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Heat Flow in the Casting – Mould System for Moulds with Gypsum and Cement Binder

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Abstract

The production of thin-walled castings with wall thickness in the range of 1.5 to 3 mm and below requires the development of insulation moulding sands and/or core materials. The test has been taken to develop these kind of materials. The study included a description of their thermophysical properties. Authors described problems related to the heat flow in the casting-mould system, i.e. mathematically described the main dependence of heat give-up during crystallization of the casting. The influence of the content of polyglicol on the thermophysical properties of the mould with gypsum and cement binder was examined. Using the ATD method determined were the increments ΔT_1 and ΔT_2 describing the temperature changes in the mould during crystallization of hypoeutectic alloy of AlSi6 and the temperature difference between casting material and mould during the crystallization. In the considered range of technological parameters a description of the heat flow kinetics was given.

Keywords: Heat flow, Moulding sand, Gypsum, Cement, Thermophysical properties

1. Introduction

Preparation of liquid metal for pouring the moulds increases constantly the energy level of the melted charge, which lasts until the energy sources powering the furnace is shut off. Shortly after this, follows the continuous give-up of heat, which lasts up to the moment, when the energy level of the metal is equal to level of the surroundings.

Pouring and filling of the mould cavity causes the transfer of liquid metal heat at the interface of mould-metal through the phenomenon of radiation and conduction. During this time the volume of the casting and moulds generates pseudoinitial temperature field, which is essential in order to fill the cavity mould, as well as a further cooling and solidification cast [1].

Type of casting mould and its material have a significant impact on the process of formation of the primary structure of the casting [2÷6]. Not without significance is also the phenomenon of heat flow between the casting and the mould and accompanying processes, i.a. the formation of gas holes, which change the conditions of process kinetics.

This flow is a complex process, in which participate: conduction, convection and radiation. These phenomena often occur together, for example conduction and convection in the liquid part of the casting, and radiation and convection – on the external surfaces of the casting and the mould.

2. Heat Flow in Solids

The main law describing the phenomenon of heat flow between any of the bodies is the Fourier law [7]. Compiled together with the equation for the balance of energy in the form of differential creates a physical model of heat conduction in solid bodies in the form of partial equation, parabolic [8]. In some cases, however, due to factors such as a large temperature gradient, very high heat flux density or short duration of heating, the Fourier law should be modified by application of relaxation time vector density stream of heat ($10^{-8} \div 10^{-12}$ [s] for homogeneous materials and $10^{-3} \div 10^{3}$ [s] for heterogeneous materials) or retardant gradient temperature [8].

Taking into account the first modification used to derive new independent differential equations by Cattaneo [9] and Vernotte [10]. Introduction of retardation, time-dependent relaxation and conductivity coefficient λ, is shown at work [11] in the form of a partial differential equation of type Jeffreys.

Presented heat flow equation are universal and apply to all the moulds described in literature [12 ÷ 14]. A description of the phenomena involved in the movement of heat are contained in [15 ÷ 18].

2.1. Heat flow by Fourier transform

In its basic form (1) is it the heat flux density with temperature gradient [2].

$$q = -k\nabla T \tag{1}$$

where: q – heat flux density, k – thermal conductivity, T – temperature

List of equations (1) and energy balance (2), taking into account the presence of an internal heat source, allows the derivation of differential equation parabolic transient heat conduction, i.e.. Fourier-Kirchhoff equation (3).

$$\rho c\frac{dT}{dt} + \frac{dq}{dx} = 0 \tag{2}$$

$$\nabla \cdot k\nabla T + Q = \rho c\frac{dT}{dt} \tag{3}$$

where: Q – internal heat source, ρ – density, c – specific heat

2.2. Heat flow by Cattaneo transform

Taking into account the relaxation phenomena of heat stream density is due to the finite size of the propagation of heat in the system and abnormalities resulting from Fourier model. Cattaneo equation is shown by formula (4) [9].

$$\tau\frac{dq}{dt} = -q - k\nabla T \tag{4}$$

where: τ – relaxation time.

Substituting the formula (4) under the formula (2) and taking into account the speed of propagation of temperature (5) and internal heat source is the equation describing heat conduction (6).

$$c_T = \sqrt{\frac{k}{\tau\rho c}} \tag{5}$$

$$\nabla^2 T(x,t) + \frac{1}{k}\left[Q(x,t) + \tau\frac{dQ(x,t)}{dt}\right] = \frac{1}{\alpha}\left[\tau\frac{d^2T(x,t)}{d^2t} + \frac{dT(x,t)}{dt}\right] \tag{6}$$

Equation (6), in which τ parameter tends to zero, is called Fourier-Briot formula.

2.3. Heat flow by Jeffreys transform

Originally derived by Jeffreysa formula concerned on the propagation of waves in the Earth's crust. Only Joseph and Preziosi in their work [11] used it to describe the phenomenon of heat flow and presented in the form (7)

$$q + \tau\frac{dq}{dt} = -k\left[\nabla T + K\frac{d(\nabla T)}{dt}\right] \tag{7}$$

where

$$K = \frac{\tau k_1}{k}$$

is deley time, k_1 – effective coefficient of thermal conductivity (Fourier coefficient), k_2 – Cattaneo conductivity factor, $k = k_1 + k_2$.

Total form of equation (7) shown by formula (8).

$$q = -k_1\nabla T(x,t) - \frac{k_2}{\tau}\int_{-\infty}^{t} e^{\frac{-(t-s)}{\tau}}\nabla T(x,s)ds \tag{8}$$

Having regard to the internal energy source and putting together formulas (8) and (2) obtains formula (9)

$$\frac{1}{{c_T}^2}\frac{d^2T}{d^2t} + \frac{1}{\alpha}\frac{dT}{dt} = \nabla^2 T + K\frac{d}{dt}(\nabla^2 T) + \frac{1}{k}\left[Q(x,t) + \tau\frac{dQ(x,t)}{dt}\right] \tag{9}$$

3. Range of studies

The aim of the study was use of ATD method to register the propagation of heat in the cement-based plant moulds, various types of gypsum and observation of changes of temperature under the influence of polyglycol.

Range of the studies included:

- the development of mas with different proportions of polyglycol,
- preparation of moulds, in the form of a sibral sleeve,
- the melting process of hypoeutectic aluminium,
- pouring moulds,
- registration of temperature changes in metal and in the mould,
- analysis of the ATD curves,
- analysis of the results.

Moulds components (table 1) were selected by adopting high-capacity penetration hypothesis of polyglycole, that by changing the volume of micropores in the matrix-binder system allows to thermophysical properties control of mould, shaping movement of kinetics of heat in the cast-mould-environment system.

Table 1.
Types of moulds, their composition and proportions (m – matrix, w – water, p – polyglycol)

Matrix	Mould	Composition			Proportion		
		m	w	p	m	w	p
Building gypsum	P1	200	130		1	0,65	
	P2	200	130	13	1	0,65	0,065
	P3	200	117	13	1	0,59	0,065
	P4	200	143	13	1	0,72	0,065
Cement	P5	200	150		1	0,75	
	P6	250	100	10	1	0,4	0,040
	P7	250	90	10	1	0,36	0,040
	P8	250	110	10	1	0,44	0,040
Dentistry gypsum	P9	200	60		1	0,3	
	P10	200	65	6,5	1	0,33	0,033
	P11	200	58,5	6,5	1	0,29	0,033
	P12	200	71,5	6,5	1	0,36	0,033

Section of the mould with the placed thermoelement for measuring the temperature is shown in the figure 1.

In order to determine the heat flow kinetics in the cast-mould system determine two parameters: ΔT_1 and ΔT_2. The methodology of their determination shown in figure 2.

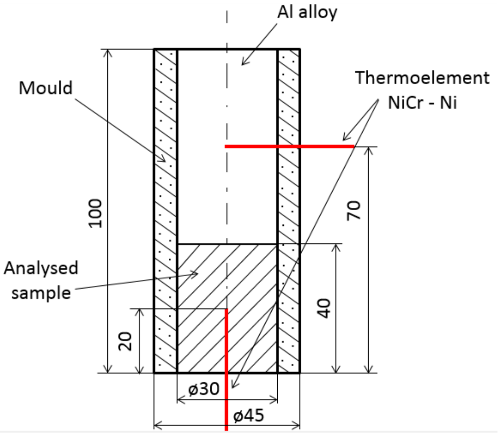

Fig. 1. Cross section of mould

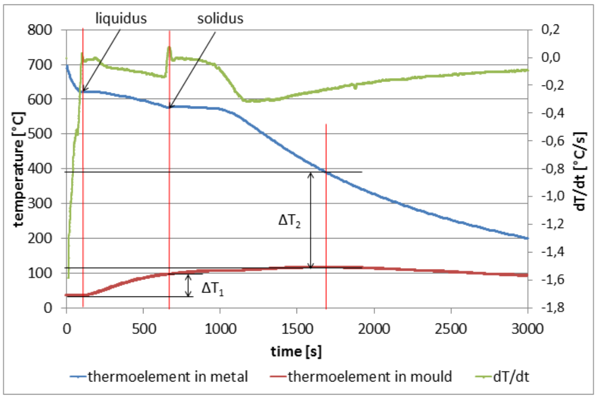

Fig. 2. Methodology of determination parameters ΔT_1 and ΔT_2

3.1. Results of studies

The results of the measurements of the step 500 [s] for all types of moulds are shown in table 2 and fig. 3.

Table 3 shows the results of the bulk size ΔT_1 and ΔT_2 with statistics.

Table 2.
The value registered for step-temperature 500 [s]

Mould	500	1000	1500	2000	2500	3000	3500	4000	4500
P1	67	84	90	88	82	74	67	61	56
P2	84	105	114	112	102	91	80	71	65
P3	77	88	106	109	103	94	84	76	70
P4	76	96	113	110	98	86	75	66	58
P5	111	147	144	124	104	87	75	65	
P6	106	143	159	153	137	119	103	89	
P7	108	152	166	152	131	111	95	83	73
P8	108	141	148	132	113	97	83	72	63
P9	108	106	128	125	114	100	88	77	69
P10	98	126	141	135	123	108	95	85	76
P11	75	88	96	104	101	95	87	80	73
P12	82	86	100	103	98	89	79	70	62

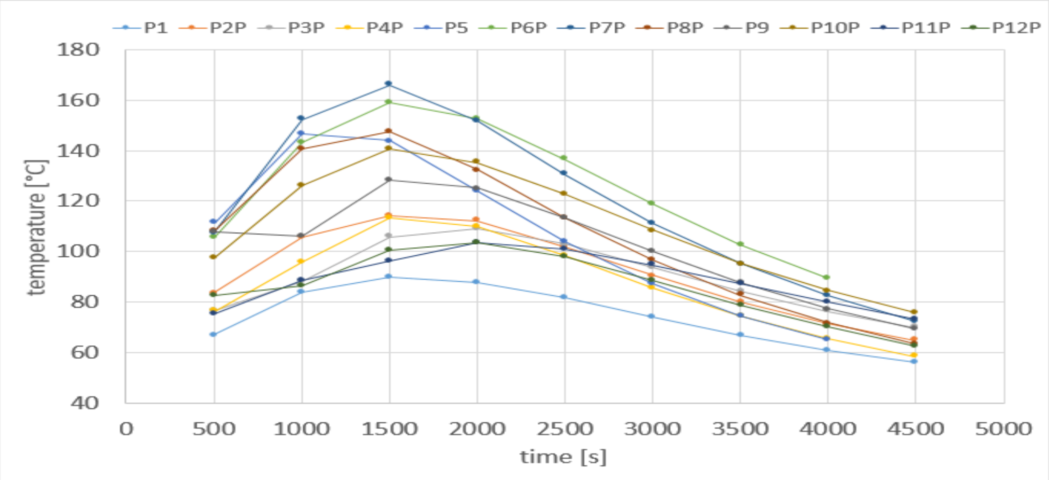

Fig. 3. Graph of temperature variation as a function of time for developed moulds

Table 3.
A summary of the results obtained

No	**Mould**	**ΔT_1 [°C]**			**ΔT_2 [°C]**		
		Diameter	**Variance**	**Standard deviation**	**Diameter**	**Variance**	**Standard deviation**
1	P1	39	1	1	216	1 201	35
2	P2	38	113	11	284	145	12
3	P3	33	85	9	234	145	12
4	P4	10	113	11	255	613	25
5	P5	53	-	-	197	-	-
6	P6	44	13	4	270	512	23
7	P7	21	41	6	274	221	15
8	P8	74	1	1	252	25	5
9	P9	52	18	4	241	648	25
10	P10	55	12	3	278	61	8
11	P11	20	25	5	188	5	2
12	P12	50	0	0	241	1	1

4. Conclusions

Based on conducted studies following conclusions have been formulated:

1) Moulds of average contents of polyglycole P6 and P7 are characterized by the highest temperature values measured in the moulds during the measurement.
2) For all masses the greatest temperature at 500 s time step was observed in the period 1500 to 2000 [s] – the highest value 166 [°C] obtained for mould P7 after 1500 [s].
3) The rise of temperature in the range of liquidus-solidus of solidificated alloy (ΔT_1) was determinated – the lowest diameter value is observed for mould P4 of 10 [°C] (m : w : p = 1 : 0,72 : 0,065), the highest for P8 of 74 [°C] (m : w : p = 1 : 0,44 : 0,040).
4) The lowest diameter value of ΔT_2 parameter, characterised as a difference between the temperature in the alloy and the maximum temperature in the mould, determined for P11 of 188 [°C] (m : w : p = 1 : 0,29 : 0,033), the highest for P2 of 284 [°C] (m : w : p = 1 : 0,65 : 0,065).
5) The analysis showed that relatively simple and fast made of technological tests used for determine of thermal properties of mould are possible.
6) Proved that the content of polyglycol variable affects of heat flow conditions in the casting-mould system.

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