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RANGE OF THERMAL CONDUCTIVITY CHANGES OF WET GREEN FOUNDRY SAND DURING CASTING SOLIDIFICATION

ZAKRES ZMIAN PRZEWODNOŚCI CIEPLNEJ WILGOTNEJ MASY FORMIERSKIEJ NA BENTONICIE W OKRESIE KRZEPNIĘCIA ODLEWU

In honour of Prof. Sc.D., Ph.D. Eng. Waldemar S. Wołczyński's 70th birthday

The paper presents results of measuring thermal conductivity of green sand mould material and time of castings solidification evaluated from cooling curves. During the experiments pure Cu (99,8 %) plate was cast into the examined 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. 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. The obtained dependence should be used in the numerical calculations to improve their accuracy.

Keywords: castings, sand mould, thermal conductivity, solidification, numerical modelling

Artykuł prezentuje wyniki pomiarów współczynnika przewodzenia ciepła materiału wilgotnej formy piaskowej z bentonitem oraz czas krzepnięcia odlewu płyty z miedzi o czystości 99.8%. Na podstawie eksperymentów stwierdzono, że temperaturowa zależność przewodności cieplnej badanej masy formierskiej nie ma prostego przebiegu, szczególnie w okresie odparowywania wilgoci, a uzyskana w części eksperymentalnej temperaturowa zależność powinna być stosowana w obliczeniach numerycznych w celu polepszenia jakości obliczeń.

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. It should be noted that modern foundry engineering requires implementation of numerical aiding when designing the casting and solidification processes. One of the key input data to the numerical algorithms are thermo-physical properties of the mould materials. as mentioned above, it is well known that they depend strongly on temperature changes of the

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sand which take place during casting, pouring and solidification. Moisture, its vaporization, transport inside the mould and condensation strongly influence thermal conductivity. That is why measurements of wet sand are required. Many different methods of measurements of the thermo-physical properties are available in literature, e.g. [5-24] and their describing is beyond scope of this paper.

However, the only method suitable to perform investigation in real casting conditions is the so called *Casting Method*, previously described in detail in [1, 4, 25-27]. The other commonly used methods, e.g. Hot-Disk or Laser Flash Analysis, require special preparation of the samples whose state during the experiment is far from the state of the real mould.

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 [1,4,25-27].

The sand mould with mounted thermocouples is shown in Figure 2 while Figure 3 shows temperature field of the examined system. 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), [24-25]:

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

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:

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

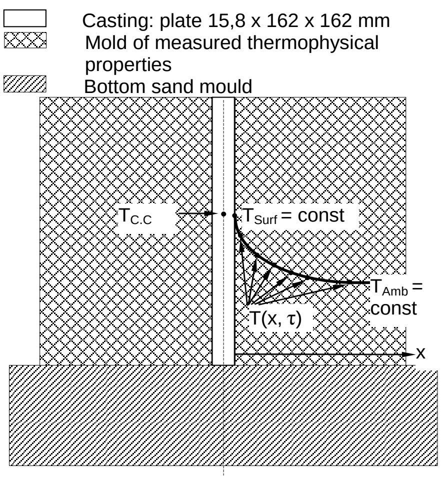

Fig. 1. Scheme of measuring system. Thermocouples location: $T_{C.C}$ – centre of the casting; T_{Surf} – surface of sand mould; $T(x,t)$ – thermocouples located in different distances from the surface; T_{Amb} – mould temperature unchanged during the solidification of casting (ambient temperature for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

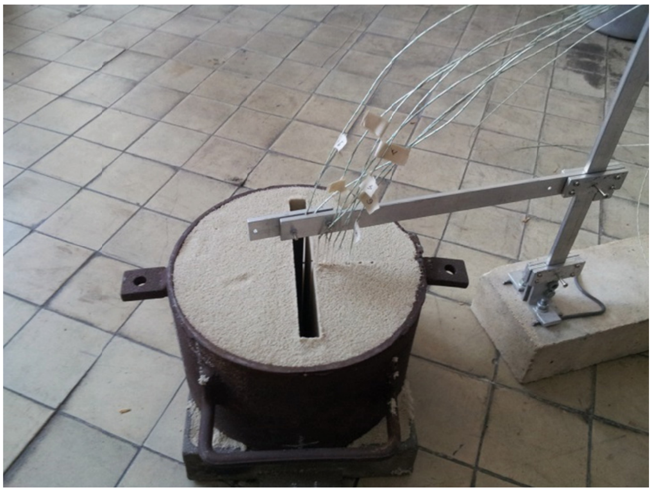

Fig. 2. The experimental mould before pouring. Visible thermocouples mounted in the mould cavity and in the mould body

Combining relationships:

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

one can easily calculate required coefficients as follows:

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

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

TABLE 1

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

Property – Symbol [Unit]	Value
Liquid Cu density – ρ_{LC} [kg/m^3]	8300
Solid Cu density – ρ_{SC} [kg/m3]	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	20
Measured mean temperature of casting crystallization – T_{CRYST} [°C]	1081.1
Dimensions of plate-shape casting [mm]	162×162×158
Measured density of sand mould – ρ_M [kg/m^3]	1552.6
Initial mould temperature T_{Amb} [°C]	19.8
Measured in experiment time of solidification – τsol [s]	116.4

The a_M heat diffusivity coefficient can be determined from the registered temperature field of the mould described by error function [4,25]:

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

3. Results and Discussion

The temperature dependence of the investigated green-sand thermal diffusivity is shown in Figure 4. From Fig. 4 it can be seen that the coefficient of thermal diffusivity changes significantly its value around 100°C; this is connected with water vaporization. The thermal conductivity coefficient conductivity takes value from the range ~14-0.7 W/(mK) during the first period of the mould heating by the solidifying casting – Fig. 5. During this period also water evaporation and vapour transport from the mould surface-layer to the mould body takes place. Then its value stabilizes and linearly decreases to about 0.5-0.7 W/(mK).

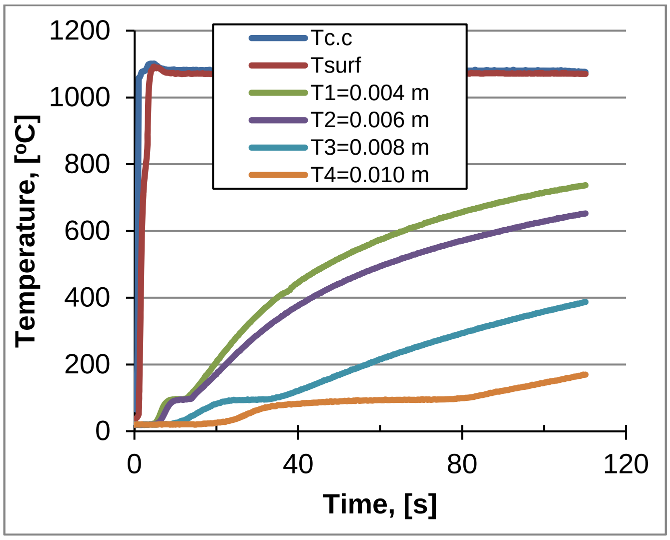

Fig. 3. Temperature field in the examined system casting-mould

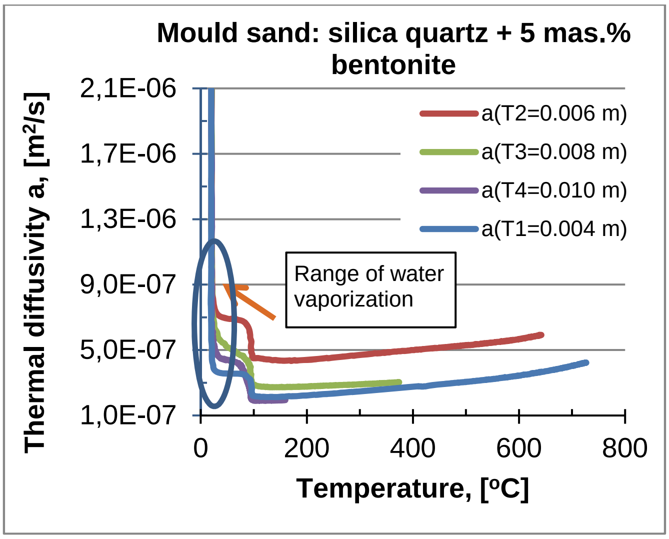

Fig. 4. The relationships: thermal diffusivity vs. temperature obtained for the examined sand in the *Casting Method* experiment

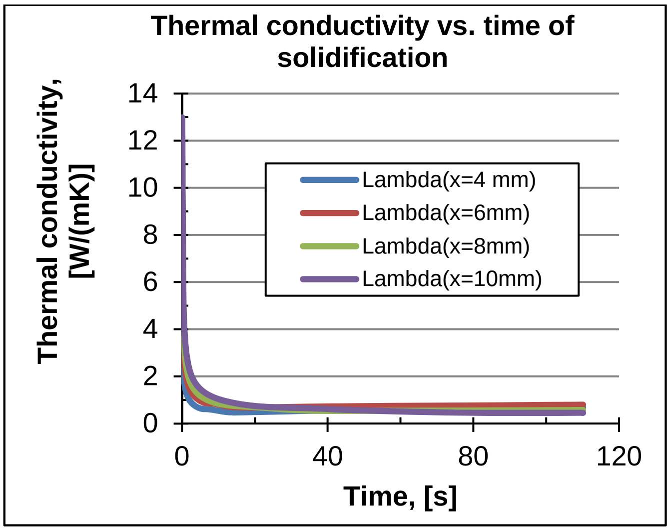

Fig. 5. The relationships: thermal conductivity vs. time of solidification obtained in the *Casting Method* experiment for the examined wet green sand

The temperature dependence of the examined sand thermal conductivity is shown in Fig. 6 and under higher magnification in Fig. 7. Again, as for the thermal diffusivity, the thermal conductivity drops around temperatures of water vaporization. From Fig. 7 it is also seen that moisture transport through the surface layers increases value of thermal conductivity (compare curves for $x = 4$ mm and $x = 6$ mm). Then values of thermal conductivity stabilize, however above 400-500°C again increase due to inter-granular radiation, which takes place mainly in the surface layers of the mould.

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.

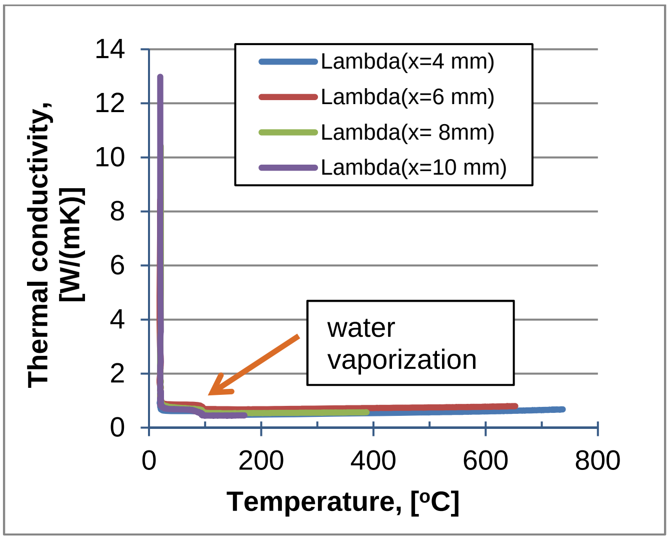

Fig. 6. The relationships: thermal conductivity vs. temperature obtained for the examined sand in the *Casting Method* experiment

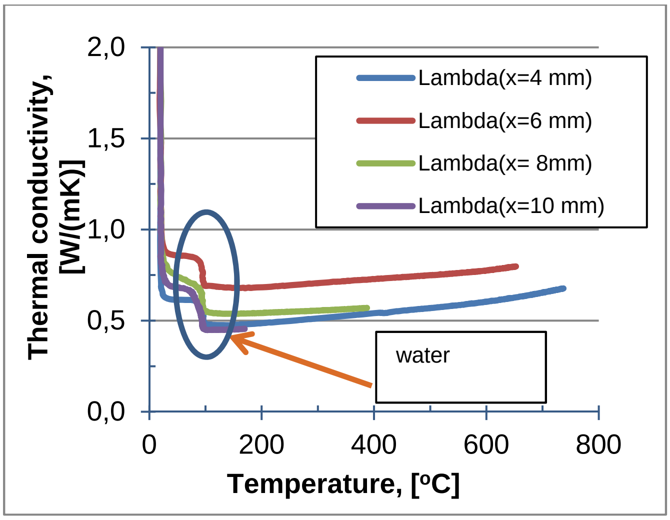

Fig. 7. The relationships: thermal conductivity vs. temperature obtained for the examined sand in the *Casting Method* experiment

4. Conclusions

Basing on the presented results the following conclusions can be drawn:

The *Casting Method* (CM) allows obtaining temperature dependence of the thermo-physical properties.

The CM is performed in real conditions of the poured sand mould, i.e. in contact with molten metal, under hydrostatic pressure of the molten metal during initial period of the metal cooling as well as in condition of the water evaporation from the wet mould.

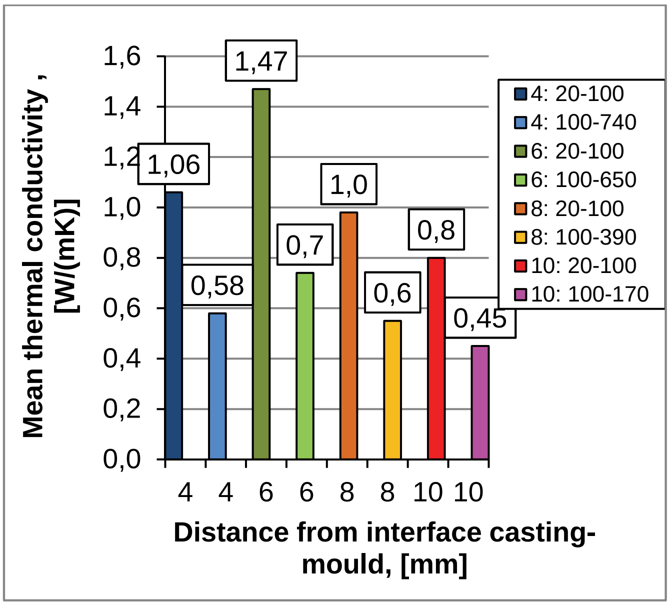

Fig. 8. Mean values of mould thermal conductivity in different distances from mould surface during casting solidification

Using mean values of the sand thermal conductivity in numerical simulations / calculations can lead to very high inaccuracy. As discussed in [25] time of solidification for different mean values of the sand thermal conductivity may be 10-40% different than the real one – Table 2.

Basing on mentioned results it should be concluded that only real temperature dependencies of sand thermo-physical properties, especially the thermal conductivity coefficient, should be implemented to the mathematical algorithms to ensure high accuracy of the numerical calculations.

Finally, it should be concluded that only the developed *Casting Method* can ensure data of high accuracy required in the numerical simulations and calculations.

TABLE 2

Time of solidification τ_{sol} by Nova Flow & Solid for different values of the mould mean λ_M thermal conductivity coefficient [25]

λ_M / W/mK	τ_{sol} / s	τ_{sol} / s	Error / %
	NovaFlow	Experiment	—
0.5	260.2	186.0	39.9
0.6	228.9		23.1
0.7	202.3		8.8
0.8	180.3		–3.1
0.9	162.7		–12.5

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Information: The English text of this paper bases on the previously published [1,4,25-28] ones, however the paper brings new, unpublished yet results of the examinations and calculations.

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