AN IMPORTANCE OF THERMOPHYSICAL PROPERTIES ON CALCULATION ACCURACY OF THERMOKINETICS OF SOLIDIFICATION

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Abstract

The thermophysical properties of steels have significant influence on the actual casting process, and on the accuracy of its numerical simulation and optimization. On a steel sample casting of cylindrical shape that was cast in a non-metallic or metallic cylindrical mould the analysis of influence and importance order of the main thermophysical properties of casting and moulding materials on calculation accuracy of temperature field in the system of casting-mould-environment has been performed. As a comparing datum of accuracy the total time of solidification (crystallisation) has been selected. For the cast material, the influence of heat conductivity $\lambda$, specific heat capacity $c$, density $\rho$, and namely in the liquid or in the solid phase, in addition of latent heat of phase transformation $L$ also has been analysed. For metallic or non-metallic moulding material an influence of the same main parameters has been analysed and in addition their combination, temperature conductivity $\alpha$ and of heat accumulation $b$. The influence of each parameter has been studied within the range from 50 to 150 % of its real value and executed graphically.

1. INTRODUCTION

Solidification and cooling of castings, ingots and continually cast billets rank among the major technological processes. It is also necessary to reduce energy and material consumption in foundry and metallurgical production using simulation of solidification. The numerical models of thermokinetics of solidification are already available on our market but are mostly inaccessible. Therefore they can not be used for the analysis of the influence of thermodynamic properties on materials entering into the system of casting-mould-environment or the influence of the boundary conditions of the solution. Relevant data collection, prior to initiating the calculation, frequently demands more time than the proper calculation of the temperature field.

2. A NUMERICAL MODEL

The original and universal mathematical model of solidification, cooling and heating has been set up and checked in order to be capable of analysing a one- to three-dimensional steady or unsteady temperature field of the casting-mould-environment system and namely of the system as a whole or its arbitrary parts during any industrial technological process whose individual processes can be solidification, cooling, heating, refrigerating and others in any sequence or singly. The model enables the simulation of traditional and also non-traditional technologies of casting in foundries, metallurgical plants, forging operations, heat treatment processes, etc. If solidification is not the matter, the metal part of the system need not be called the casting but a component, a billet, a block, a forging, and the like.

Solidification (crystallisation) and cooling rank among the most important technological processes. It is the case of generally up to the three-dimensional (spatial) transfer of not only heat but also mass. In the system of casting-mould-surroundings, all three kinds of heat transfer take place. In such a range the problem is unable to be solved accurately. It is not exactly solvable in the case when mass transfer is not under consideration and from the three kinds of heat transfer in the system the conduction is considered decisive. The temperature field is described by the Fourier equation which is exactly unsolvable. The chance of their
successful solution lies in the numerical methods. From these the explicit differential method has been chosen. It will allow the most elegant way of simulation of development of latent heat of the phase or structural transformations that in both of the mentioned equations appear as a member of the so-called heat flow from the internal source. For the proper simulation of latent heat development the thermodynamic function of enthalpy is introduced.

On the network borders in contact with the surroundings (the area of the foundry, metallurgical plant, laboratory) mostly the boundary condition of the 3rd kind is taken into account. When setting up the balance equations on the internal surface (on the mould-casting or core-casting interfaces) the boundary conditions of all four kinds may be applied. It depends on which way the heat transmission on the melt-mould interface is characterised.

3. THE INFLUENCE OF THERMODYNAMIC PROPERTIES

On a steel sample casting of cylindrical shape that was cast in a fireclay or cast iron cylindrical mould the analysis of influence of the main thermophysical properties of casting material on calculation accuracy of temperature field in the system of casting-mould-environment has been performed (Fig. 1).

As a comparing datum of accuracy the total time of solidification (crystallisation) and mechanism of forming of temperature field of a solidifying casting represented by isotherms in longitudinal axial section through the casting and the mould have been selected. In addition an analysis of the influence of thermophysical parameters of moulding material on solution accuracy of thermokinetics of solidification has been performed.

**Fig. 1** Longitudinal-axis section of the system

For the cast material an influence of thermal conductivity \( \lambda \), specific heat capacity \( c \), density \( \rho \) and namely in the liquid (index \( L \)) or in the solid phase (index \( s \)), in addition of latent heat of phase transformation \( L \) too has been analysed.

**Fig. 2** Influence of the heat conductivity \( \lambda_s \) of casting solidified in metallic or non-metallic mould

For example, the influence of heat conductivity \( \lambda \) of a cast material is shown in Fig. 2, when this steel cylinder solidifies in a metallic or non-metallic mould. Deviation of heat conductivity \( \lambda_s \) of solidifying cast material (steel) from actual values in a metallic or non-metallic mould is plotted on the x-axis and the deviation from the actual total solidification time is plotted on the y-
axis. This parameter deviation was selected within the range from 50 to 150% of its actual value.

The order of influence of another parameters of a casting material solidifying in a cast iron (metallic) mould on the total solidification time is roughly as follows: \( \lambda_s, L, \rho_s, c_s \). The influence \( \lambda_s \) is the most considerable (Fig. 3). The order of the all properties is: \( \lambda_s, L, \rho_s, \rho_L, c_s, c_L, \lambda_L \).

The order of influence of parameters of a casting solidifying in a fireclay (non-metallic) mould is as follows: \( L, \rho_L, c_L, \lambda_L \). The influence of latent heat \( L \) is the most significant (Fig. 4). The order of the all properties is: \( L, \rho_L, \rho_s, c_L, c_s, \lambda_s, \lambda_L \). The order of importance differs from that one for the cast iron mould, only \( \lambda_L \) is in both cases on the last place.

![Influence of the main thermodynamic properties of castings. (Steel cylinder in metallic mould.)](image1)

![Influence of the main thermodynamic properties of castings. (Steel cylinder in non-metallic mould.)](image2)

In Fig. 3 the influence of the main thermodynamic properties of castings (Steel cylinder in metallic mould) on the calculation accuracy of the total solidification time is illustrated. Their deviations within the range \( \pm 50\% \) signify the most slope tangent of the curves.

The analysis of the effect of each parameter was conducted separately. The remaining parameters were considered with their real values.

For metallic or non-metallic moulding material an influence of the same main parameters has been analysed and in addition their combination, an influence of thermal conductivity \( a \) and of heat accumulation \( b \) introduced for characterisation of a mould by foundry technologists.

The order of influence of parameters of metallic (index \( m \)) or non-metallic (n) moulding material on the total solidification time is as follows: \( \lambda_m, \rho_m, c_m, \lambda_n, \rho_n, c_n \). (Fig. 6). The curves for \( \rho \) and \( c \) for the both moulding materials practically coincide, for the influence is almost the same.
4. CONCLUSIONS

The influence of the individual parameters has been analysed separately, the other parameters have been taken for that once in their real value. The influence of each parameter has been studied in a range from 50 to 150 % of its real value (on the axis of abscissas). The influence of the parameter on the total solidification time has been studied the relative value of which towards the real solidification time (corresponding to the real mean value of the just analysed property) is plotted on the axis of ordinates. The tangents slope to the curves is of different value for different parameters and even for the same parameter the slope differs for the values of parameters to the left or to the right of their real value. In the case that the parameters of some materials entering into the solution are not sufficiently known and their values need to be estimated, the curve region of a lower slope is chosen and according to this the given property is either underestimated or overestimated towards the hypothetical real value in order to obtain more accurate results of calculation.

If a requirement to an accuracy of calculation of solidification thermokinetics controlled by the total solidification time (in a range of + 50 %) will be given in advance, then it is possible to estimate from the obtained graphs what error can burden the used thermophysical parameter.

Therefore it is suitable before calculation of solidification thermokinetics to perform the calculation analysis of influence of thermophysical properties of particular materials entering into the system (material of a casting, of chill, of a mould, of cores, of powdered materials for covering the risers, insulators, etc.) on a simplified geometrical form of particular system. Only then a qualified decision follows how accurate determination of parameters will be necessary for following routine calculation of the proper operating system in order to achieve the required accuracy of the results of the temperature field solution. The required accuracy will be basically given by a type of a setting according to the fact whether the main object of the solution will be the
proper casting (directional solidification, determination of internal non-homogeneities and removing of them, the character of primary crystallisation, shortening of solidification time, etc.) or a mould or cores (increasing of permanent moulds service life, use of different moulding materials into different mould parts, heat load of moulds, formation of scabs, a problem of condensing zone, etc.).

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REFERENCES


