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Thermal Conductivity of the Green-Sand Mould Poured with Copper

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Abstract

The paper presents results of measuring thermal conductivity of green-sand mould material and time of pure-copper plate castings solidification evaluated from cooling curves. During the experiments pure Cu (99,8 %) plate was cast into the green-sand moulds. Basing on the measurements it was stated that thermal conductivity of the moulding sand has complex temperature variability, especially during the water vaporization and the obtained dependence should be used in the numerical calculations to improve their accuracy.

Keywords: castings, green-sand mould, thermal conductivity, solidification

1. Introduction

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 [1].

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.

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 [2, 3]. The latter strongly depends on the mentioned thermo-physical properties of the mould [4]. In foundry practice, in many cases shape castings solidify in sand-moulds. Thermo-physical properties of sand moulds strongly depend on temperature changes, 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 [5] 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 [5-7].

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), [4-5]:

$$\sqrt{\tau_{\mathrm{SOL}}} = \frac{\sqrt{\pi} M_{\mathrm{C}}}{2 F_{\mathrm{C}} b_{\mathrm{M}} \left(T_{\mathrm{CRYST}} - T_{\mathrm{Amb}}\right)} \left(L_{\mathrm{C}} + C_{\mathrm{C}}^{\mathrm{liq}} \Delta T_{\mathrm{OH}}\right) \quad (1)$$

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 :

$$b_{\mathrm{M}} = \sqrt{\lambda_{\mathrm{M}} \, C_{\mathrm{M}} \, \rho_{\mathrm{M}}} \quad (2)$$

Combining relationships:

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

one can easily calculate required coefficients as follows:

$$\lambda_{\mathrm{M}} = b_{\mathrm{M}} \sqrt{a_{\mathrm{M}}} \qquad C_M = \frac{b_{\mathrm{M}}}{\rho_{\mathrm{M}} \sqrt{a_{\mathrm{M}}}} \quad (4)$$

where: a_{M} – heat diffusivity coefficient of the mould material.

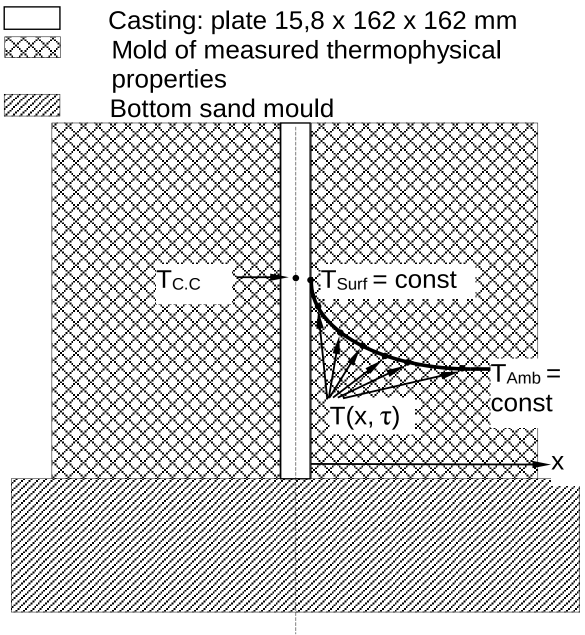

Fig. 1. Scheme of measuring system. Thermocouples location: $T_{\mathrm{C.C}}$ – centre of the casting; T_{Surf} – surface of sand mould; $T(\mathrm{x},\tau)$ - thermocouples located in different distances from the surface; T_{Amb} – mould temperature unchanged during the solidification of casting (ambient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

Fig. 2. The experimental mould before pouring. Visible thermocouples mounted in the mould cavity and in the mould body

Table 3. Thermo-physical properties and geometrical dimensions of the Cu casting (purity 99,8 % Al) and density of the mould used during the calculations

Property – Symbol [Unit]	Value
Liquid density - ρ_{LC} [kg/m^3]	8300
Solid density - ρ_{SC} [kg/m^3]	8900
Heat capacity in liquid state near temperature of melting $C_{\mathrm{C}}^{\mathrm{liq}}$ [J/(kgK)]	540
Latent heat of fusion - L_{C} / J/kg	205000
Melt overheating - ΔT_{OH} / K	10
Measured temperature of crystallization - T_{CRYST} [ºC]	1078
Dimensions of plate-shape casting [mm]	162 x 162 x 158
Measured density of sand mould - ρ_{M} [kg/m^3]	1365.8
Initial mould temperature T_{Amb} [ºC]	40.97
Measured in experiment time of solidification - τ_{sol} [s]	98.5

The a_{M} heat diffusivity coefficient can be determined from the registered temperature field of the mould described by error function [5]:

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

3. Results and discussion

The temperature field of the examined green-sand is shown in Figure 3.

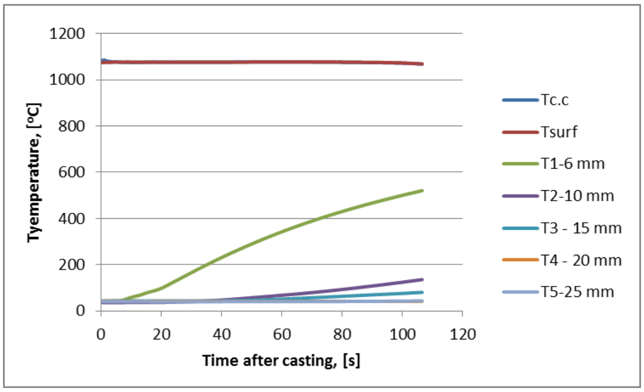

Fig. 3. Temperature field of the examined system. Tc.c. is temperature measured in the centre of the plate-casting; Tsurf is temperature of the mould inner surface; T1 to T6 are temperatures measured inside the mould body on different distances from the inner surface

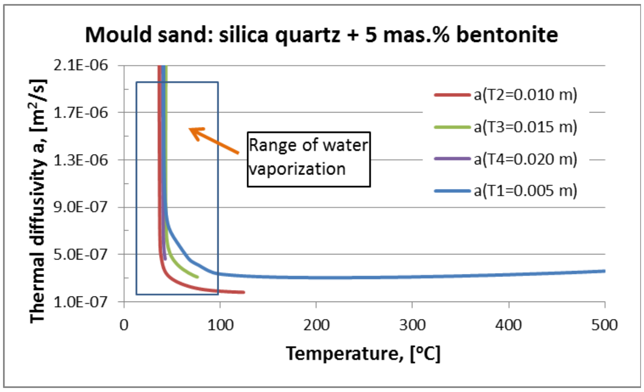

Fig. 4. The thermal diffusivity coefficient calculated from the registered temperature field shown in Fig. 3

The temperature dependence of the investigated green-sand thermal diffusivity is shown in Figure 4, while the heat conductivity changes are shown in Fig. 5. From Figure 5 it can be seen that the coefficient of thermal conductivity takes value from the range 4- 1 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 its value significantly decreases and stabilizes within range of 0.6-0.7 W/(mK).

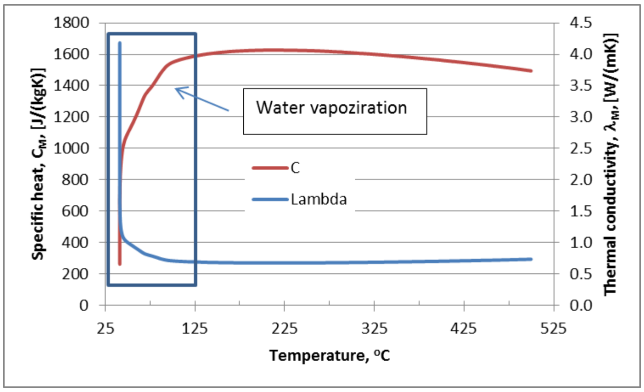

Fig. 5. The Relationships: thermal conductivity vs. temperature obtained in the *Casting Method* experiment for the examined green-sand

From Fig. 5 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 level even ~ 4 W/(mK) after pouring in a wet green-sand mould. However, it decreases rapidly to value of ~ 1.2 W/(mK) and then slowly decreases in the temperature range (ambient to ~100 °C) to a (0.6 – 0.7) W/(mK). It should be noted that this first period of mass (water vapour) and heat transfer can strongly influence the shaping of the inner layer of the solidifying casting.

Finally, it should be taken into account that only real temperature dependence of the thermo-physical properties, especially the thermal conductivity coefficient, can ensure high accuracy of the numerical calculations.

Acknowledgements

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