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SECTION 6. Metallurgy and energy.

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TO THE QUESTION OF THE SOLIDIFICATION PROCESS OF STEEL CASTINGS WITH DIFFERENT WALL THICKNESSES

Abstract*: The article was defined the transition time of the non-alloy steel 15L from liquid phase to solid phase in conditions of the castings manufacturing with the walls thickness from 1 mm to 20 mm.*
Key words*: temperature, steel, thickness, solidification, time.*
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Introduction

In modern conditions of the machine-building production, the different types of the cast are the progressive technological form-building processes of the castings manufacturing of complex configuration. In some cases, it is possible to obtain finished (which does not require subsequent machining) parts of high accurate and an unique casting, weighing up to several tons.

The essence of the casting process is in the solidification of the molten material in a closed special mould, which configuration corresponds to the geometric shape of the casting. The solidification process is characterized by the change of the ratio of liquid and solid phases of the casting over time. On the solidification time the volume of the filled molten material, the configuration of the casting, the properties of the alloy (metallic or non-metallic) at different temperatures and etc are affected. The account of all factors during the performing of the technological process of the casting can reduce the defects and to obtain the equilibrium structure of the casting.

The most accurate values of the solidification time of metallic castings, for example hollow with different wall thickness, it is possible to obtain by the mathematical modeling.

Materials and methods

Modeling of the solidification process of casting was carried out in a computer program LVMFlow. The molten non-alloy steel grade 15L [1] at an initial temperature of T_{s0} 1610 °C was subjected by the solidification. The solidification process was occurred before the solidus temperature [2] $T_{sol.}$ 1475.448 °C (kinetic solidus 1462.472 °C). Liquidus temperature [3] $T_{liq.}$ for this steel is 1511.367 °C, eutectic temperature [4] $T_{eut.}$ – 1141.31 °C.

Non-alloy steel 15L for casting has the following chemical composition: iron – 97.34 %, carbon – 0.16 %, silicon – 0.36 %, manganese – 0.7 %, chromium – 0.5 %, phosphorus – 0.04 %, sulfur – 0.04 %, copper – 0.3 %, nickel – 0.5 %, aluminium – 0.06 %. Steel possesses casting properties: CLF up – 70 %, CLF down – 30 %. Total emissivity ε_s for the liquid alloy is 0.1, for austenite – 0.11, for cementite – 0.1. Steel properties have been calculated by phases.

The solidification process was characterized by kinetic parameters:

1. Liquid alloy: crystallization heat of the primary phase $Q_{cr.}$ – 270 kJ/kg.

2. Austenite: the 1st phase growth coefficient – 0.2 mm/°C · s, nucleation/growth ratio – 0.1, crystallization heat Q_1 – 130 kJ/kg.

3. Cementite: the 2nd phase growth coefficient – 0.1 mm/°C · s, nucleation/growth ratio – 0.01, crystallization heat Q_2 – 330 kJ/kg.

The mould was made from the mechanically mouldable sand *Green sand JSM* [5]. Wet mixture on based of the quartz sand and 6.92 % bonding additives. The initial temperature of the mould T_{m0} was taken at 20 °C. Total emissivity the mould material ε_m is 0.93 when a gas-permeability [6] P 1.53 · 10^{-6} m^2/Pa · s and a rigidity 1.0.

The refractory coating of mould was absent. Interfacial heat transfer was set by the air gap at a temperature of 1415.45 °C. Upper, lateral and lower coefficients were taken as 100 %.

The calculation of the some physical properties of the mould material and steel was carried out by the mathematical models (1 – 7):

- heat conduction of the mould material λ_m, W/(m · °C)

$$\lambda_m = \lambda_{m.liq.} + 1.57 \cdot 10^{-4}(T_{s0} - T_{liq.}), \qquad (1)$$

where $\lambda_{m.liq.}$ – heat conduction of the mould material at $T_{liq.}$, W/(m · °C).

- heat conduction of steel λ_s, W/(m · °C)

$$\lambda_s = \lambda_{s.liq.} - 4.63 \cdot 10^{-3}(T_{s0} - T_{liq.}), \qquad (2)$$

where $\lambda_{s.liq.}$ – heat conduction of steel at $T_{liq.}$, W/(m · °C).

- specific heat of the mould material c_m, J/(kg · °C)

$$c_m = c_{m.liq.} + 4.09 \cdot 10^{-1}(T_{s0} - T_{liq.}), \qquad (3)$$

where $c_{m.liq.}$ – specific heat of the mould material at $T_{liq.}$, J/(kg · °C).

- specific heat of steel c_s, J/(kg · °C)

$$c_s = c_{s.liq.} + 2.94 \cdot 10^{-2}(T_{s0} - T_{liq.}), \qquad (4)$$

where $c_{s.liq.}$ – specific heat of steel at $T_{liq.}$, J/(kg · °C).

- density of the mould material ρ_m, kg/m^3

$$\rho_m = \rho_{m.liq.} - 4.65 \cdot 10^{-2}(T_{s0} - T_{liq.}), \qquad (5)$$

where $\rho_{m.liq.}$ – density of the mould material at $T_{liq.}$, kg/m^3.

- density liquid phase of steel ρ_{sA}, kg/m^3

$$\rho_{sA} = \rho_{sA.liq.} - 5.46 \cdot 10^{-2}(T_{s0} - T_{liq.}), \qquad (6)$$

where $\rho_{sA.liq.}$ – density liquid phase of steel at $T_{liq.}$, kg/m^3.

- density solid phase of steel ρ_{sB}, kg/m^3

$$\rho_{sB} = \rho_{sB.liq.} - 3.2 \cdot 10^{-1}(T_{s0} - T_{liq.}), \qquad (7)$$

where $\rho_{sB.liq.}$ – density solid phase of steel at $T_{liq.}$, kg/m^3.

The wall thickness s of the casting was taken from 1 mm to 20 mm (geometric modulus 0.05...1 cm). To obtain of the reliable results, the steps numbers of calculation of the solidification process were accepted 648.

The quasi-equilibrium model of the calculation of solidification of the ingot was adopted for the solution [7].

Results and discussion

The fig. 1 is presented by the dependence of the percentage ratio of liquid phase from shrinkage of the material [8].

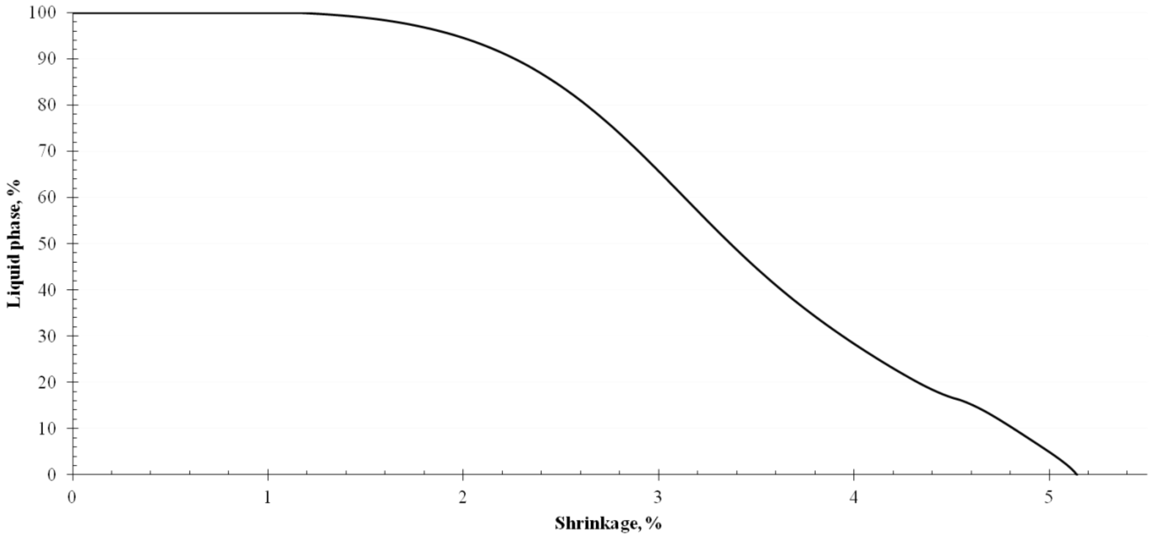

Figure 1 – The dependence of the percentage ratio of liquid phase from shrinkage of the material.

The chart analysis shows that shrinkage of the total volume of casting does not exceed 1.5 % when liquid phase of steel. The solid solution – austenite is formed with a decrease of temperature of the molten steel. Shrinkage of casting increases. When complete solidification and the formation of cementite, shrinkage of volume of the casting is approximately 5.17 %.

The fig. 2 are presented the dependencies of the cooling rates $v_{cool.}$ of casting with *s* 5 mm, 10 mm, 15 mm and 20 mm from temperature.

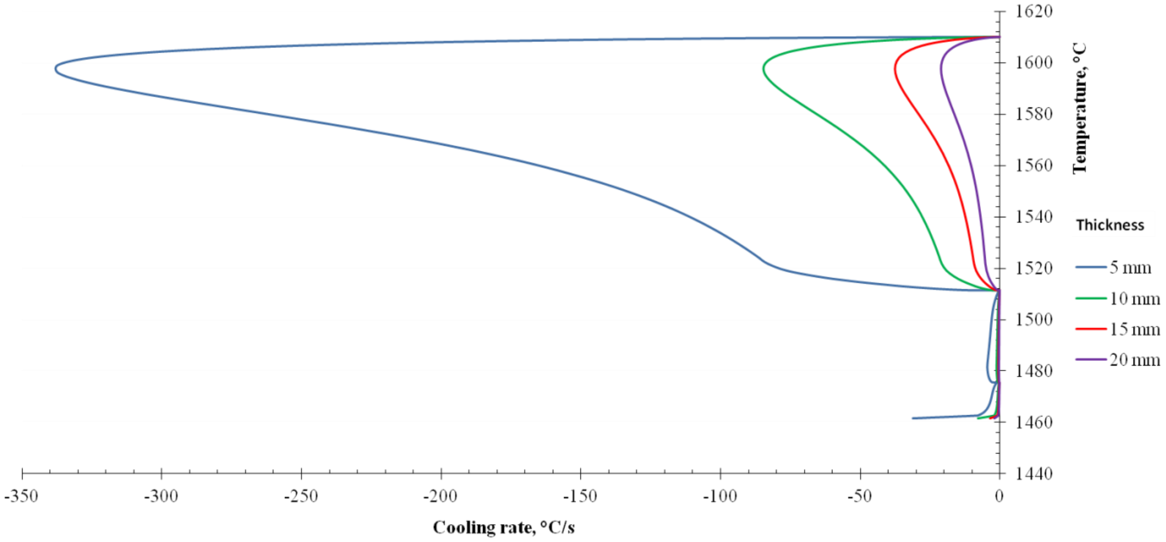

Figure 2 – The dependencies of the cooling rate of casting wall by the different thickness from temperature.

With decreasing temperature of molten steel from 1610 °C to 1600 °C, $v_{cool.}$ of the walls of castings is maximum in absolute value. Moreover, than less *s* of casting, the faster it is solidified. At the achievement of temperature of the molten steel value 1600 °C there is a decrease of $v_{cool.}$ to the minimum value in the point $T_{liq.}$. In the range $T_{liq.}$ and $T_{sol.}$ value of $v_{cool.}$ is minimal and approaches to zero.

The chart of the transition of liquid phase to solid from time is presented in Fig. 3.

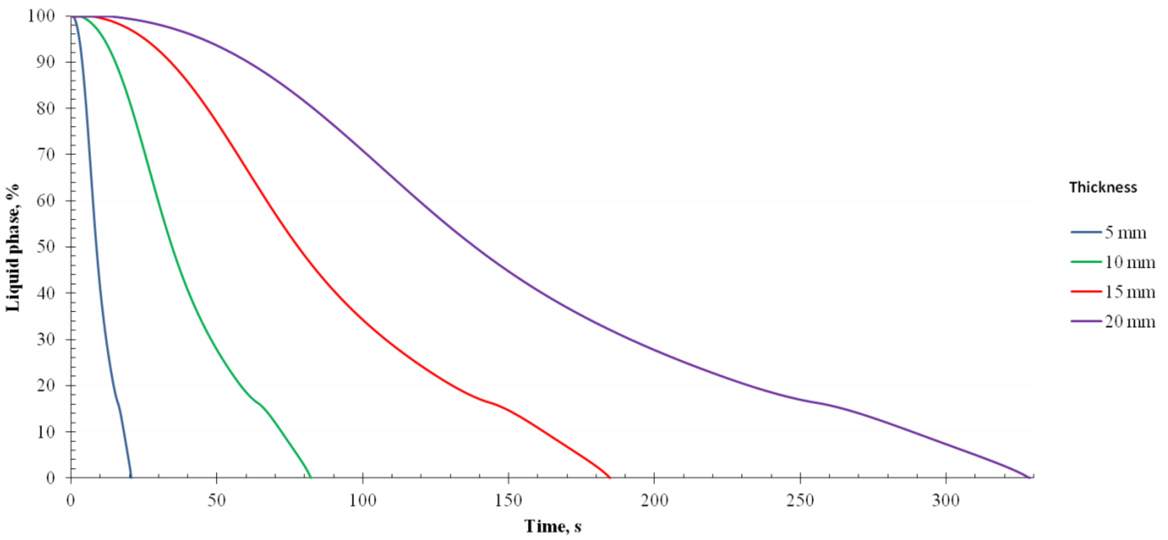

Figure 3 – The dependencies of transition of liquid phase in solid from time.

The solidification time $t_{sol.}$ (s) for any *s* of the casting, made of steel grade 15L, is calculated by the formula (8)

$$t_{sol.} = 0.822s^2, \quad (8)$$

where 0.822 – specific solidification of steel grade 15L, s/mm.

The chart analysis confirms correctness empirically derived of the formula (8).

Conclusion

The account of the manufacturing time of castings is one of the most important issues of the foundry industry. The calculation of time of the each operation contributes to the rational allocation of the energy resources.

The received formula for calculation of the solidification time of the molten non-alloy steel grade 15L with different wall thickness allows to optimize the process of casting manufacturing. This is an actual issue for casting steel of the different grades.

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