A method for determination of heat storage capacity of the mold materials using a differential thermal analysis

E Ol'khovik
Admiral Makarov State University of Maritime and Inland Shipping, 5/7, Dvinskaya st., Saint-Petersburg, 198035, Russia

E-mail: olhovick@gmail.com

Abstract. The article proposes a method for determining of the heat storage capacity of the mould materials. Modern materials for mouldsare made using a variety of technologies, and the manufacturers of binders and additives ensure thermal properties of certain materials only when using a certain recipe.In practice, for management of the casting solidification process (creation of the volume or directed mode) it is favorable to apply various technological methods, including modification of one of the important properties of the casting mould, which is heat storage capacity. A rather simple technique based on the application of the differential thermal analysis was developed for its experimental definition. The obtained data showed a possibility of industrial application of the method.

1. Introduction
Improving the quality of steel castings and their obtaining with good mechanical properties is an important scientific and technical problem of foundry production. The successful solution of this problem is possible through the use of efficient technologies.

Detailed information about the course of the physical processes happening during solidification and subsequent cooling of the metal of casting in the mold is necessary in order to elaborate the technological solutions. The thermal processes happening both in the metal and on borders of metal-mold and metal-core define the formation of the majority of main defects. The ability to managethermal processes and to predict the possible types of their interactions allows the process engineer to develop a package of measures [1], providing the obtaining of high quality cast details.

The most important property of the mold materials is their heat physical properties: thermal capacity, a coefficient of heat conductivity and heat storage capacity which in turn depends on the technology of mixture preparation (the structure of initial components, existence of additives, etc.) and conditions of the molds production (extent of consolidation, hold time after molding, drying, etc.).

2. Experimental work. A method of measurement
In this work, due to development of special techniques of the differential thermal analysis, the research of heat physical properties of themoulding materials, including a specified analysis of heat storage capacity of a sandmold, is proposed.

The differential thermal analysis is based on simultaneous measurement of temperature in several points of an alloy and a mold, thereby, it is possible to receive a fuller picture of metal solidification of in the mold.Thus there is an opportunity for analytical calculation of such magnitudes as thermal capacity, heat conductivity and heat storage capacity of the materials participating in cast molding.

The differential thermal analysis allows obtaining important data about kinetics of phase transformations from the results of measurement of the difficult temperature field. The technique developed in this work allows making the process of measurements continuous. Besides, it allows usto study even the fast-proceeding phase transformations during metalsolidification.

The intensity of heat exchange between the casting and the mold is various in the different periods of solidification. At the beginning of contact of the liquid metal with the cold mold the intensity of heat removal from the surface of the casting is high, and then, in the process of warming up of the mold, the intensity of heat exchange decreases. The nature of the intensity change of heat removal from the casting entirely depends on heat physical properties of the mold.

Obviously, the use of molding materials with various heat physical properties is one of the means of regulation of the castings properties. According to work results, the corresponding choice of heat physical properties of the molding mixture allows adozens of time change of the speed of the casting solidification.

The basic heat physical constants are: heat conductivity coefficient – λ, specific heat capacity - C, and density – ρ, coefficient of heat storage capacity – $b_{\text{ф}} = \sqrt{\lambda \cdot c \cdot \rho}$ and thermal diffusivity - $a = \dfrac{\lambda}{c \cdot \rho}$.

A direct measurement of heat capacity of the disperse materials in general and molding [2] mixtures in particular is connected with special difficulties. The matter is that the existing methods of direct determination of the coefficient of heat capacity belong to the methods of usual calorimetry. Because of small heat conductivity of the disperse materials the temperature balance in the calorimeter is established extremely slowly, and the losses of heat by the calorimeter in environment are considerable and it is difficult to keep records of them. In this regard for definition of heat capacity of the molding mixtures we have used the indirect methods that allowcalculatingof the coefficient of heat capacity according to experimentally found other heat physical characteristics [3]. But, despite the possibility of λ calculation of other heat physical coefficients, some researchers prefer a direct determination of the coefficient of heat conductivity of the molding mixtures [4].

The developed scheme for carrying out of the thermal analysis of alloys is represented in Figure 1. For implementation of the thermal analysis, the mold (Figure 2) made of quartz sand (96 %) with addition of binding was prepared in the following proportions: a polyvinyl acetate emulsion – 1 %, divinyl-styrol latex – 1 %, water – 2 %, in which one of the thermocouples previously painted with special non-stick paint was located.The control thermocouples were also located in the moldat a pre-determined distance from the experimental casting [5].

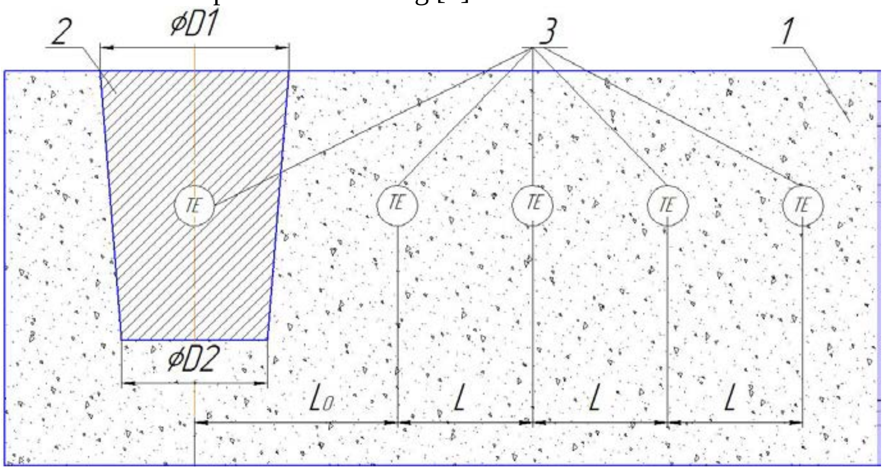

Figure 1. A principal scheme for determination of heat storage capacity of the mold material with the use of differential thermal analysis: 1 – casting mold, 2 – experimental casting, 3 – set of thermocouples (TE), L – distance between the thermocouples.

a b

Figure 2. The casting mold with defined thermocouples (a) and the experimental casting (b) for determination of the heat storage capacity of the mold.

The volume of the casting was previously calculated and included into the volume of metal solidifying within 3 minutes. In the electric furnace the aluminum alloy made of the Aluminum 6063-T6 (ISO)grade was prepared and filled into the mold (Figure 2b). Installed thermocouples are measuring the change of temperature in the casting sample and in the mold.With the use of the multichannel analog-digital converter (ADC) the data from each thermocouple were fixed in the personal computer with the frequency of one measurement per second.

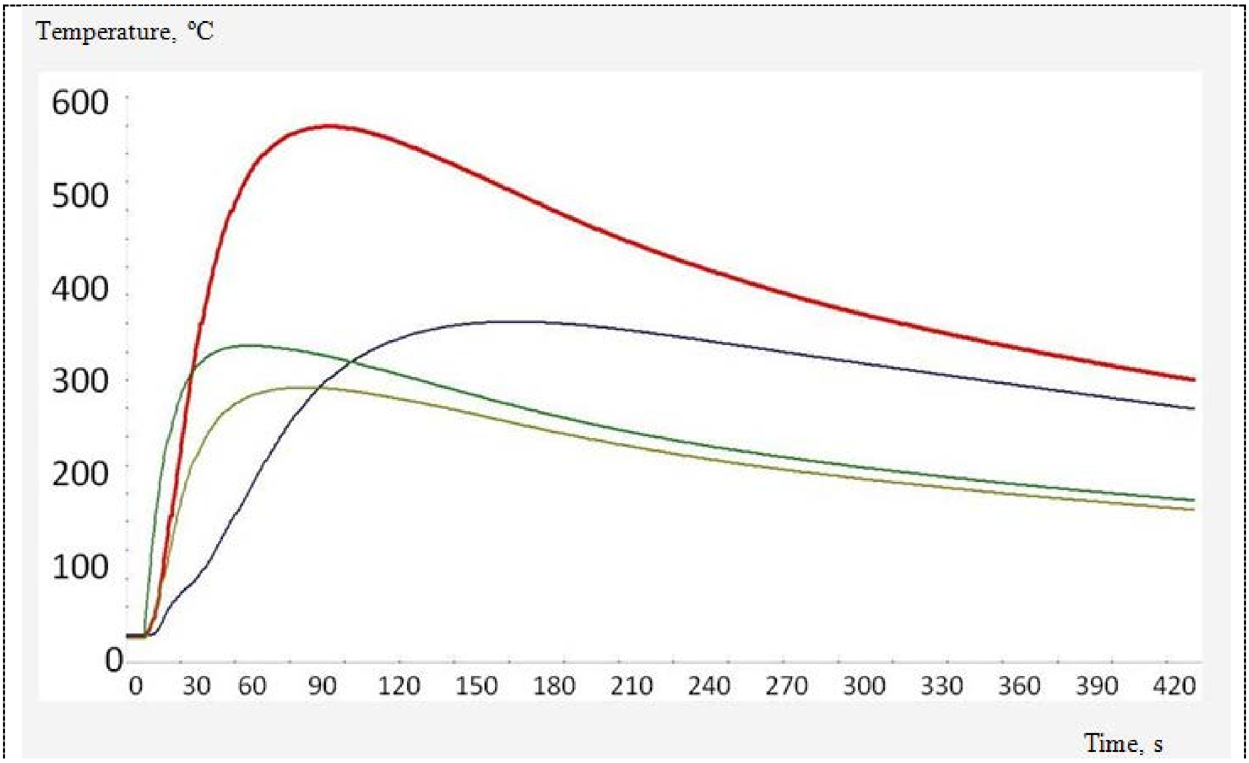

Figure 3. Experimental data of the differential thermal analysis
——Temperature in the center of the experimental casting sample (Al-alloy)
——, ——,——Temperature in the mold (alpha-set)

3. Results

For experimental determination of heat physical properties of the moldingmaterials it is necessary to possess a qualitative mathematical apparatus which is capable of analyzing the data obtained by results of the differential thermal analysis (Figure 3).

For this purpose the computational model of the process of cooling of the casting in the moldon the basis of the differential equation of heat conductivity has been developed. In the finite-difference calculations of the heat transfer between the casting and the mold the method of elementary balances has been applied, when the equation of thermal balance for an *i*-element of splitting of the wall acquires the following view:

$$\sum_{j=1}^{m} \cdot k_{i,j}^{n} (T_i^n - T_j^n) F_{i,j} \Delta\tau = c_i G_i (T_i^n - T_i^{n+1}) \quad (1)$$

where k – the heat transfer coefficient between elements i and j, m – the number of non adiabatic element faces; F – the contact area between elements i and j; G – the specific heat of the material element and its mass; $\Delta\tau$ – a time step; n – a time index.

When the i element contacts a j element the coefficient of heat transfer will be determined by formula

$$k_{i,j} = 1/\left(\frac{L_i}{\lambda_i} + \frac{L_j}{\lambda_j}\right) \quad , \quad (2)$$

for an extreme element of the conditionally allocated part of the mold,

$$k_{i,\alpha} = 1/\left(\frac{L_i}{\lambda_i} + \frac{1}{\alpha_i}\right) \quad , \quad (3)$$

where L – distance from the center of gravity of the *i*-element (with the coefficient of heat conductivity of 1) to the next element (or to the border of the conditionally allocated part of the mold) in the direction of the movement of the thermal stream.

The thickness of the mold is allocated conditionally, for the purpose of reduction of the computational area, and it can be of any value.Heat diffusionon the boundary of mold and in the allocated part is expediently presented as an equality of thermal streams at variable coefficient of heat transfer α_m. During warming up of the whole conditionally allocated thickness it is necessary to consider heat transfer conditions on the conditional border of the mold. The results of calculation of heat transfer are carried out in the mold of temperature fields at various time points until full solidification of the casting.

4. Conclusion

Thus, at each temporary step of the process of casting solidification there is information about the temperature for each of the thermocouples located both in the experimental casting and in various sites of the mold. In this case, it is possible to make a system of the equations (1…3) where one can take measured temperatures as unknown values, heat physical characteristics of the mold(heat conductivity coefficient – λ and specific heat capacity – C)as constants. We have considered that the density of metal and the density of the material of the moldare initially known with the sufficient accuracy. Jointly solving not less than 3 equations, it is possible to execute calculation λ, C that is sufficient information for calculation of heat storage capacity of the mold.

The conducted experiments have showed a good convergence of results. For the material of the mold, the described above adequate results in comparison with the literary data have been received.

The advantage of the developed method is a possibility of creation of dependence of the value of heat storage capacity of the moldmaterial, both from the point of the metal temperature and the mold temperature. The offered method can be used for the increase of the efficiency of foundry technologies, including the creation of the mode of the volume or directed solidification [6, 7] and for definition of heat physical characteristics of new mold materials.

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