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Numerical modeling of equiaxed structure forming in the cast during alloy solidification

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Abstract

In this study, we assumed that only the equiaxed structure created in the cast and the characteristic dimension is the final radius of grain. Because of the difference between the initial temperature of the molten metal and of the mold, there are significant differences in the average cooling rate when the liquidus temperature is achieved. The cooling rates vary within the range of 0.78 $K.s^{-1}$ to 29.88 $K.s^{-1}$. Since the average radius of grain is a function of the cooling rate, the radii of the smallest grains are 17.71 m, while the radii of the biggest grains are 366.22 m.

Keywords: numerical modeling; solidification; equiaxed structure; characteristic dimension; grain radius

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1. Introduction

The casting process is the most direct and shortest route from a component design to final product. This makes casting one of the major manufacturing processes, while casting alloys are some of the most widely used materials. One of the main reasons for the versatility of the casting process is the wide range of mechanical and physical properties covered by casting alloys. They may be of complex equipment and they are used in 90% of all manufactured goods [1]. Solidification is an inherent part of casting process. The structure of the casting is generated during the solidification and also is often the final structure of the casting. It also follows that the

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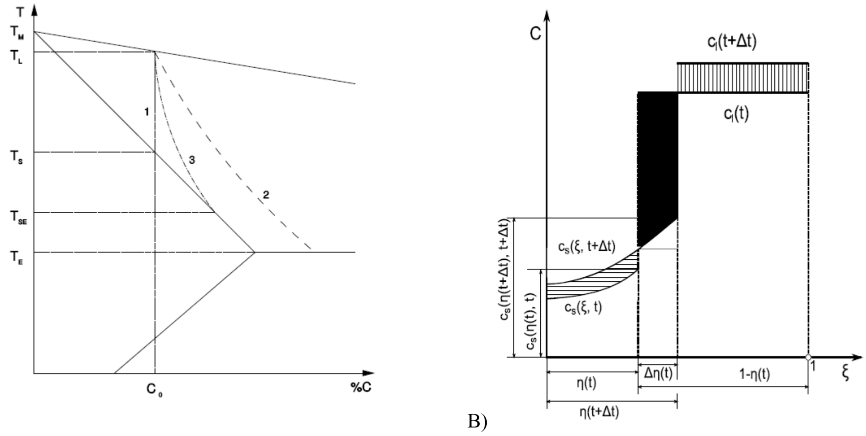
mechanical properties of the casting, which are a direct consequence of the microstructure, are controlled through the solidification process [2, 3]. Solidification models often analyze solidification events at a micro-, a macro- and an intermediate scale (the meso-scale) [4, 5]. The intermediate scale allows for the description of the microstructure features at grain level, without resolving the grain boundary. On this level solid-liquid interface appears in three regions: liquid, mushy (containing both liquid and solid phase), and solid. The macro scale relates the (growing) solid phase as a whole and allows for the description of certain parameters such as dimension of the grains or the extent zones of particular types of structures.

The casting solidification is the heterogeneous process, so it is differently in each point of the casting. The course of solidification can be described by a cooling curve or by a solidification curve – curve between the liquidus and solidus lines in the phase diagram (Fig. 1A). The first case describes the variation of the temperature within the time and allows for the designate of the cooling rate at any time during the process. Whereas the second case is characterized by the quantitative changes of the part of solid and liquid phase in function of temperature. All possible solidification curves (e.g. line no. 3 in Fig. 1A) take place between two extreme cases i.e. equilibrium solidification (line no. 1 in Fig. 1A) and non-equilibrium solidification (line no. 2 in Fig. 1A). The first of them describes homogeneous distribution of solute concentration both of in liquid and solid phase of the casting. The second of them describes significant pushing out of solute to liquid phase and lack of diffusion of solute in solid phase. During the indirect solidification (line no. 3 in Fig. 1A) there is no alignment of the distribution of solute concentration in solid phase but is significant diffusion of solute. In the real castings, except the rapidly solidifying layers adjoining to the mold and the slowly solidifying central areas of the massive castings, the indirect solidification occurs.



A) B)

Fig. 1. A) Models of solid phase growth in binary alloys (T – temperature, C –chemical composition of the alloy; T_M – solidification temperature of the base component, T_l – liquidus temperature, T_s – solidus temperature for equilibrium solidification T_{SE} – solidus temperature for indirect solidification); B) The momentary distribution of solute concentration in the grain.

Numerical simulations are used for optimization of casting production. In many cases they are a unique possible technique for carrying out of the experiments which real statement is complicated. Computer modeling allows defining the major factors for a quality estimation of alloy castings. Simulations help to investigate interaction between solidifying casting and changes of its parameters or initial conditions [6]. In order to the efficient performance of large series of computational studies using reasonable resources, the framework needs to be not only accurate but also computationally efficient. Increasing capacity of computer memory makes it possible to consider growing problem sizes. At the same time, increasing of the precision of simulations triggers even greater load. There are several opportunities to tackle this kind of problems. For instance, one can use parallel computers [7, 8], the other can use accelerated architectures such as GPUs [9] or FPGAs [10], and the other can use special organization of computations [11–14].