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Identification of Substitute Thermophysical Properties of Gypsum Mould

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Abstract

Simplifications used in simulation program codes require the use of substitute parameters in the material databases (also called apparent or substitutive). On the one hand, they formally fit into the records used in the heat flow model, porosity, properties etc. and on the other hand they should be determined in conditions most similar to the real casting-mould system.

The article presents results of a research on thermophysical parameters of gypsum mould used for precision casting moulds. Experiments were carried out on a cylindrical mould made of Plasticast gypsum, in which the heat source was a cylinder filled with liquid aluminium alloy of the temperature of 655°C. Energetic validation was carried out by using the NovaFlow&Solid ver. 6.3 simulation code.

As a result of validation tests, substitute thermophysical parameters of gypsum were determined. For determined parameters, best-fit of solidification time from the experiment and simulation was obtained and the curves of gypsum mass heating were satisfactorily recreate.

Keywords: Gypsum mould, Validation, Materials date base, Simulation code, Thermophysical parameters

1. Introduction

Currently moulds made of gypsum masses are used in the foundry industry for small and precision casting in large numbers of items. It mainly refers to the jewellery industry and prosthetics, where casting moulds are made of wax mixes injected or extruded into the matrix. Due to the casting manufacture method used (casting: vacuum, with reduced pressure, centrifugal) the gypsum mass must have appropriate parameters significantly affecting the casting's quality [1, 2, 3, 4, 5].

Currently thanks to the possibility of making casting models with incremental techniques (3D print) the potential use of gypsum moulds even for single casting is significantly increasing. These could be machine parts prototypes or artistic castings with complex shapes, where it will not be possible or profitable to prepare instrumentation for making wax models and then classical method investment castings.

Designing a new casting technology requires incurring large costs associated with the preparation of instrumentation necessary to perform casting moulds. Therefore, before making the mould it is necessary to optimize the procedure of casting technology in order to obtain castings with a high quality at low production costs.

The key issue limiting the use of gypsum mass for making massive castings (of about a dozen kilograms) with thick walls is low intensity of cooling from the solidifying casting by the mould. A slow solidifying process will contribute, among others, to: formation of a coarse structure, larger intermetallic phases precipitates, increase of porosity (in particular gas) proportion and thus deterioration of the cast mechanical properties [6, 7, 8, 9, 10]. Additionally, the impossibility of applying a local increase of heat collection intensity (e.g. through coolers, cooling channels) may contribute to problems with supplying heat substations with casting without the use of reduced pressure.

All these aspects justify the use of a simulation of virtual mould cavity filling process, cast solidification and also the time of cast cooling in order to its safe retrieval from the gypsum mould.

Rational procedure of design optimization of casting technology involves the use of computer systems to support this process - simulation codes as they are called in foundry. However, it should be remembered that the simulation of the casting process is based on models having a lot of simplifications in relation to the reality of the casting-mould system and the results of these calculations are an approximation of the process physics.

It needs to be highlighted that foundry simulation codes have their own databases suggested by their creators. However, the parameters there are often copied from literature and/or are based on unauthorized experimental research carried out in conditions not parallel to the time-temperature conditions of a real foundry process (conditions undergoing dynamic changes due to non-stationary heat shock).

Therefore the effective use of a simulation system requires identification and knowledge of, adapted to the reality, physical parameters (thermal) of the casting - mould system. The lack of as complete as possible identification of these values, used in modelling dependencies, is the cause of limitation of the development and scope of models describing casting solidification.

2. Research methodology

Research of gypsum mass thermal parameters were carried out on a cylindrical mould with the outside dimension of Ø100x200mm. Elimination of the boundary effect and directing the heat flow were obtained by using a Ø30x150 cylindrical-shaped heat source (Fig. 1a) filled with casting aluminium alloy AlSi7Mg, the chemical composition of which is presented in Table 1.

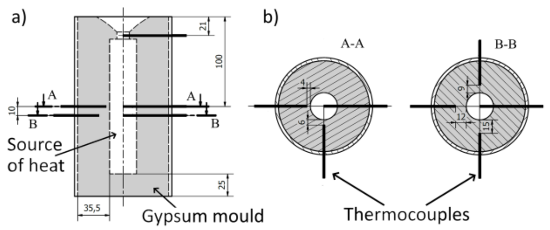

Fig. 1. Places of temperature measurement: a) inside the heat source b) in the gypsum mould

Table 1.
Chemical composition of the AlSi7Mg alloy

Si	Mg	Cu	Fe	Mn	Ni
7.58	0.14	0.07	0.15	0.02	0.01
Zn	**Ti**	**Sn**	**Pb**	**Co**	**Al**
0.19	0.18	<0.01	<0.004	<0.003	rest

In order to identify the heat transport intensity from its source to the outside of the gypsum mass, temperature measurement were carried out with the use of K type thermocouples. The measurement was taken in the thermal axis of the heat source and in the gypsum mould, where the distance from the surface of the heat source were 4, 6, 9, 12 and 15 mm. Thermocouples' placement is schematically shown in Fig. 1b.

The mould was made of Plasticast gypsum mass by Ransom&Randolps, which meets high requirements relating to the expansion of the plastic model (the model was printed with HIPS materials) and to keeping dimensions during the mould burning/annealing process. The water and gypsum mixture was thoroughly mixed and then degassed in vacuum. Then it was poured into the prepared mould with thermocouples (Fig. 2a) and degassed again. After the gypsum mass had bonded, the mould was annealed according to the manufacturer's instructions. The mould with the temperature of the ambience was filled with liquid aluminium and silicon alloy of the temperature of 655±1°C. The test stand and the filled mould cavity are shown in Fig. 2b.

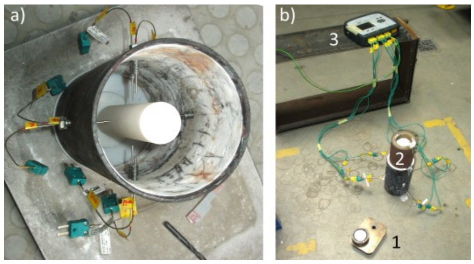

Fig. 2. The mould prepared to be filled with gypsum – a), test stand after the mould cavity was filled – b), where: 1 – sample for chemical composition test, 2 – extra level, 3 – recorder

Simulation tests were carried out using the NF&S 6.3 simulation code. An iterative method was proposed for carrying out the simulation experiment in order to solve the issue.

Validation of the model in question, which comprises the thermophysical parameters searched for, was carried out on the basis of comparative analysis of solidification times determined from the cooling curves in geometric/thermal centre of the casting (energetic validation), and on comparative analysis of the heating curves, recorded in the predefined gypsum mould points.

The thermophysical parameters of gypsum mould were determined using the simplified inverse problem solution - trial&error method (Fig. 3).

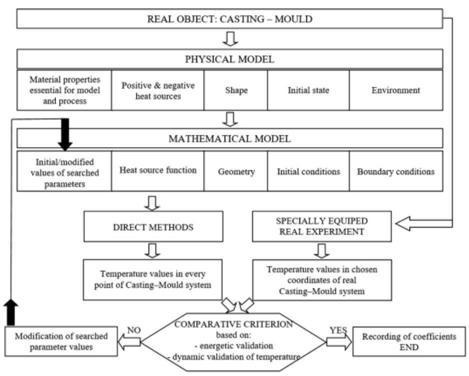

Fig. 3. Scheme of energetic/dynamic validation with the comparison criterion [11]

3. Research Results

The temperature curve of the heat source's cooling in its thermal axis with its first derivative was presented in Fig. 4.

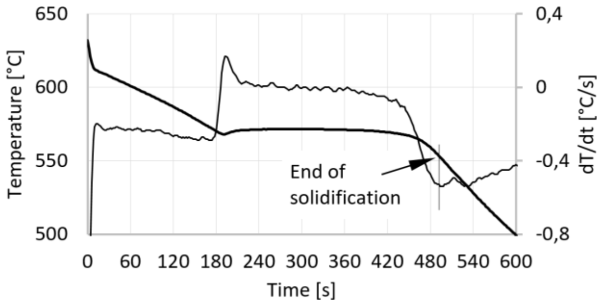

Fig. 4. Cooling curve in the thermal axis of the heat source with the first derivative

The values obtained show that the actual solidification time of the casting in its thermal axis was 458 seconds and the average cooling rate was 0.1°C/s for the range from the beginning of the liquid alloy solidification to the end of the silicon eutectic solidification.

Changes of the gypsum mass heating and cooling depending on the distance from the heat source surface are presented in Fig. 5.

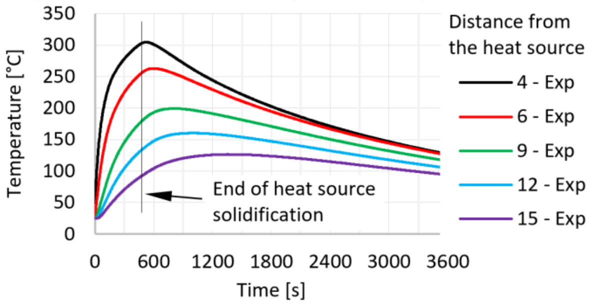

Fig. 5. Gypsum mass cooling curves depending on the distance from the heat source

For simulation aluminium alloy data were taken, thermophysical properties of which are considered sufficiently recognised in own research of the Foundry Department in Institute of Materials Technology in Poznan University of Technology.

First, validation was carried out for gypsum mass parameters available from the literature [12], where the value of thermal conductivity λ was 0.43 W/m/°C, specific heat c=1000 J/kg/°C, and density ρ=1200 kg/m^3.

The comparison of temperature curves recorded from the experiment to the curves obtained simulationally for the tested casting-mould system is shown in Fig. 6, and the heating and cooling of gypsum mass is shown in Fig. 7.

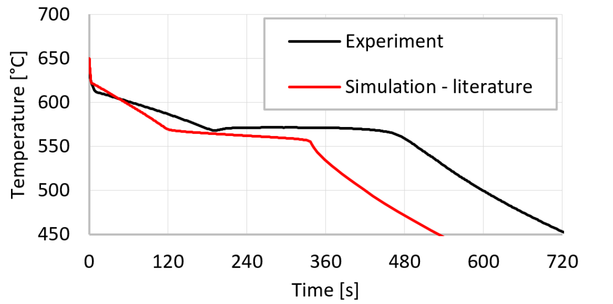

Fig. 6. Cooling curves of the casting-mould system obtained from experiment and simulation

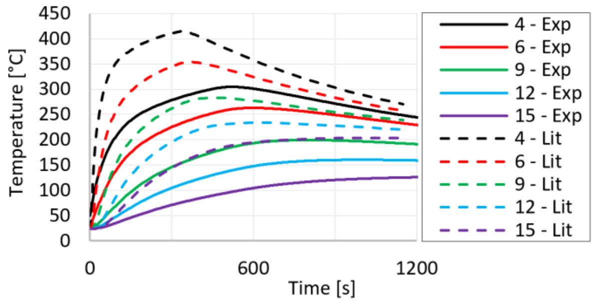

Fig. 7. Gypsum mass heating curves depending on the distance from the heat source

The obtained graphs show that the use of literature data for gypsum mould is insufficient to correctly determine the thermal conditions of the casting-mould system and the heating of gypsum mass. Therefore, a series of simulations were performed to determine the thermophysical coefficients for a gypsum mass at variable values of λ (Fig. 8) and constants c=1200 J/kg/°C and ρ=1220 kg/m^3.

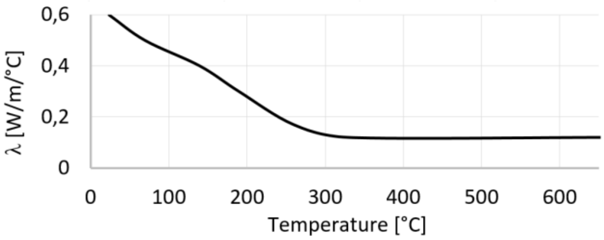

Fig. 8. Values of thermal conductivity

The cooling rate curves of heat source obtained as a result of validation in relation to the experimental curves are shown in Fig. 9, and the heating and cooling of gypsum mass in Fig. 10.

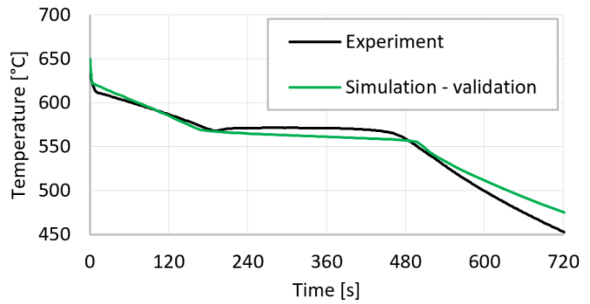

Fig. 9. Cooling rate of heat source after validation process

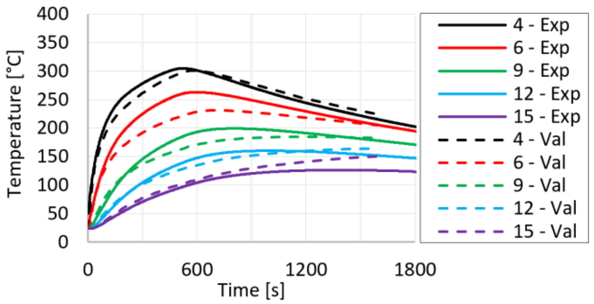

Fig. 10. Cooling rate of gypsum mould after validation process

4. Conclusions

As a result of validation tests, substitute thermophysical parameters of gypsum, constant substitute specific heat c_{subst}=1200 J/kg/°C, substitute density ρ_{subst}=1220 kg/m^3 and specific heat conductivity λ_{susbt} in the range from 0.12 to 0.6 W/m/°C were determined.

In conclusion, a proper use of a given casting simulation code requires knowledge, proper understanding and recognition of parameters of the modelled thermal phenomena as well as a proper approach to their validation. Only effective validation activities determine the actual usefulness of a simulation code for optimising a casting technology concept. The first step of a validation should always encompass adjustment of thermophysical properties in the simulation code database to the conditions of the real casting-mould system conditions. This should consist in conducting experiments based on thermal analysis of the system in real time of the process. This type of validation, called the energy validation, should lead to database corrections made with the use of inverse problem solving methods. For determined parameters, best-fit of solidification time from the experiment and simulation was obtained and the curves of gypsum mass heating were satisfactorily recreate. The coefficients determined as a result of the tests were inserted into the NovaFlow&Solid simulation code database.

Acknowledgements

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