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High Temperature Thermal Properties of Bentonite Foundry Sand

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Abstract

The paper presents results of measuring thermal conductivity and heat capacity of bentonite foundry sand in temperature range ambient – 900 ^{O}C. During the experiments a technical purity Cu plate was cast into the green-sand moulds. Basing on measurements of the mould temperature field during the solidification of the casting, the temperature relationships of the measured properties were evaluated. It was confirmed that water vaporization strongly influences thermal conductivity of the moulding sand in the first period of the mould heating by the poured casting.

Keywords: Castings, Solidification, Bentonite sand mould, Thermo-physical properties

1. Introduction

In foundry practice in many cases shape castings solidify in sand-moulds. The solidification and feeding processes depend on grain-size of the casting, which can be controlled by heterogeneous nucleation and/or or by the intensity of cooling [1-2]. The latter strongly depends on the thermo-physical properties of the mould [3]. It well known that the amount and rate of heat transferred from a solidifying melt to foundry mould and ambient determines the structure and properties of the casting. Nowadays designing of the casting technology uses numerical simulation of the heat and mass exchange processes. Simulation of the solidification processes requires knowledge of several boundary parameters, among others, the thermo-physical parameters of the system casting – mould – ambient [4-5]. For a mould these are: coefficient of thermal diffusivity, coefficient of heat capacity, coefficient of thermal conductivity and mass density. For a casting these are: mainly: densities of liquid and solid state, liquid and solid heat capacities and heat of solidification. Thermo-physical properties of sand moulds strongly depend on temperature changes during cooling of poured castings. It is also well known that transport of moisture from the interface casting-mould through the mould body strongly influences mould thermal conductivity [4, 6-11]. Unfortunately these relationships are in most cases unknown. Moreover, the available software packages have mean values of those existing in literature and using them can lead to low accuracy of the calculations. Thus, there is a need of establishing the temperature dependencies of the mentioned thermo-physical properties as well as a need of performing a confrontation: experimental results vs numerical calculations of the solidification process. Many different methods of measurements of the thermo-physical properties are available in literature [4] and their describing is beyond scope of this paper.

2. Experimental

In this experiment pure Cu plate was cast into wet green-sand mould. During the experiment temperature field of the mould as well as cooling curve of the solidifying casting were registered.

The details of the experiment are shown in Figure 1 and are already described in detail in [8-11].

The sand mould with mounted thermocouples is shown in Figure 2. The material properties of the casting – mould system used during calculations are collected in Table 1. The measured time of solidification was confronted with the one calculated from the analytical formula (1), [3, 8-11]:

$$\sqrt{\tau_{SOL}} = \frac{\sqrt{\pi} M_C}{2 F_C b_M (T_{CRYST} - T_{Amb})} \left(L_C + C_C^{liq} \Delta T_{OH} \right) \quad (1)$$

M_C and F_C – mass and cooling surface of casting; b_M – coefficient of heat accumulation of mould material is given by the mould thermal conductivity λ_M , heat capacity C_M and density ρ_M :

$$b_M = \sqrt{\lambda_M \, C_M \, \rho_M} \quad (2)$$

Combining relationships:

$$b = \sqrt{\lambda \, C \, \rho} \qquad a = \frac{\lambda}{\rho \, C} \quad (3)$$

one can easily calculate required coefficients as follows:

$$\lambda_M = b_M \sqrt{a_M} \qquad C_M = \frac{b_M}{\rho_M \sqrt{a_M}} \quad (4)$$

where: a_M – heat diffusivity coefficient of the mould material.

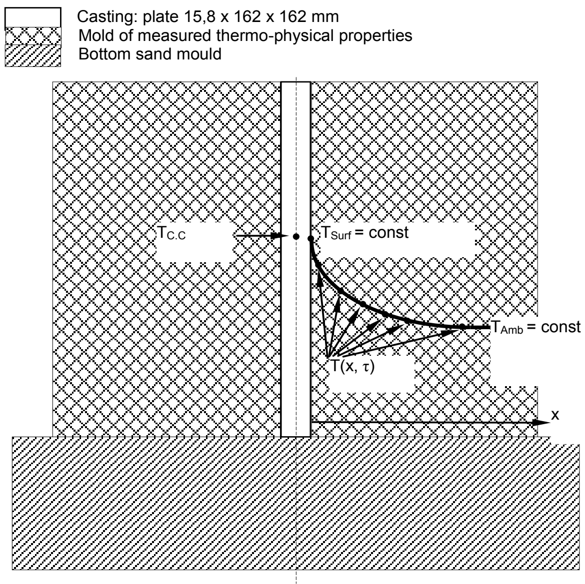

Fig. 1. Scheme of measuring system. Thermocouples location: $T_{C.C}$ – centre of the casting; T_{Surf} – surface of sand mould; $T(x,\tau)$ - thermocouples located in different distances from the surface; T_{Amb} – mould temperature unchanged during the solidification of casting (ambient temperature for the casting) [8, 11]

Fig. 2. The experimental mould after pouring. Visible thermocouples mounted in the mould cavity and in the mould body [9]

Table 1.
Properties and geometrical dimensions of the casting and mould used during the calculations

Property – Symbol [Unit]	Value
Liquid Cu density - ρ_{LC} [kg/m^3]	8300
Solid Cu density - ρ_{SC} [kg/m^3]	8900
Cu heat capacity in liquid state near temperature of melting C_C^{liq} [J/(kgK)]	540
Cu latent heat of fusion - L_C / J/kg	205000
Melt overheating - ΔT_{OH} / K	10
Measured mean temperature of casting crystallization - T_{CRYST} [^{o}C]	1073.8
Dimensions of plate-shape casting [mm]	162 x 162 x 158
Measured density of sand mould - ρ_M [kg/m^3]	1355.5
Initial mould temperature T_{Amb} [^{o}C]	16.5
Measured in experiment time of solidification - τ_{sol} [s]	95.5

The a_M heat diffusivity coefficient can be determined from the registered temperature field of the mould described by error function [8]:

$$\frac{T_{x,\tau} - T_{Surf}}{T_{Amb} - T_{Surf}} = erf(u); \quad \text{where: } u = \frac{x}{2\sqrt{a_M \tau}} \quad (5)$$

3. Results and Discussion

The temperature field in the examined system casting – green sand mould is shown in Fig. 3 while Fig. 4 shows the method of evaluating the time of solidification from the casting cooling curve using first derivative of temperature after time.

The temperature dependence of the investigated green sand thermal conductivity and heat capacity (calculated for the T1=0.004 m distance from casting-mould interface) is shown in Figure 5. From Figure 5 it can be seen that the coefficient of thermal conductivity takes value from the range well above 2 W/(mK) during the first period of the mould heating, just after pouring. During this period water evaporation starts and vapour transport from the mould surface to the mould body takes place. Then the thermal conductivity value significantly decreases and stabilizes within range of 0.7-0.8 W/(mK) in temperatures 100 – 700 ^{o}C. However, above the temperature of 700 ^{o}C the thermal conductivity increases to the value of about 1.3 W/(mK) which can be attributed to inter-granular heat radiation. Fig. 6 shows thermal conductivity changes of different mould regions during casting solidification.

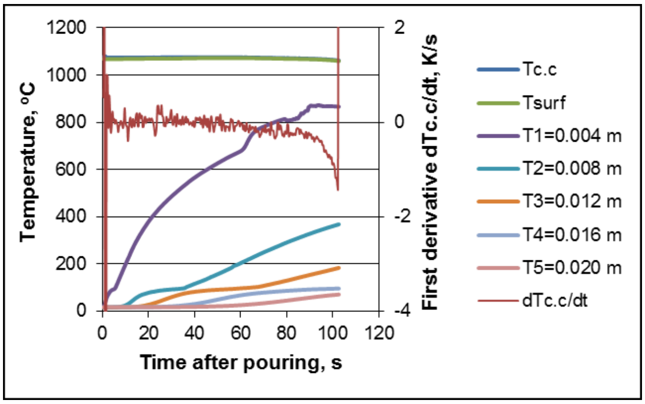

Fig. 3. Temperature field of the examined system. Tc.c. is temperature measured in the centre of the plate-casting; Tsurf is temperature of the mould inner surface; T1 to T5 are temperatures measured inside the mould body on different distances from the inner surface

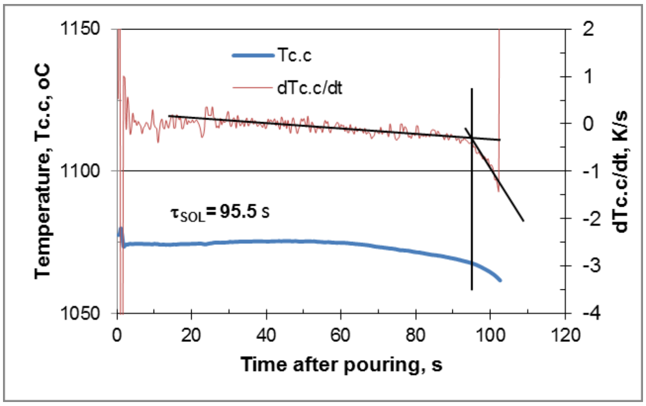

Fig. 4. The illustration of the method of evaluating τ_{Sol} time of solidification from the **dTc.c./dt** first derivative of the **Tc.c.** cooling curve registered in the centre of the casting

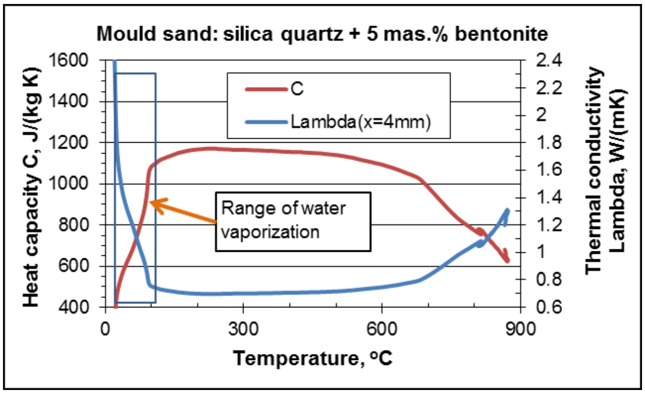

Fig. 5. The relationships: *thermal conductivity and heat capacity vs. temperature* obtained in the *Casting Method* experiment for the examined green-sand at T1=4 mm

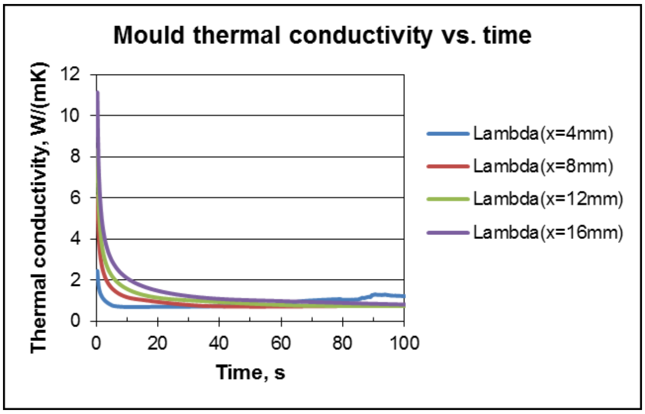

Fig. 6. Thermal conductivity calculated from the registered temperature field shown in Fig. 3

From Fig. 6 it can be seen that moisture vaporization strongly influences thermal conductivity during the first period of the mould heating by the cast copper. This experiment shows that the thermal conductivity reaches even level ~ 11 W/(mK) in outer mould parts after pouring the casting.

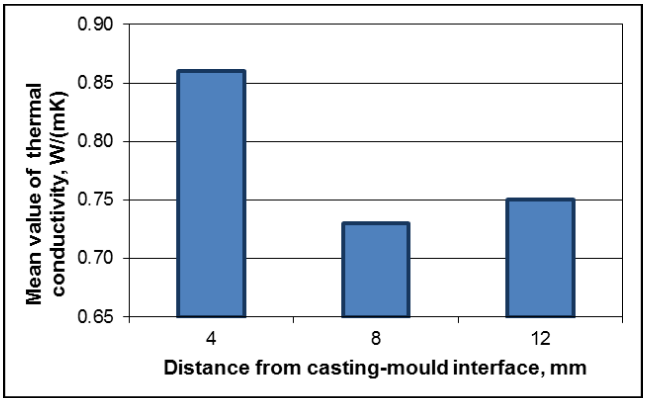

Fig. 7. Mean values of mould thermal conductivity in different distances from mould surface during casting solidification

Then it decreases rapidly to the value of ~ 1.2 W/(mK) and then slowly decreases to about (0.7 – 0.9). W/(mK). However, it should be noted that the first period of mass (water vapour) and heat transfer can strongly influence the shaping of the inner layer of the solidifying casting. It should be also noted that the stabilization of thermal conductivity in the whole mould body takes about 30% of the total time of casting solidification. It should be also noted that thermal conductivity mean values of different mould parts are also different as it is shown in Fig. 7.
The observed differences depend, among others, on initial moisture content as well as on the rate of moisture transport connected with melt casting temperature.
Finally, it should be concluded that real temperature dependences of given sand thermo-physical properties, especially the thermal conductivity coefficient, should be implemented to ensure high accuracy of the numerical calculations.

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Information: The English text of this paper bases on the previously published [11] ones, however the paper brings new, unpublished yet results of the examinations and calculations