

# Determination of Heat Accumulation Coefficient for Oil Bonded Moulding Sands

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## Abstract

The possibility of controlling the solidification and cooling time of castings creates prospects of improving their structure and by the same their properties. Thermal properties of the mould constitute therefore an important factor which is necessary to consider while seeking for the mentioned improvement. The presented work illustrates the method of determining some basic thermal coefficients of moulding material, i.e. the coefficient of temperature equalisation  $a_2$ , known also as the temperature diffusivity, and the heat accumulation coefficient  $b_2$ , which characterises the ability of moulding material to draw away the heat from a casting. The method consists in experimental determining the temperature field within the mould during the processes of pouring, solidification and cooling of the casting. The performed measurements allow for convenient and exact calculations of the sought-after coefficients. Examinations were performed for the oil bonded moulding sand of trade name OBB SAND 'E'. The experiment showed that the obtained value of  $b_2$  coefficient differs from the value calculated on the basis of theoretical considerations available in publications. Therefore it can be stated that theoretical calculations of the heat accumulation coefficient are thus far not sufficient and not quite reliable, so that these calculations should be verified experimentally.

**Keywords:** Theoretical basis of casting processes, Moulding material, Oil binder, Heat accumulation coefficient for moulding sands, Temperature equalization coefficient

## 1. Introduction

Thermophysical properties of moulding materials affect significantly the structure and properties of castings, since they are decisive for the rate of heat transfer through the mould. The concept of thermophysical properties (of moulding materials) is understood as a set of properties responsible for the rate of absorbing and drawing away the heat from the cast alloy poured into the mould cavity [1]. The lack of calculation methods concerning these properties of moulding materials can result both from their complex structure and the complexity of the mechanism of heat transfer across a sand mould, involving heat conduction through a single grain, contact heat transfer between

adjoining grains, as well as radiation and convection heat exchange between grains [2,3].

The most important parameters in heat transfer between a casting and a mould are [2]: the specific heat value  $c$ , thermal conductivity  $\lambda$ , the temperature equalization coefficient  $a_2$ , the heat accumulation coefficient  $b_2$ , the metal/mould interfacial heat transfer coefficient (the coefficient evaluating heat inflow into a sand mould)  $\alpha_1$ . The relationships taking into account the above mentioned parameters indicate that the quantity of heat accumulated by the mould increases with an increase of the specific heat and bulk density of the moulding sand (at a constant value of  $\lambda$  coefficient). In this case the heat transfer from the metal/mould interface farther into the mould is slowed down. In turn, if the specific heat and bulk density remain

constant, and  $\lambda$  increases, both  $a_2$  and  $b_2$  grow up, while the interfacial heat transfer coefficient  $\alpha_1$  for the sand mould decreases with time in every section of the mould.

Both coefficients, i.e. the interfacial heat transfer coefficient  $\alpha_1$  and heat accumulation coefficient  $b_2$  characterise the ability of moulding sand to draw the heat away from a casting. The larger is the volume (mass) of a mould corresponding to the unit surface area of the cooled casting, the larger quantity of heat can be accumulated in the mould and then irradiated to the environment. Moulding sands with high heat accumulation coefficients make possible pouring metals characterised by a high melting point into moulds made of material with a relatively low sintering point [2].

The effective (average) values of heat accumulation coefficient  $b_2$ , determined for the whole temperature range occurring in the mould during the solidification of particular metal, are of special interest in thermal theory. The formulas for solidification time or cooling time of a casting are derived for the  $b_2$  values understood in such a way. Therefore the methods of evaluating thermophysical properties of moulding materials should permit determination of the average value of heat accumulation coefficient [1,3,4].

There exists several methods of determining the heat accumulation coefficient for moulding materials. One of them is the method of measuring the solidification time of a test casting. The professional literature suggests the use of a slab model casting of dimensions  $0.3 \text{ m} \times 0.3 \text{ m} \times 0.03 \text{ m}$ . The mould for examination should be prepared of the investigated material in such a way that its wall thickness would surpass the wall thickness of the model casting. A thermoelement for temperature measurements is placed in the middle part of the casting, then the metal overheated to the possibly low degree is poured. The recorded values of temperature against time allow to determine the solidification time of the casting [4-9]. This being known, one can calculate the  $b_2$  value from the following equation:

$$b_2 = \frac{\sqrt{\pi} R_1 \rho L_m}{2 g_{kr} \sqrt{\tau_k}} \quad (1)$$

where:  $R_1$  – the relative wall thickness of the model casting;  
 $\tau_1$  – solidification time of the model casting [4].

This method allows for determination of both the heat accumulation coefficient value ( $b_2$ ) from the measured solidification time and the temperature equalization coefficient value ( $a_2$ ) from the measured mould temperature [8].

The other known method is the method of ‘pouring out’. The mould cavity is filled with molten metal, the time of holding the metal in the mould is measured, then the remaining non-solidified metal is poured out. Next the solidified metal shell is taken out and its thickness is measured. The  $b_2$  coefficient is calculated from the formula [4-7,10]:

$$b_2 = \frac{\sqrt{\pi} \rho}{2} R_1 \sqrt{\left( \frac{c}{\sqrt{\tau_k}} \ln \frac{T_m - T_f}{T_s - T_f} \right)^2 + \left( \frac{L_m}{(T_s - T_f) \sqrt{\tau_k}} \right)^2} \quad (2)$$

## 2. Methods and results of investigation

Taking into account the small number of measuring methods concerning thermophysical properties of moulding materials, mastering of such methods seems reasonable. The work undertakes a trial of determining the coefficients of temperature equalization ( $a_2$ ) and heat accumulation ( $b_2$ ) for moulding sand on the basis of measurement data from temperature field records obtained during solidification of CuSi3Zn3Mn1 (BK 331) alloy of known solidification heat (L) in oil-bonded moulding sand of known specific heat (c).

A laboratory stand suitable to perform the measurements of temperature distribution in sand moulds was prepared. The molten CuSi3Zn3Mn1 alloy was gravity cast at the temperature of 1025°C. Moulds were made of moulding sand of trade name O.B.B. SAND ‘E’, which is oil-bonded natural moulding sand of the finest fraction (AFS grain fineness number 140) and average grain size equal to 0.09 mm. The material exhibits long lifespan and can be used directly for moulding because the binder does not become dry. High compressive strength (1200 g/cm<sup>3</sup>), shear strength (380 g/cm<sup>3</sup>), as well as good permeability and greensand fluidity ensure the excellent dimensional accuracy of castings. Temperature values during metal inflow, solidification, and cooling were recorded by means of PCL-818 computer laboratory measurement card. The Visual LAB data acquisition program was used for measurements, and the applied sampling frequency of each temperature channel was equal to 100 Hz. The experimental mould was equipped with 8 NiCr-Ni thermocouples [11-14].

The experimental moulds were prepared in flasks of dimensions 150×100×50 mm. Pattern dimensions were 60×40×15 mm. After mould preparation and pattern removing, thermoelements were fixed as follows: one of them inside the mould cavity ( $x_0$ ), the next at the casting/mould boundary ( $x_1$ ), then further 6 thermocouples were placed at distances increased each time by 5 mm, i.e.  $x_2 = 5 \text{ mm}$ ,  $x_3 = 10 \text{ mm}$ ,  $x_4 = 15 \text{ mm}$ ,  $x_5 = 20 \text{ mm}$ ,  $x_6 = 25 \text{ mm}$ ,  $x_7 = 30 \text{ mm}$  from the casting/mould interface.

The results of temperature measurements are graphically presented in Figs. 1 and 2:

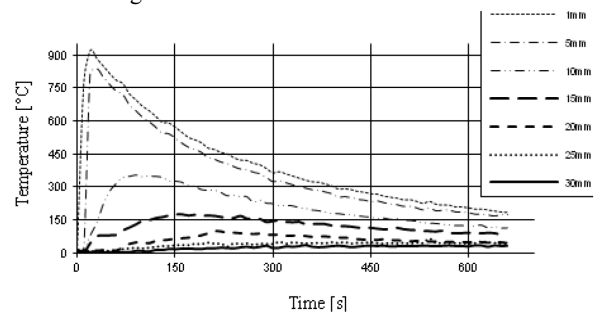


Fig.1. Temperature change within the mould during the solidification of the casting versus time

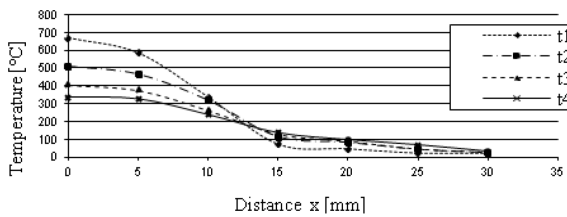


Fig. 2. Temperature change across the mould during the solidification of the casting

After performing the temperature field measurements in experimental moulds, it was possible to calculate the coefficient of temperature equalization  $a_2$  from the formula [15]:

$$a_2 = \frac{x^2}{4\tau} \left( \operatorname{arg\,erf} c \frac{T_x - T_{2p}}{T_k - T_{2p}} \right)^{-2} \quad (3)$$

The  $a_2$  value can be calculated if one knows the temperature ( $T_x$ ) of a point at a distance  $x$  from the contact surface, the initial temperature of the mould ( $T_{2p}$ ) and the casting/mould contact temperature ( $T_k$ ) at a given moment of time ( $\tau$ ).

The calculation results are presented in Table 1.

Table 1. The results of calculations of the coefficient of temperature equalisation  $a_2$

Distance from casting/mould interface	Time $\tau$ [s]	Temperature $T_x$ [°C]	Coefficient $a_2$ for oil-bonded sand
$x_2 = 0.005$ m	150	335	$8.72 \cdot 10^{-7}$
	300	316	$5.31 \cdot 10^{-7}$
	450	263	$3.72 \cdot 10^{-7}$
	600	236	$3.60 \cdot 10^{-7}$
$x_3 = 0.01$ m	150	71	$6.99 \cdot 10^{-7}$
	300	112	$5.53 \cdot 10^{-7}$
	450	130	$3.99 \cdot 10^{-7}$
	600	135	$3.84 \cdot 10^{-7}$
$x_4 = 0.015$ m	150	46	$4.53 \cdot 10^{-7}$
	300	80	$3.02 \cdot 10^{-7}$
	450	91	$2.69 \cdot 10^{-7}$
	600	97	$2.60 \cdot 10^{-7}$
$x_5 = 0.02$ m	150	22	$7.31 \cdot 10^{-7}$
	300	41	$4.45 \cdot 10^{-7}$
	450	48	$3.48 \cdot 10^{-7}$
	600	68	$3.09 \cdot 10^{-7}$
$x_6 = 0.025$ m	150	22	$1.06 \cdot 10^{-6}$
	300	23	$5.71 \cdot 10^{-7}$
	450	29	$4.09 \cdot 10^{-7}$
	600	32	$3.76 \cdot 10^{-7}$
$x_7 = 0.03$ m	150	22	$1.53 \cdot 10^{-6}$
	300	23	$7.67 \cdot 10^{-7}$
	450	28	$5.23 \cdot 10^{-7}$
	600	30	$4.11 \cdot 10^{-7}$
<b>average</b>			<b><math>5.39 \cdot 10^{-7}</math></b>

Next the heat accumulation coefficient  $b_2$  was calculated from the formula [4,15]:

$$b_2 = \sqrt{\lambda_2 c_2 \rho_2} \quad (4)$$

where  $\lambda_2$  is the thermal conductivity of moulding sand [W/m K],  $c_2$  – the specific heat of moulding sand [J/kg K], and  $\rho_2$  – density of moulding sand [kg/m<sup>3</sup>].

Determining  $\lambda_2$  from the relationship:

$$a_2 = \frac{\lambda_2}{c_2 \rho_2} \quad (5)$$

and substituting it into the Formula 4, we obtain:

$$b_2 = c \rho \sqrt{a_2} \quad (6)$$

Fig. 3 presents the values of the heat accumulation coefficient calculated for the examined moulding sand at selected locations within the mould and the following Fig. 4 shows curves depicting the change of  $b_2$  coefficient with the temperature change.

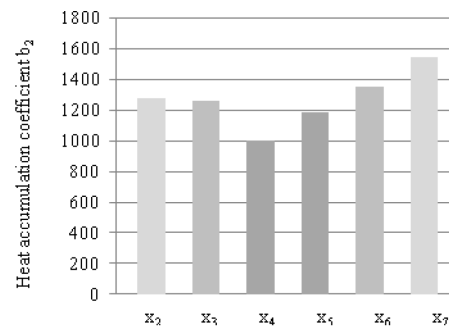


Fig. 3. The values of the heat accumulation coefficient at selected locations within the mould made of the O.B.B. Sand ‘E’

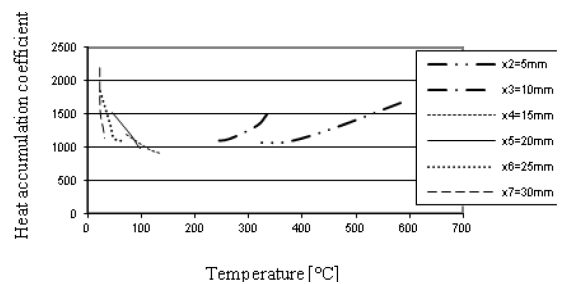


Fig. 4. The temperature dependence of the heat accumulation coefficient of the moulding sand O.B.B. Sand ‘E’

Fig. 3 reveals that the values of the  $b_2$  coefficient are similar for the distances between 0.005 m and 0.02 m from the metal/mould interface, i.e. about 1250 [W·s<sup>1/2</sup>/m<sup>2</sup>·K], then they increase to reach the value of about 1550 [W·s<sup>1/2</sup>/m<sup>2</sup>·K] at a distance of 0.03 m from the surface of a casting.

Fig. 4, in turn, indicate the slow decrease of the coefficient  $b_2$  with the temperature decrease for the distances close to the casting/mould interface, and its rapid increase with the decrease of temperature for the  $x$  distances ranging from 20 to 30 mm. Substituting the calculated above average value of the coefficient of temperature equalisation  $a_2$  into the Formula 6 we obtain the average heat accumulation coefficient of the examined oil-bonded sand, which is equal to:

$$b_2 = 1303,85 \text{ [W} \cdot \text{s}^{1/2} / \text{m}^2 \cdot \text{K]}.$$

Calculation of this coefficient based on the data published in professional literature leads to the result:

$$b_2 = 1037,24 \text{ [W} \cdot \text{s}^{1/2} / \text{m}^2 \cdot \text{K]},$$

which differs by about 30% from the value determined on the basis of actual measurements of temperature within the mould. The heat accumulation coefficient characterises the ability of moulding material to absorb heat emitted during the solidification and cooling of a casting. As the Formula 4 indicates, it increases with an increase in thermal conductivity, specific heat, and the density of the sand. Greater value of the coefficient corresponds to the greater ability to draw away heat from the casting.

### 3. Conclusions

1. The performed experiments allow to determine the basic thermophysical properties of the oil-bonded moulding sand, i.e. the coefficient of temperature equalisation  $a_2$  and the heat accumulation coefficient  $b_2$  in the selected points within the mould. The applied methods allows for convenient and sufficiently precise calculation of their values.
2. It has been found that the temperature of the mould decreases rapidly within the distance of 15 mm from the casting/mould interface, farther on the temperature decreases only slightly.
3. It has been also found that the  $b_2$  coefficient of the examined material stays unaltered within the distance up to 20 mm from the casting/mould interface and is equal to 1250  $[\text{W} \cdot \text{s}^{1/2} / \text{m}^2 \cdot \text{K}]$ , while for greater distances it rises significantly and reaches the value of 1550  $[\text{W} \cdot \text{s}^{1/2} / \text{m}^2 \cdot \text{K}]$  at a distance of 30 mm.
4. The experimentally determined value of the heat accumulation coefficient of the oil-bonded moulding sand differs significantly from the  $b_2$  value calculated on the basis of data published in professional literature, the first value being equal to 1303  $[\text{W} \cdot \text{s}^{1/2} / \text{m}^2 \cdot \text{K}]$ , while the second one reaches only 1037  $[\text{W} \cdot \text{s}^{1/2} / \text{m}^2 \cdot \text{K}]$ . It can be said that theoretical calculations of the heat accumulation coefficient are thus far not sufficient and not quite reliable, so that these calculations should be verified experimentally.
5. The  $a_2$  and  $b_2$  coefficients are decisive for the heat transfer from the casting to the mould. Since their values can be affected by the appropriate selection of moulding material composition and the way in which the mould is prepared for pouring, one can control to a certain degree the rate of heat transfer from a casting to the mould. This is equivalent with the possibility of

influencing the solidification rate and solidification time, what can in turn affect the structure and properties of the final casting.

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