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HEAT EXCHANGE IN THE SYSTEM MOULD – RISER – AMBIENT. PART I: HEAT EXCHANGE COEFFICIENT FROM MOULD EXTERNAL SURFACE

WYMIANA CIEPŁA W UKŁADZIE FORMA – NADLEW – OTOCZENIE. CZĘŚĆ I: WSPÓŁCZYNNIK WYMIANY CIEPŁA Z ZEWNĘTRZNEJ POWIERZCHNI FORMY

The subject of the paper is heat exchange in the system casting – riser – ambient. The examinations were focused on evaluating temperature dependence of the coefficient of heat exchange from mould external surface (or from riser thermally insulated surface) to ambient. The examinations were carried out for the surface temperatures of 200-800°C. On the basis of the performed examinations it was stated that the relationship $\alpha_{ext.eff}$ vs. surface temperature can be described by a polynomial of 3^{rd} degree with accuracy of 90-95% and that the $\alpha_{ext.eff}$ coefficient significantly depends on the examined material mass density.

Keywords: casting, casting mould, solidification modelling, heat exchange coefficient

Praca dotyczy określenia temperaturowej zależności współczynników, opisujących intensywność wymiany ciepła w układzie odlew – nadlew – forma odlewnicza – otoczenie. Na podstawie pomiarów temperatury i bilansów cieplnych określono wartości sumarycznego współczynnika wymiany ciepła do otoczenia z powierzchni nagrzanej warstwy ochronnej (izolacyjnej) górnej powierzchni nadlewu, w zakresie temperatury 200-800°C. Uzyskano zależności o stosunkowo dobrym dopasowaniu, na poziomie R^2 (0.9-0.95). Porównawcza analiza wyników dla dwóch zbadanych materiałów, różniących się gęstością masy i pojemnością cieplną, wykazała, iż nie ma prostej zależności pomiędzy nimi, to jest wartość sumarycznego współczynnika wymiany ciepła nie zmienia się wprost proporcjonalnie do iloczynu gęstości masy i pojemności cieplnej. Uzyskane wyniki mogą być wykorzystane do określenia warunków początkowo-brzegowych w konstruowanych modelach numerycznych wymiany ciepła w układach odlew – nadlew – forma odlewnicza – otoczenie.

1. Introduction

In foundry practice of solidification of shape castings or ingots the open surfaces of risers or ingot-heads are usually insulated to lower the heat transferred to the ambient – Fig. 1.

Simulation of the solidification processes [1] requires knowledge of several boundary parameters, among others, the coefficient of heat transfer to the ambient from the mentioned above metal surfaces as well as from outer moulds surfaces. The coefficient, here denoted as $\alpha_{ext.eff}$ (effective coefficient of heat exchange from external surface to ambient), describes sum of the heat transferred via radiation and convection, while conduction is assumed to be negligible [2 – 3]. The value of the $\alpha_{ext.eff}$ influences, among others, the solidification process of risers and castings, especially the feeding process. The feeding process depends on grain-size of the casting, which can be controlled by heterogeneous nucleation, e.g. [4-6] or by the intensity of cooling, e.g. [7-9], which depends also on the $\alpha_{ext.eff}$ value.

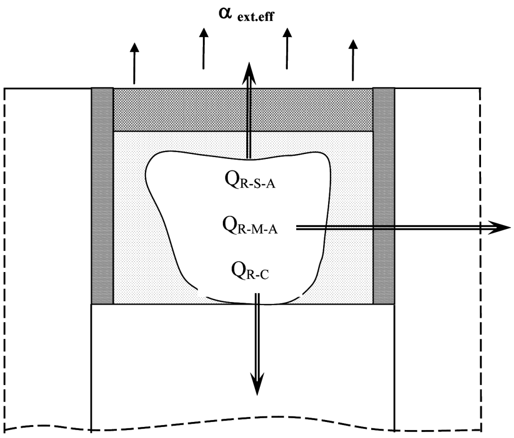

Fig. 1. Scheme of the heat exchange in the system casting – riser – mould – ambient. Q_{R-S-A}: heat exchange riser-shield-ambient; Q_{R-M-S}: heat exchange riser-mould ambient; Q_{R-C}: heat exchange riser – casting

The laboratory stand used during the examinations, shown in Fig. 2, consists of a heating plate with regulated heating power (1), insulating cylinder (3), distance ring of stainless steel (4) and accumulating plate of known

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thermo-physical properties (5). The investigations are aimed at determining coefficient of thermal exchange from the riser non-shielded surface and shielded with an insulating material, e.g. sand mass. These are coefficient of heat emissivity ε and $\alpha_{ext.eff}$.

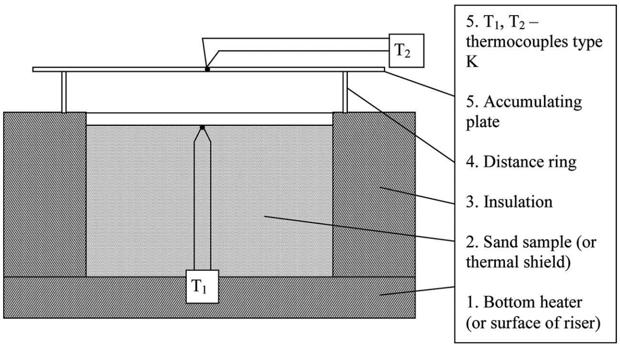

Fig. 2. Scheme of the laboratory stand used during the examinations of the heat emissivity ε coefficient [10]

Details of the heat emissivity measurement are presented in Ref. [10], while the present part is aimed at determining the $\alpha_{ext.eff}$ coefficient for outer surfaces of the sand-shield of a given density. The heat balance of the cooled plate-shape shield, emitting heat to ambient, is as follows:

$$dQ_{acc} = dQ_{ext.eff} \tag{1}$$

$$dQ_{acc} = -V\rho c d(T_{SURF} - T_{AMB}) = -V\rho c d\vartheta_{SURF} \tag{2}$$

$$\vartheta_{SURF} = (T_{SURF} - T_{AMB}) \tag{3}$$

$$dQ_{ext.eff} = [\sigma_0 \varepsilon (T_{SURF}^4 - T_{AMB}^4) + \alpha_{ext.conv}] A d\tau \tag{4}$$

$$dQ_{ext.eff.} = \alpha_{ext.eff} \vartheta_{SURF} A d\tau \tag{5}$$

After introducing (2) and (5) to (1) and rearranging one can obtain the following formula for calculating the $\alpha_{ext.eff}$ coefficient:

$$\alpha_{ext.eff} = \frac{-V\rho c}{A\vartheta_{SURF}} \frac{d\vartheta_{SURF}}{d\tau} \tag{6}$$

where:

- dQ – infinitesimal heat quantity, J
- Q_{acc} – heat accumulated in plate-shape shield, J
- $Q_{ext.eff}$ – heat emitted from external surface to ambient, J
- V – Volume of the plate-shape shield, m^3
- A – cooling surface of the plate-shape shield, m^2
- ρ – mass density of the plate-shape shield material, kg/m^3
- T_{AMB} – temperature of ambient, K
- T_{SURF} – temperature of the cooling surface A, K
- ϑ_{SURF} – relative temperature of surface A, K
- σ_o – black body radiation coefficient, 5.67*10-8 $W/(m^2K^4)$
- ε – surface emissivity coefficient
- τ – time, s

The $\alpha_{ext.eff}$ coefficient consists of the convection part ($\alpha_{ext.conv}$) and the radiation part (7)

$$\alpha_{ext.eff} = \alpha_{ext.conv} + \sigma_0 \varepsilon \frac{T_{SURF}^4 - T_{AMB}^4}{T_{SURF} - T_{AMB}} \tag{7}$$

from which the ε – surface emissivity coefficient can be easily calculated [10].

2. Results and discussion

The results of the performed examinations are shown in Figs 3-5. From Figs 3-4 it can be seen, that the relationship $\alpha_{ext.eff}$ *vs. surface temperature* can be described by a polynomial of 3^{rd} degree with accuracy of 90-95%. Furthermore, it appears from Fig 5, that values of $\alpha_{ext.eff}$ for *Sand 2* are approximately by 30% higher, though the $\rho * c$ of *Sand 2* is only by 25% higher than that of the *Sand 1*. It proves that there is need of individual $\alpha_{ext.eff}$ measurements for shields of different thermo-physical properties.

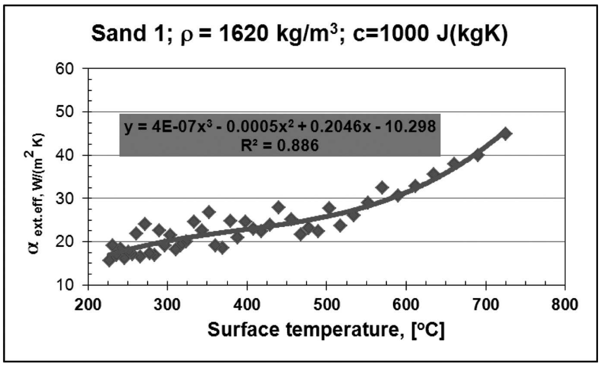

Fig. 3. Exemplary temperature dependence of the $\alpha_{3.eff}$ coefficient obtained for silica sand of density 1620 kg/m^3 and heat capacity 1000 J/(kg K)

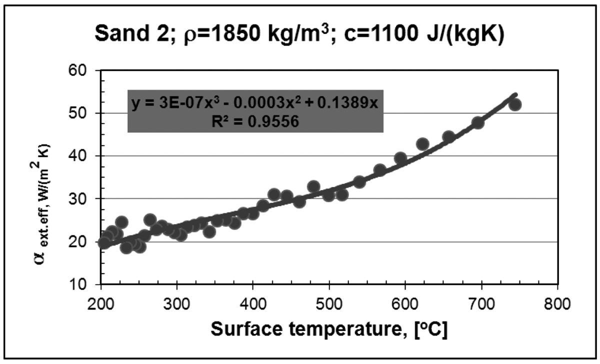

Fig. 4. Exemplary temperature dependence of the $\alpha_{ext.eff}$ coefficient obtained for silica sand of density 1850 kg/m^3 and heat capacity 1100 J/(kg K)

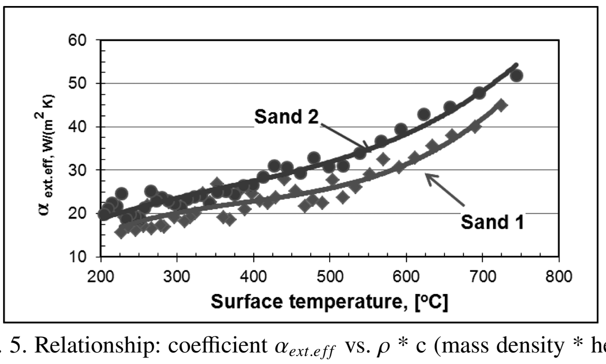

Fig. 5. Relationship: coefficient $\alpha_{ext.eff}$ vs. ρ * c (mass density * heat capacity) for the examined sand masses shields

Summing up, the results obtained using this simple measurement method allow to evaluate with enough accuracy temperature dependence of the $\alpha_{ext.eff}$ coefficient. The values obtained in the presented examinations allow to formulate boundary conditions for the computer-aided simulation of the processes of heat and mass transfer in the casting-mould-riser-ambient system [11-12].

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