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THE EFFECT OF MICROALLOYING ON FORMATION OF MICROSTRUCTURE PARAMETERS AND THERMAL-CONCENTRATION STATE OF SOLIDIFYING MELT

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Introduction

The problem of improving reliability and lasting of fast wearing machine parts, which were manufactured from steel cast, has been required of creation and using practice of various materials. One of most rational ways to cast quality increasing is the using of middle-carbon microalloyed in return for expensive high alloyed steels. For this, the microalloyed steels must possess good casting properties and enough high density of metal and surface quality of cast.

Not a little importance the heat remove velocity exerts on formation of metal's primary structure by cooling and crystallization. The changing in several limits of heat remove allows to control of crystallization and parameters of forming microstructure. This can be technologically reached by way of cast methods selection (external chill, different molding sand), choice of mold materials and heating temperature of mould, use of refractory coating etc. By steel microalloying of strong carbonitride elements forming in liquid metal and during crystallization process non-metal inclusions also exerts essential influences on primary structure formation.

1. Experimental unit and researches methods

In this connect the experimental investigation of temperature field distribution and more precision definition of thermal-physic properties in crystallizing steel with and without microalloying has an interest. Also the size range distribution of carbonitride in casts was studied.

Figure 1 presents the scheme of experimental unit for researches and modeling of microalloying additions effect on crystallization process, metal microstructure formation, cast quality by various regimes of casting and cooling, thermal-physic properties

definition of using steels. Experimental unit consists: of shaft electric furnace (1); refractory (chamotte) cylindrical chamber (2); C-A thermocouples with 0.3 mm diameter (3); Pt-Pt/Rh thermocouples (4); rate making amplifiers (5); analog-digital converter (6); computer (7); digital-analog converter (8); automatic temperature regulator block (9).

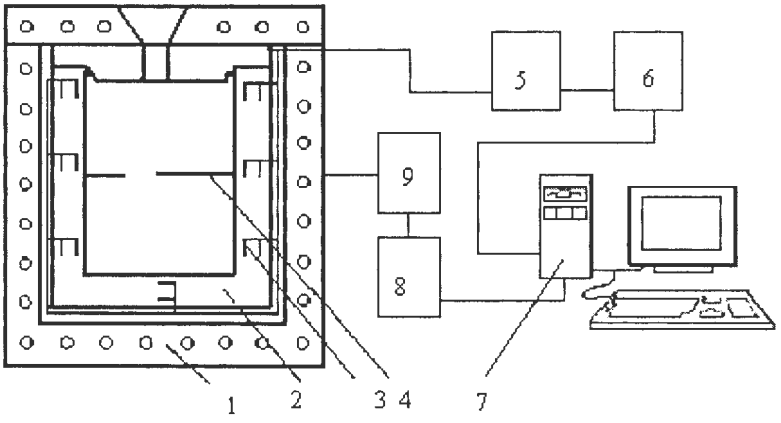

Figure 1. Scheme of experimental unit.

C-A thermocouple was set on each of three levels in three pairs (in center and on surface of wall of chamotte chamber) with displacement on 120°. Pt-Pt/Rh thermocouples was placed in middle level of chamott chamber with bias from C-A thermocouples on 60 , such order that first Pt-Pt/Rh thermocouple places on inner surface of chamber, second – in distance of 0.5 inner radius of chamott chamber; third – on the axle of chamber. One by one pairs of C-A thermocouples were set in chamotte top and bottom of chamber.

For more precision control of temperature in chamber and for directed heat stream (by necessity) the heaters of shaft furnace were divided on sections. In lining of shaft furnace near each heater sections the control thermocouples were placed. Temperature regulation in furnace working space was carried out through changing of supply voltage according control command of computer by means of automatic temperature regulator block (this purpose the necessary software was elaborated). The signals of all thermocouples through rate making amplifiers and analog-digital converter acted into computer for further processing.

2. Matematical model heat mass exchange processes by crystallization and cooling

Processes of melt crystallization and temperature fields distribution in cylindrical chamotte chamber can be described by equations:

$$c_1(t_1)\cdot\rho_1(t_1)\cdot\frac{\partial t_1}{\partial\tau}=\frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\cdot\lambda_1(t_1)\cdot\frac{\partial t_1}{\partial r}\right)+\frac{\partial}{\partial z}\left(\lambda_1(t_1)\cdot\frac{\partial t_1}{\partial z}\right)+\rho_1(t_1)\cdot L\frac{\partial\Psi}{\partial\tau} \tag{1}$$

$$c_2(t_2)\cdot\rho_2(t_2)\cdot\frac{\partial t_2}{\partial\tau}=\frac{1}{r}\cdot\frac{\partial}{\partial r}\left(r\cdot\lambda_2(t_2)\cdot\frac{\partial t_2}{\partial r}\right)+\frac{\partial}{\partial z}\left(\lambda_2(t_2)\cdot\frac{\partial t_2}{\partial z}\right) \tag{2}$$

where $c_1(t_1), c_2(t_2)$ – the heat capacity coefficient; $\rho_1(t_1), \rho_2(t_2)$ – densities, $\lambda_1(t_1), \lambda_2(t_2)$ – coefficients of heat conductivity of metal and chamotte, accordingly; L – heat of crystallization; Ψ – relative share of solid phase in metal;
by corresponding initial and boundary conditions.

The solution of the equation (1,2) was carried out by method of finite differences under the completely implicit circuit. The four-point gauge, Thomas algorithm and locally one-dimension methods were used. For most precision improving of numerical value of boundary condition the fictitious nodes of calculated net were introduced.

Experimental data of temperature distribution were used for resolving of coefficient inverse problem of heat conductivity. Coefficients of heat conductivity (λ) and volume heat capacity ($C = c \cdot \rho$) as temperature (t) function were find in kind of series:

$$\lambda=\lambda_0+\lambda_1 t+\lambda_2 t^2+\ldots;\quad C=C_0+C_1 t+C_2 t^2+\ldots. \tag{3}$$

Expansion coefficients $\lambda_i(i=0,1,2)$, $C_i(i=0,1,2)$ were determined by way of iteration on the base of deviation minimisation [1].

More precise values of thermal-physic characteristics were used in calculation of temperature fields in microalloyed and comparison steels. On the base of experimental and calculated data the parameters exerted on primary structure formation of crystallizing steel were determined.

Microalloying by strong carbonitrides elements leads to formation of numerous crystal nucleuses by metal solidifying. Size range distribution of carbonitrides phase exerts great influence on mechanical properties of steel, in first turn – impact toughness. Carbonitrides formation occurs already in liquid melt and their growth defines by temperature and time. Phase growth (as layer) process can be written as diffusion

$$D\frac{\partial C}{\partial x}\Big|_{x=y} = \frac{\partial y}{\partial t}(C_S - C_L) \tag{4}$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}, \quad x > y \tag{5}$$

where $x = y$ – coordinate of agile boundary of growing phase; C_S – equilibrium concentration of saturated substance at side of solid solution; C_L – concentration of substance in phase [2].

The solution of system equation with corresponding initial and boundary conditions allows to obtain of growth dynamic of layer boundary and concentration distribution of substance in metal matrix.

3. Experimental results

Researches of adequacy of obtained calculated values to experimental data were carried out on casts microalloyed of titanium, when time of input till crystallization beginning was 15 and 60 minutes. Figure2 shown experimental distribution of carbonitride phase in dependence of time of titanium input till crystallization beginning.

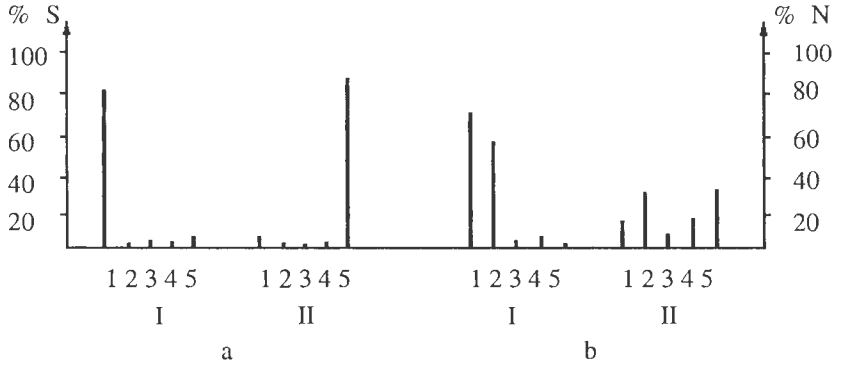

Figure 2. The size range distribution of carbonitride phase by titanium inputted in 60 (a) and 15 (b) minute till crystallization beginning (I – quantity share if inclusions, II – square share of inclusions; 1– inclusions up to 1 μm, 2 – 1 ÷ 5μm, 3 – 5÷ 10 μm, 4 – 10÷ 20 μm, 5 – more 20 μm).

By equal concentration of elements in metal the squares share of coarse (more 20 μm) inclusions are 92% and 40 % and quantity share this inclusion – 11% and 5% for titanium input time 60 and 15 minutes till crystallization, accordingly.
Because the technology of "late modifying" is more rational. This technology foresees the input of carbonitrides-forming elements immediately before steel crystallization.

Researches of ductility of samples from experimental steels shown increasing of impact toughness on 30% for steel microalloyed within 60 minutes till crystallization beginning and in 2.2 fold for "late modified" steel.

Examinations of primary structure of experimental steels were fulfilled on metal that was cast in identical conditions (Figure 3).

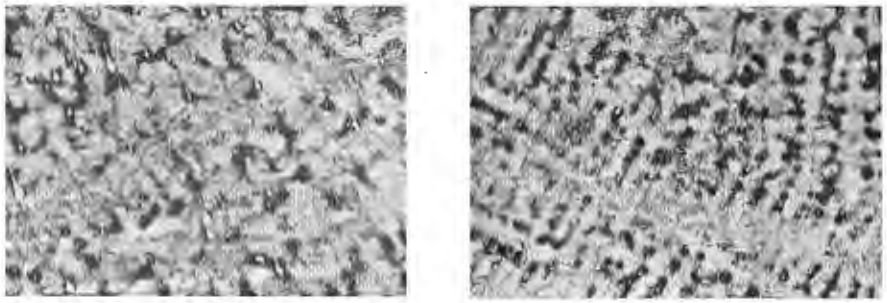

Figure 3. Primary microstructure of experimental steels without microalloying (a) and with titanium microalloying (b)

It has been established that modifying addition promotes to size reduction of dendrite structure as in columnar growth zone as in zone of equiaxed crystals. The presence of strong carbonitride– forming elements results to increasing of directly solidified zone extent that can be explained with reducing of solidification interval and changing of physical and thermal-physical characteristics of steel, formation of numerous crystal nucleuses. In the modified steel the dendrite one-fold axes more thin, inter axial section also more discrete and square of biggest from its in 4-6 fold less than in compared steel.

Degree of fineness of modified dendrite structure is 36.2 mm^{-1} that almost in two fold more than in compared steel (18,4 mm^{-1}). Density of dendrite structure equals 5.4 for modified and 3.6 for compared steel.

Conclusion

Thus, proposed methods allow to investigate crystallization processes and to estimate microalloying effect on microstructure parameters and changing of steel physical properties by various regimes of cooling. Mathematical model of hear mass exchange

processes in melt by crystallization allows to reduce the number of experiments by researches and to define more precisely thermal-physic characteristics of investigated steels.

References

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