1. General Electric Computed Tomography used in Foundry Research Institute

The CT scan is beginning with saving of two-dimensional image of sample. On this stage the lamp is generating radiation that is partially absorbed by analyzed sample. The detector integrates the radiation and converts it in to digital image, that can be saved on computer. During scanning the sample is rotating to acquire three-dimensional image. The principles of CT scanning is presented on fig. 2 [5].

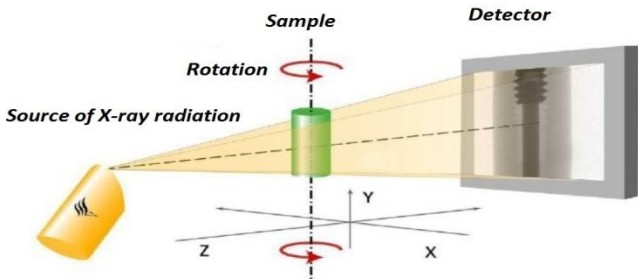


Fig. 2. Principle of CT scanning

Computer software used in converting digital images from detector allows to export STL (STereoLithography) file. The image of polyurethane foam and filter are presented on fig. 3.

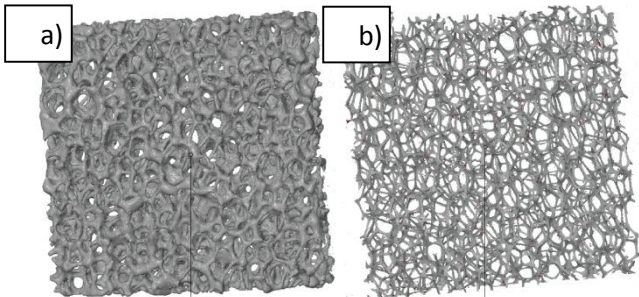


Fig. 3. CT image a) ceramic-carbon filter, b) polyurethane foam

The CT during scanning can generate interference's that are also converted to the STL file. The another computer software ATOS 6.2 was used to remove unnecessary artifacts. On fig. 4 the removal of interference was presented.

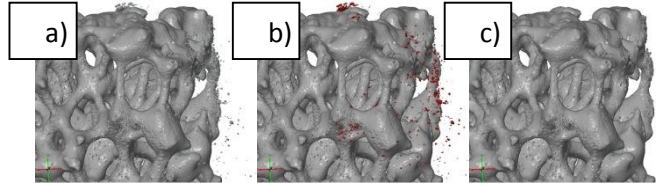


Fig. 4. Removal of interference's a) image with artifacts, b) selecting the interference's, c) clean STL image

The possibility of working on files based on real geometry allows to evaluate the quality of impregnation process. The thickness of branches and holes left in pyrolysis of polyurethane foam can be measured. On fig. 5 the dimensions of single branch and hole inside the branch are presented.

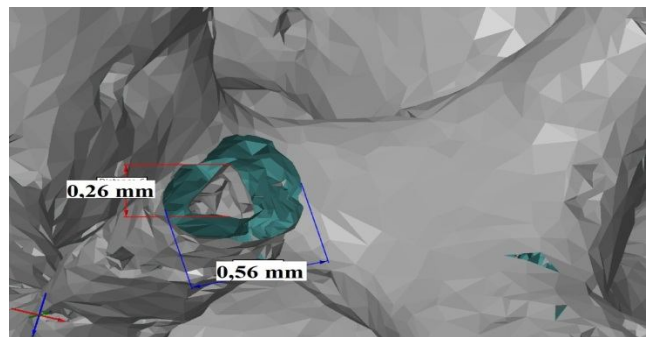


Fig. 5. Dimensions of branch and hole inside the branch in foam filter

For the comparison of polyurethane foam and final foam filter the branches of polyurethane foam was also measured. In the final foam filter the average dimensions of measured few branches was 0,56 mm and the hole inside the branches was average 0,26 mm. On fig. 6 the measurement of branch of polyurethane foam is presented. The measured average thickness is 0,26 mm.

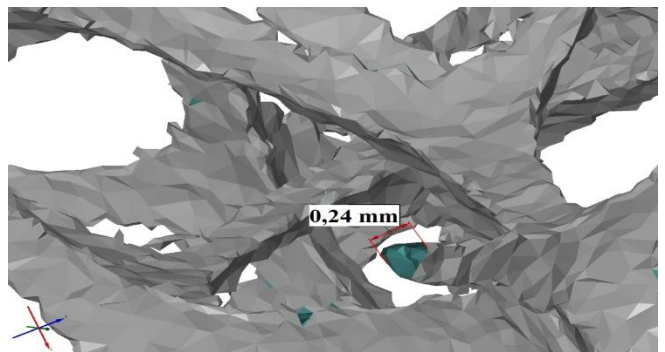


Fig. 6. Dimensions of branch thickness in polyurethane foam

The measurements of branch thickness allows to evaluate the impregnation properties of the slurry used in production process.

3. Computer simulations

The data from CT scanning can also be used in computer simulation. The simulation software use the STL files as an input geometry files of single part or entire assembly's. Basic way of simulation of liquid metal to flow thru filter is defining pressure drop, drag, porosity of filter. The Flow-3D simulation software is able to import filter as STL. This way the real geometry foam filter can be simulated. To define the filter as component in Flow-3D the drag of the filter need to be described [6]:

$$OADRAG = b_1 \frac{V_f^3}{\mu(1-V_f)^2} \quad (1)$$

$$OBDRAG = b_2 \frac{V_f^3}{\rho(1-V_f)} \quad (2)$$

OADRAG – linear drag coefficient,
 OBDRAG – nonlinear drag coefficient,
 V_f – foam filter porosity,
 μ – dynamic viscosity, [Pa*s],
 ρ – density, [$\frac{kg}{m^3}$].

The properties are acquire experimentally. The known data can be found in simulation software [6]. In table 1 the known values of b_1 and b_2 are presented.

Table 1.
 Values of b_1 and b_2 parameters

Filter Type	b_1 (kg/m ³ s)	b_2 (kg/m ⁴)	R ²
Cellular 100 csi	28221	70851	0.9188
Cellular 200 csi	53477	33311	0.9933
Cellular 300 csi	58577	114435	0.9671
Foam 10ppi	46711	375408	0.8659
Foam 20ppi	38123	592484	0.9533
Foam 30ppi	55779	677299	0.9592

The pressure drop in dependence of flow velocity is presented on fig. 7 [6].

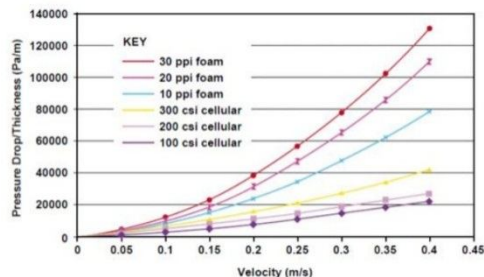


Fig. 7. Pressure drop in flow function

For the flow simulation, simple running system was designed in CAD program. The dimensions are presented on fig. 8.

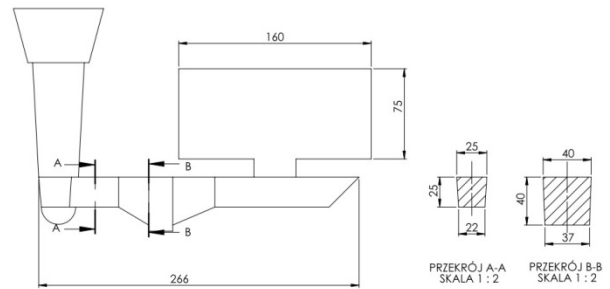


Fig. 8. Running system used in flow simulations

The fluid velocity, turbulence intensity and dynamic viscosity and filling time was measured before and after the filter. The turbulence intensity is the value that describes the level of turbulence that is occurring during flow. This parameter can be described by equation [8]:

$$I = \frac{\mu'}{U} \quad (3)$$

μ' - mean root-square of turbulent velocity,
 U - mean flow velocity.

Data was measured by point inside the running system. The location is presented on fig. 9.

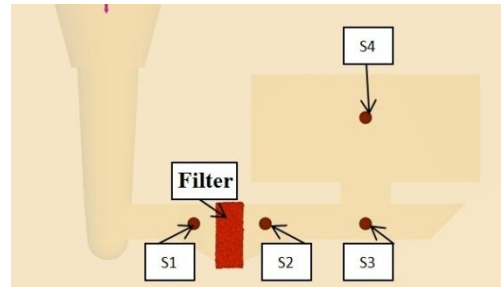


Fig. 9. Measurement points placement

The simulation was performed in three conditions. The running system without filter, foam filter defined by parameters and running system with foam filter imported from CT scan. Running system was designed according to presented in work [7]. The volume of cavity is $V = 930 \text{ cm}^3$, mass $m = 5,5 \text{ kg}$. Alloy EN-GJS-500-7 was imported from program database for mould material green sand was used. The initial temperature $T_{in} = 1310^\circ\text{C}$. The boundary conditions was the same in all simulations. The simulation was performed to evaluate the flow conditions. The heat transfer phenomena was not considered in this simulations.

Simulation I

The first simulation was run without filter in the running system. The filling time was $t_f = 4,34 \text{ s}$, the time after the rectangular cavity was filled $t_r = 3,49 \text{ s}$. On fig. 10 the measured values of velocity, dynamic viscosity and turbulence intensity in time frame $t = 0,57 \text{ s}$ are presented.

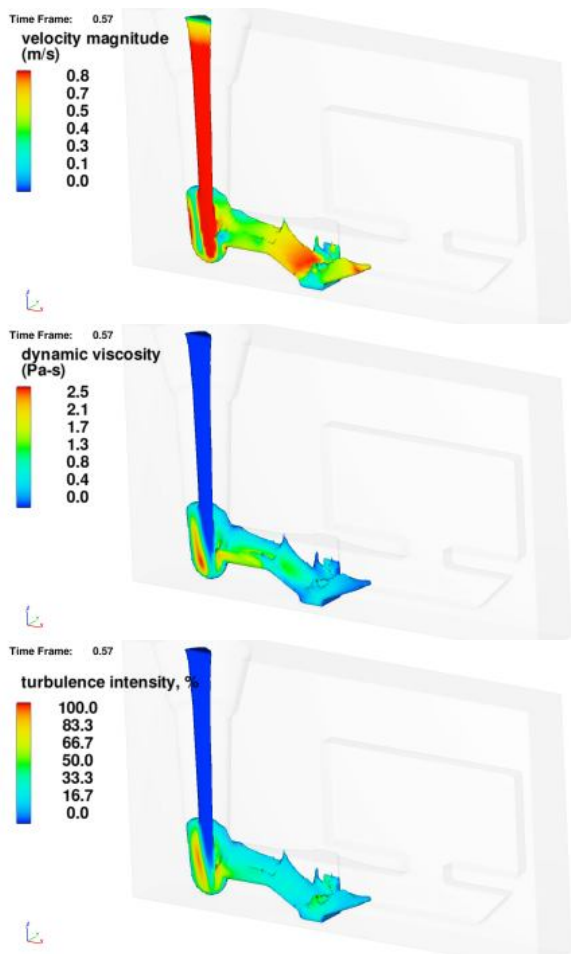


Fig. 10. Visualization of results a) velocity, b) dynamic viscosity, c) turbulence intensity

The flow of liquid metal in the filter nest is very dynamic and turbulent. The high value of turbulent intensity shows that there is a mixing process of flowing alloy. Analyzing of velocity vectors on fig. 11 there is back wave of flowing liquid metal.

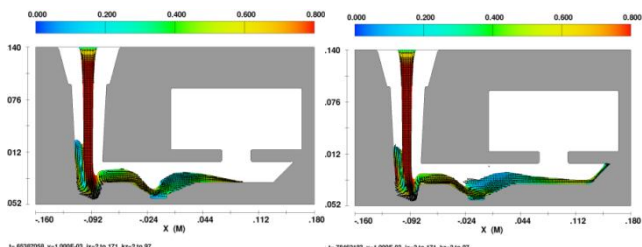


Fig. 11. Visualization of velocity vectors, $t_1=0,6$ s, $t_2=0,78$ s

Simulation II

In the second simulation filter was defined by the parameters from software database. Filling time was $t_f = 4,2$ s, filling time of rectangular cavity was $t_r = 3,37$ s. On the fig. 12 the visualization of results are presented.

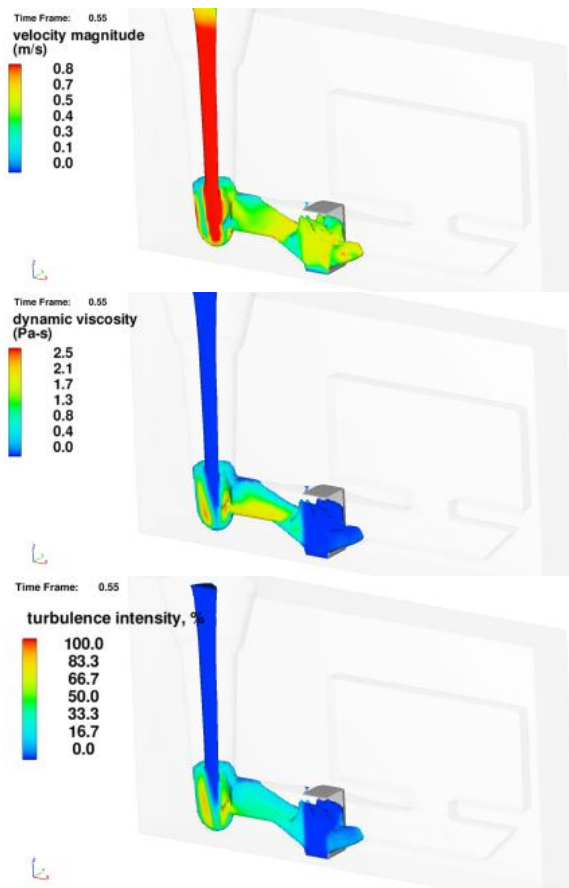


Fig. 12. Visualization of results a) velocity, b) dynamic viscosity, c) turbulence intensity

Results show that using the filters forced the flow to become more calm. The turbulence intensity is lower than in simulation I. The velocity vectors on fig. 13 show that flow is more directed.

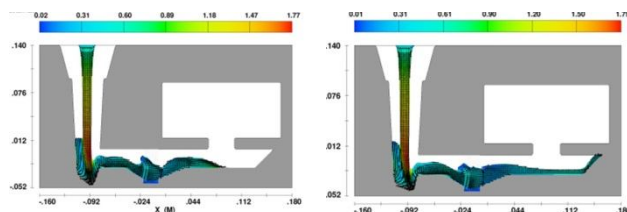


Fig. 13. Visualization of velocity vectors, $t_1=0,62$ s, $t_2=0,78$ s

Simulation III

In the third simulation the STL foam filter was imported. The filling time was $t_f = 4,37$ s, filling time of rectangular cavity was $t_r = 3,52$ s. On the fig. 14 the visualization of results are presented.

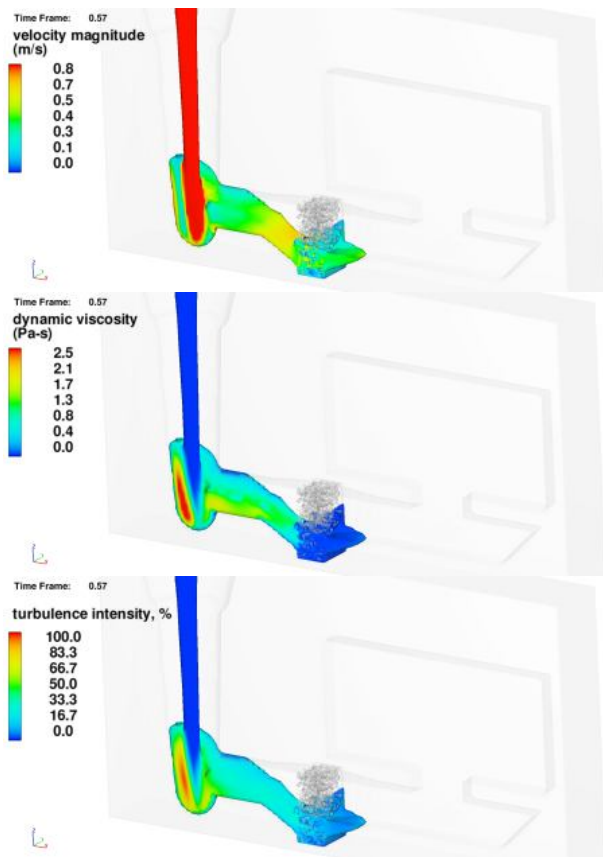


Fig. 14. Visualization of results a) velocity, b) dynamic viscosity, c) turbulence intensity

Simulation show that imported geometry of foam filter give similar result to results acquired in second simulation where the filter of defined by parameters. The velocity vectors presented on fig. 15 show very similar characteristics.

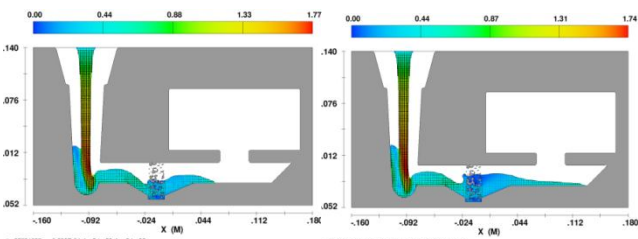


Fig. 15. Visualization of velocity vectors, $t_1=0,65$ s, $t_2=0,79$ s

The results from measurement points are presented on fig. 16 – 19.

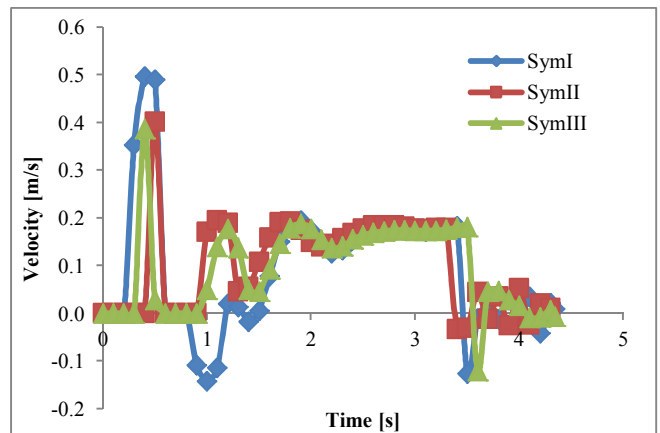


Fig. 16. Flow velocity in measurement point S1

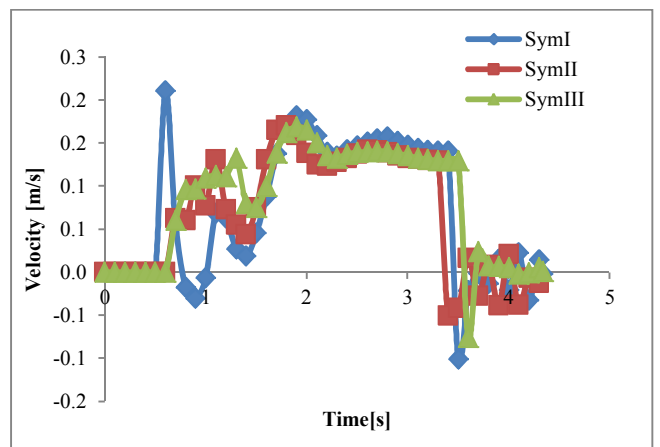


Fig. 17. Flow velocity in measurement point S2

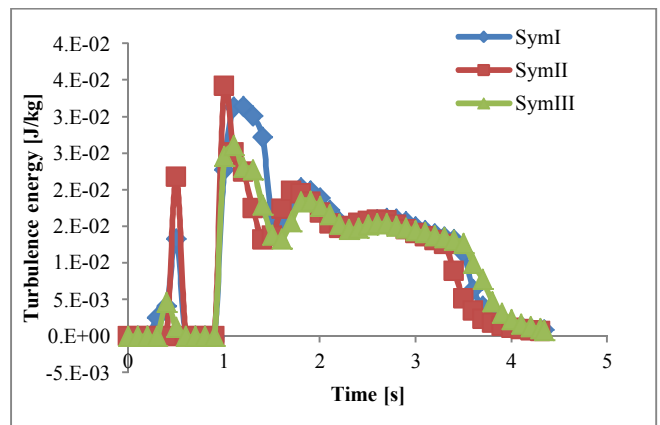


Fig. 18. Turbulence energy measured in point S1

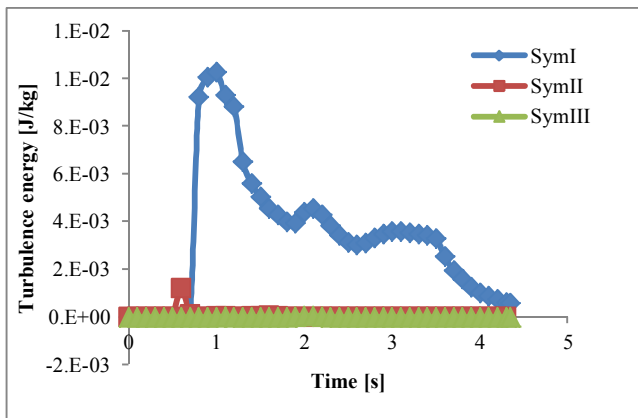


Fig. 19. Turbulence energy measured in point S2

As was presented on visualization fig. 10 – 15 in the area of filter nest in simulation without filter there was back wave which is represented by the minus value of velocity. Comparing the simulation II and III the velocity characteristics are similar. Turbulence energy measured in the S1 and S2 point are showing that before filter for simulation II and III the energy is high but after the filter the flow is stead. The measurement points S3 and S4 was pass over.

4. Conclusions

Computer Tomography is a diagnostic tool that can be used not only for checking casting quality but also for measuring the casting tooling such as foundry filters. Possibility of using 3-dimensional data in simulation allows to create database with information about various filters with different parameters. Measurements of dimensions of the branches of foam filters allows to evaluate the quality of impregnation properties of slurry and polyurethane foam. Additionally using the thermo-physical data of ceramic-carbon material such as thermal conductivity,

thermal capacity can be used in casting simulation to include heat transfer during filling process.

Acknowledgments

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