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Issue Article

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THE EFFECT OF CASTING SPEED ON THE PHASE TRANSITION IN THE VOLUME OF STEEL CASTING

Abstract: *The process of phase transition of a liquid metal to a solid state during cooling was modeled in the article. Dependences of the change in the Péclet number, enthalpy, phase transition between liquid and solid phases and the temperature gradient of melt at casting speeds of 5, 50 and 200 mm/s were obtained. It is noted that at higher casting speeds, the investigated process parameters practically do not change at the temperature transition zone half width of 75 and 150 K.*

Key words: *liquid phase, solid phase, temperature, casting speed, casting.*

Language: *English*

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Introduction

Melt undergoes various phase transformations over time during the casting process [1-2]. Since these processes are accompanied by significant temperature differences in the volume of the casting produced, depending on the casting method, taking into account the type of material, phenomena such as shrinkage, heterogeneity of the structure and other casting defects are possible [3-7]. These undesirable phenomena may be the result of non-compliance with the casting process. Thus, the casting quality, that is, the uniform crystallization of the liquid phase, is also affected by the casting process modes. For example, the casting speed affects the filling time of the mold cavities with melt, and, accordingly, the uniformity of cooling the entire volume of the casting. This is important in the conditions of casting critical parts [8]. Thus, by choosing different casting speeds for the experiment, it is possible to determine the mechanism of the phase transition in the volume of metal melt. Since it is difficult to study the thermal phenomena occurring during the casting process, special computer programs of engineering analysis allow you to simulate the casting process in full under various modes [9-10].

Materials and methods

Heat exchange processes during the transition from the liquid phase to the solid phase under conditions of casting steel into a mold were studied. Steel has a low fluidity, which means that compliance with the quality of the casting will be time-consuming. Based on these considerations, steel was chosen as the casting material. The following casting process conditions were accepted: melting temperature – 1356 K; latent heat of solidification – 205 kJ/kg; heat capacity at constant pressure, solid phase – 380 J/(kg×K); heat capacity at constant pressure, liquid phase – 531.18 J/(kg×K); ambient temperature – 300 K; melt inlet temperature – 1473 K; heat transfer coefficient, mold – 800 W/(m^2×K); surface emissivity – 0.8. The casting speed of 5, 50 and 200 mm/s was adopted as a variable mode of the process. Readings of change in temperature properties in the transition phases of the casting volume were obtained at dT (temperature transition zone half width) equal to 75, 150 and 300 K.

Results and discussion

The following phenomena of the steel casting process were taken as investigated: the Péclet number, enthalpy, phase transition between phase 1 and phase 2, and temperature gradient.

The nature of heat transfer in the liquid phase of material is determined by the Péclet number. Heat can be transferred convectively or molecularly, depending on the magnitude of the Péclet number in moving melt flow.

Enthalpy is a function that characterizes the state of a system in thermodynamic equilibrium. The independent variables of the function are internal energy, pressure and volume.

The temperature gradient determines the direction and speed of temperature change in a certain place.

The dependences of the Péclet number, enthalpy, phase transition between phase 1 and phase 2, and temperature gradient on the melt temperature are shown in the Figs. 1-4.

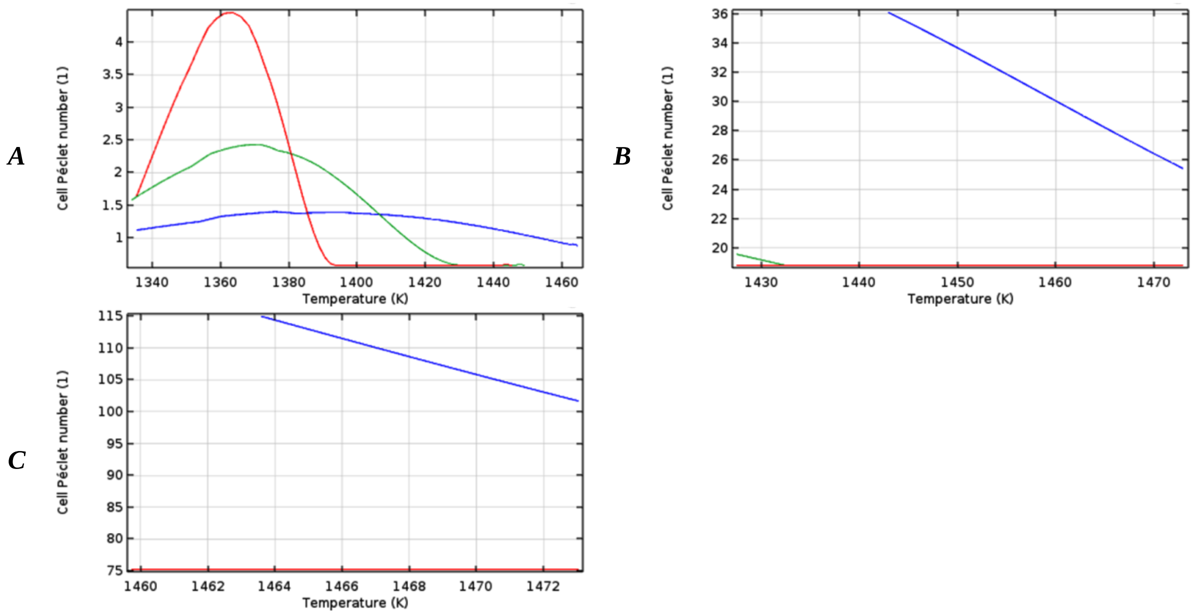

Figure 1. Dependences of the Péclet number on the melt temperature: *A* – casting speed is 5 mm/s; *B* – casting speed is 50 mm/s; *C* – casting speed is 200 mm/s. — temperature transition zone half width is 75 K, — temperature transition zone half width is 150 K, — temperature transition zone half width is 300 K.

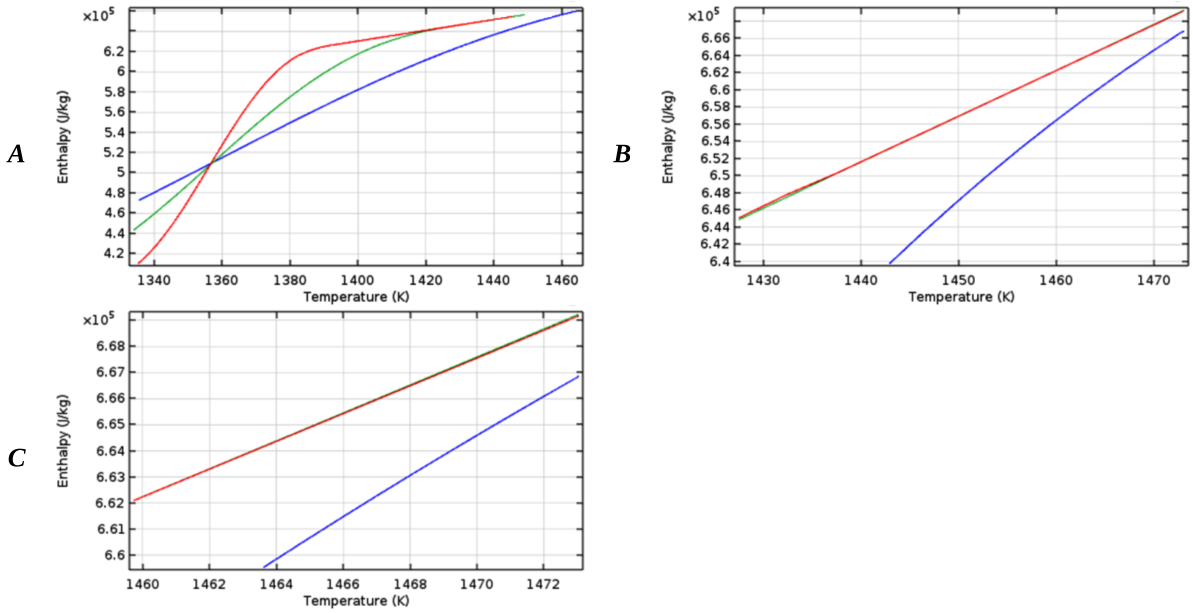

Figure 2. Dependences of enthalpy on the melt temperature: ***A*** **– casting speed is 5 mm/s;** ***B*** **– casting speed is 50 mm/s;** ***C*** **– casting speed is 200 mm/s. — temperature transition zone half width is 75 K, — temperature transition zone half width is 150 K, — temperature transition zone half width is 300 K.**

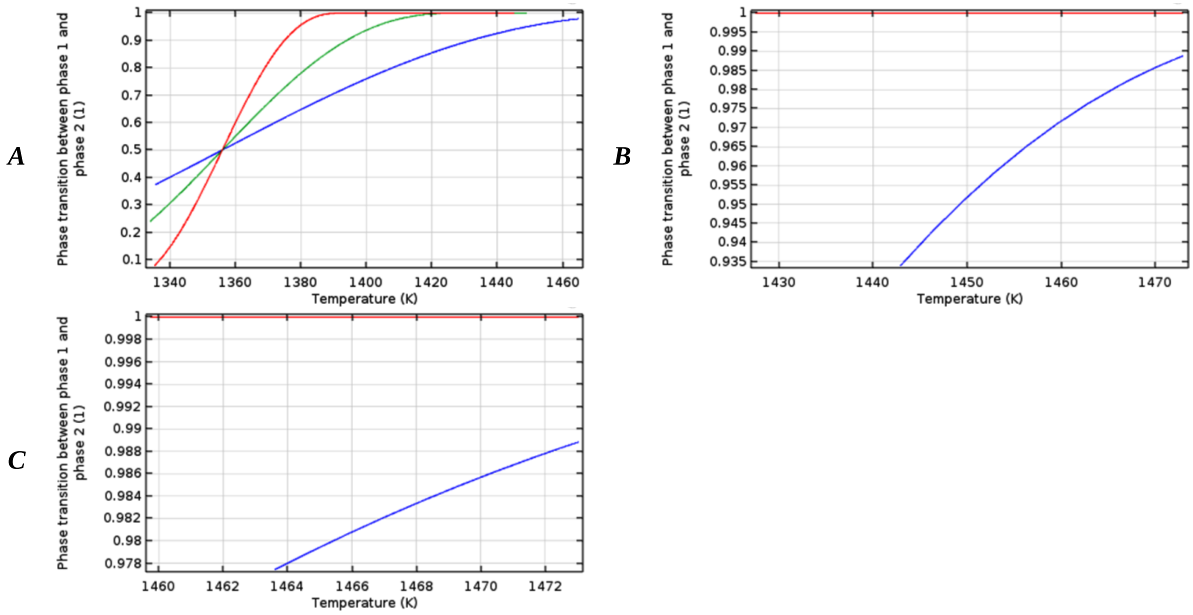

Figure 3. Dependences of the phase transition between phase 1 and phase 2 on the melt temperature: ***A*** **– casting speed is 5 mm/s;** ***B*** **– casting speed is 50 mm/s;** ***C*** **– casting speed is 200 mm/s. — temperature transition zone half width is 75 K, — temperature transition zone half width is 150 K, — temperature transition zone half width is 300 K.**

The molecular thermal conductivity of melt flow was noted at a casting speed of 5 mm/s. The largest values of the Péclet number for a given casting speed at different dT were determined with a shift of several kelvins starting from 1362 K. For dT equal to 75 and 150 K, the nature of the parameter change is the same: first, an increasing function to the largest value, then a decreasing function to zero. The change in the Péclet number was calculated in the range from 0.9 to 1.4 with a dT equal to 300 K. The temperature range of melt at a casting speed of 5 mm/s is 130 K. Convective heat transfer prevails at higher casting speeds. At the same time, there is no change in the convective heat transfer in the melt volume at dT equal to 75 and 150 K. There was a slight decrease in the values of the Péclet number at a small temperature range at a higher temperature. The melt temperature ranges at casting speeds of 50 and 200 mm/s are 50 and 13 K, respectively.

Enthalpy of the casting process increases with increasing melt temperature. Low casting speeds lead to a significant change in enthalpy over a longer temperature range. Enthalpy varies slightly over shorter temperature ranges with increasing casting speed. It is also noted that at a casting speed of 5 mm/s, all dependencies at a temperature of 1357 K have an enthalpy value of 5.1×10^5 J/kg. This is true for all dT values considered. The dependences for dT equal to 75 and 150 K vary equally at casting speeds of 50 and 200 mm/s.

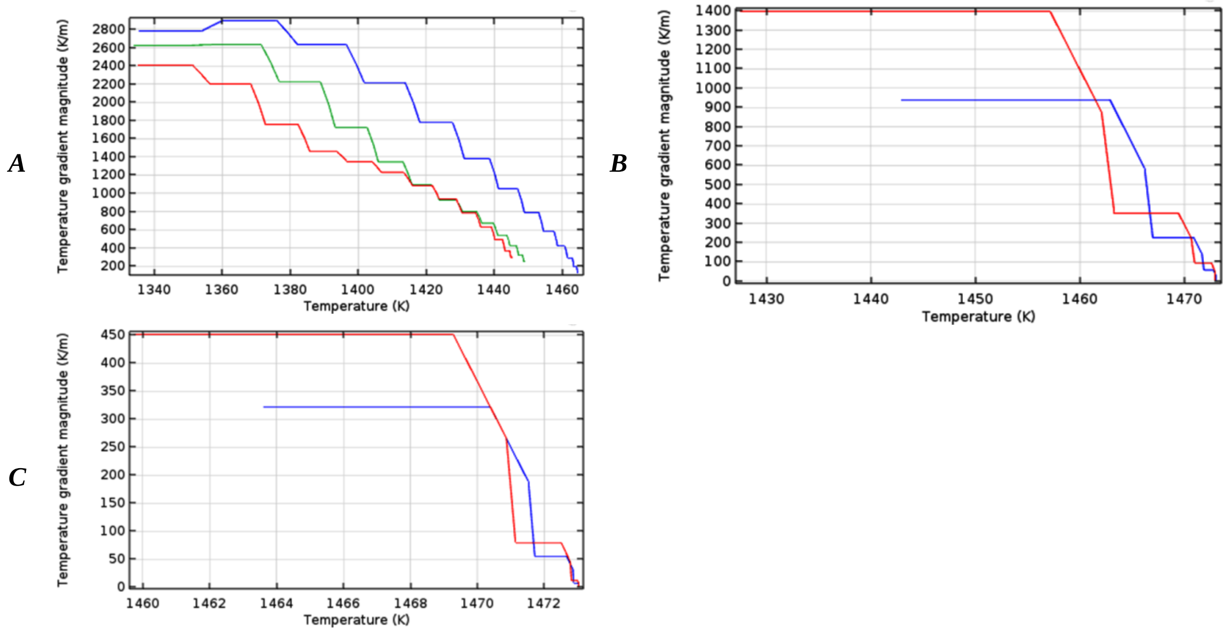

Figure 4. Dependences of the temperature gradient on the melt temperature: *A* – casting speed is 5 mm/s; *B* – casting speed is 50 mm/s; *C* – casting speed is 200 mm/s. — temperature transition zone half width is 75 K, — temperature transition zone half width is 150 K, — temperature transition zone half width is 300 K.

In the graphs shown in Fig. 3, one corresponds to the liquid phase, and zero corresponds to the solid phase. The graphs show that at a low casting speed and dT equal to 75 K, melt solidifies completely in the temperature range from 1384 to 1336 K. The crystallization process is still in transition phases at dT equal to 150 and 300 K. At high casting speeds, where high temperatures were observed, the solidification phase was completed by 3-7%.

The temperature gradient increases with a decrease in the melt temperature in all considered experimental cases. The change in the temperature gradient over time has a linear character: a decreasing function with alternating constant and variable ranges. At a casting speed of 5 mm/s, the temperature gradient is maximum, and at casting speeds of 50 and 200 mm/s is minimum. The temperature gradient values defined for dT equal to 300 K are more at low casting speed and less at high casting speed relative to other accepted dT values.

Conclusion

The casting speed affects the magnitude of the temperature range in which phase transformations are formed in the casting volume. The nature of change in the studied parameters, such as the Péclet number, enthalpy, phase transition between phase 1 and phase 2, and temperature gradient, is almost the same at high casting speeds. The temperature range of crystallization of the casting (1384-1336 K) at a casting speed of 5 mm/s was determined. With an increase in the casting speed, the values of the Péclet number and enthalpy increase, and the temperature gradient decreases.

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