ON THE INFLUENCE OF MHD FLOW PARAMETERS ON THE INGOTS STRUCTURE

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Abstract: We discuss the capabilities of the proposed method to establish the dependence between the MHD parameters of melt mixing and structure of crystallized ingot.

1. Introduction

To obtain ingots with high mechanical characteristics, MHD stirring is often used. However, the process of choosing optimal values of MHD parameters assuring a satisfactory quality of cast articles is expensive and time-consuming in each specific case, which is due to the absence of reliable basic mathematical models connecting the structure of cast articles with the melt motion in the vicinity of the crystallization front. One of the causes of such situation probably roots in an immense variety of scales used for the description of the crystal formation process and melt motion. A high practical importance of the development of such mathematical models calls for the use of alternative methods based on macroscopic processes connecting melt motion with macrostructure formation.
Since the cause of crystallization is the process of heat removal from the melt into the environment, it makes sense to examine, first, how it occurs in the absence of stirring and then take into account the influence of stirring on this process.

2. Problem statement and description of the method

As known [1], certain semi-quantitative information about the structure of ingots/castings in the absence of melt stirring can be obtained by computing thermal processes in the systems ingot/mold or casting/casting form. The final result of such computation is the establishment of a relation between the solid phase thickness and time. In fact, the following Figure 1 taken from [1] shows that the curve of the solidification velocity $dS/d\tau$ of a steel ingot of 700 mm diameter has four distinct segments. In our opinion, these segments can be interpreted, with a certain degree of reliability, as characteristic thicknesses of regions with different macrostructures. Thus, the region 1 corresponds to the structure consisting of small close-packed equiaxial crystals arising at the initial solidification stage and characterized by the maximal heat flow value as a result of maximal temperature gradient between the melt and the cold wall of the mold. The region 2 characterizes a transition from fine-grained structure to a columnar dendritic structure in the region 3. The transition point from region 1 to region 2 can be interpreted as a point of critical values of dimensionless thermal parameters characterizing the crystallization front instability at the boundary of region 1, and region 2 – as a transition region from region 1 to region 3. The region 3 is characterized by a heat flow decrease as a result of increasing thermal resistance of the solid phase and decreasing temperature difference between the crystallization temperature and the growing mold temperature. The transition point from region 3 to region 4 characterizes the moment of the appearance of coarse equiaxial crystals as a result of the melt overcooling and the establishment of thermal equilibrium between the ingot and the mold, i.e. the moment of the transition to the bulk crystallization of the melt.

Electromagnetic impact on the melt in the process of ingot/casting crystallization leads to the appearance of forced turbulent convection, which cardinally changes the fields of temperature and impurities concentration in the melt and results in the formation of narrow hydrodynamic temperature and diffusive boundary layers in the vicinity of the crystallization front.

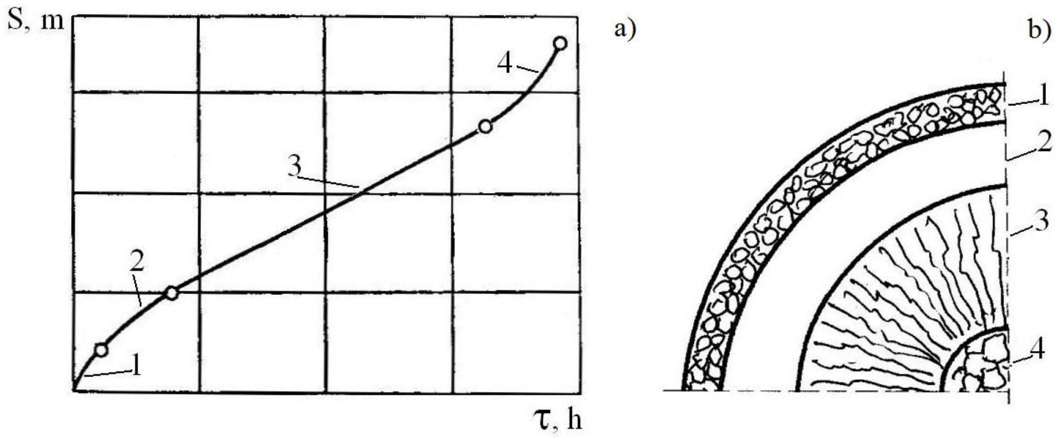

Figure1: diagram of cylindrical ingot transversal solidification in casting form (a), and corresponding ingot structure (b). See the text for additional details.

The appearance of boundary layers intensifies heat transfer from the melt into the solid phase at the expense of a large temperature gradient created in the boundary layer. This accelerates the crystallization process as a result of a decrease in the melt crystallization temperature due to an increase in the impurity concentration (if the distribution coefficient $K_0 < 1$, where $K_0 = K_s / K_l$ is the ratio of impurity concentrations in the solid and liquid phases).

We are developing a method of creating a semi-empirical mathematical model connecting characteristic grain size of the structure in the direction of the solid phase growth with the thickness δ of the so-called mixed boundary layer [2]. This thickness is determined in the coordinates system r^*, φ, z^*:

$$\delta = \int_0^{\delta_T} \frac{u(n)}{\langle V_0 \rangle} \left[1 - \vartheta(n)\right] dn, \qquad (1)$$

where $r^* = R_0 - r;\ z^* = Z_0 - z$ are the coordinates; δ_T - the thickness of temperature boundary layer; $u(n)$ - velocity profile in the boundary layer; $\langle V_0 \rangle$ - mean velocity of the melt in the flow core; $\vartheta(n) = \dfrac{T - T_{cr}}{T_{core} - T_{cr}}$ - dimensionless temperature profile in the boundary layer; $\vec{n} = \vec{e}_r r^* + r^* \vec{e}_\varphi \varphi + \vec{e}_z z^*$ - a normal to the crystallization front. Since $u(n)$ and V_0 directly, while $\vartheta(n)$ - through a dependence on the melt velocity depend on such MHD criteria as $Ha = B_0 R_0 \sqrt{\sigma / \eta}$ and $\mathrm{Re}_\omega = \omega R_0^2 / \nu$, Eq. (1) determines the relation between the boundary layer thickness δ and MHD parameters.

We assume to evaluate the connection between the thickness of the mixed boundary layer and the ingot structure by measuring the change in the heat flow in the process of ingot crystallization and the thickness of the temperature boundary layer. At that, it is necessary to study the ingot macrostructure at various intensities of MHD stirring and to compare this information with respective estimations of MHD and thermal processes.

The method being elaborated does not refer to bulk crystallization arising at the last stage of solidification.

3. Conclusion

We have provided a possible method to reveal the correlations between parameters of MHD effect on the molten metal and the structure of crystallized ingots. The ways to implement it are identified.

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4. References

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