Research of influence of inoculator particles dispersion on the period of liquid steel crystallization at roll continuous casting for obtaining thin plates

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Abstract
Roll continuous casting of liquid steel into rolls-crystallizers with use of inoculator for acceleration of crystallization of metal in course of thin plates production is considered. Inoculator behavior when cooling in the space between rolls at steel casting is analyzed, formula for determination of cooling time of inoculator is suggested. Dependence of cooling time of inoculator from the quantity of its share is revealed. Optimum dispersion of particles0.3 ÷ 0.5 mm for production of strips of 2 ÷ 4 mm in thickness is suggested that will provide fast cooling of liquid steel in the space between rolls.
Keywords: CASTING AND ROLLING MILL, ROLL CONTINUOUS CASTING, INOCULATOR, CRYSTALLIZATION, LIQUID STEEL, ROLLING OF STRIPS, QUANTITY OF SHARE, COOLING

Introduction

Manufacture of rolling products of continuous cast billets in comparison with rolled ones provides economy of metal, reduction of employees number, reduction of payback periods in case of development of the new enterprises and reduction of energy consumption. The tendency to reduction of production process from liquid steel to finished products is caused by high rates of these processes. At the present time, much attention is paid to continuous casting of liquid steel between two rotating cooling rolls; it allows soft reduction of strip. Therefore, improvement of process of roll casting in crystallizers is relevant issue.

Analysis of the latest achievements and publications

Increase of competitiveness of the modern metallurgical enterprises is provided with a complex of actions among which minimization and optimization of expenses of energy and resources, improvement of quality of production, etc. are the most important [1]. On this basis, interest in use of casting and rolling modules which comprise casting and rolling mills for obtaining billets by continuous casting using roll casting of steel has increased.

Losses of energy in ferrous metallurgy are connected with high temperature of processes, necessity of multifold heating and cooling of products, losses of energy in the form of emission, convection, physical and chemical heat of melting products and so forth. Therefore, in order to reduce energy losses, it is necessary to reduce temperature of processes and quantity of stages of temperature changes [1].

These requirements are provided in course of development of new technological processes reflecting combination of processes of casting and rolling [2, 3, 4].

Continuous casting of steel in connection with rolling is conductive to economy of capital investments due to exclusion of expenses on park of molds, provides economy of energy, which is spent for heating of ingots in soaking pits, allows lower environmental pressure on the atmosphere, increasing quality of steel products, improvement of operating conditions of operating personnel.

Such process allows reducing cycle of obtaining finished products from several days to several hours, reducing mass of the equipment approximately by 1.5 times, reducing number of employees by 30%, increasing process productivity by 25%. The formation of machines with roll casting of steel should be considered as further development of casting and rolling installations. Such process is the most perspective and energy saving technology of thin plates production. Obtaining flat products consists in formation of strip directly from liquid metal by crystallization and its deformation between two rotating rolls. Unlike usual continuous casting and rolling of metal products, two combined processes take place in case of roll casting: crystallization of melt and plastic deformation of crystallized part at first, and then of whole mass of metal [1, 5].

There are technologies where liquid steel is suggested to be cast directly into overhanging rolls, which are crystallizers [3], and to reduce quickly a metal overheat before casting using suspended casting [6]. An opportunity to utilize metal waste (facing, cutoff pieces, poured shots, cuts) is one of advantages of suspended casting. Researches have proved [8] that the rate of crystallization of melt of Steel 35 increases from 0.15 mm/s (when casting without additives) to 0.2 – 0.8 mm/s (in case of addition of iron powder) at introduction of ferrous additions.

The possibility of intensification of continuous casting of steel is limited mainly by hardening rate of continuous cast ingot. This process is connected with complexity of extraction of the physical and hidden heat of metal which is crystallized; therefore, it is determined by thermal-physical properties: heat conductivity, heat diffusivity, thermal capacity etc. For the purpose of acceleration of cooling of liquid steel, it is recommended to apply inoculators [6], which are small particles of substance (microrefrigerators) and allow acceleration of metal crystallization.

One of shortcomings of steel casting into rolls-crystallizers is that it is difficult to hold liquid steel in space between rolls due to its high level of fluidity in molten state; it also may pour out that leads to losses of finished products. The design of rolls-crystallizers has been improved that prevents pouring out of liquid steel when casting [7], and also actions for reduction of its overheat in space between rolls that is possible when forming of the additional centers of crystallization in volume of metal in rolls-crystallizers at roll continuous casting have been provided.

Article objective: to select optimum dispersion of particles of inoculator for acceleration of crystallization of liquid steel at roll continuous casting in the mill for thin strips obtaining.

Article tasks:

- to investigate behavior of inoculator in case of its addition into liquid steel when roll continuous casting;
- to determine structure of inoculator which must be added at continuous casting of low-carbon steel;
- to determine dependence of time of inoculator melting on the quantity of its share and to determine its optimum value.

Technique of research of inoculator particles dispersion influence on the period of crystallization of liquid steel at roll continuous casting for thin strips obtaining.

Researches of roll continuous casting of metal into casting and rolling mill, which comprises two cylindrical horizontal rolls-crystallizers arranged in rolling mill bearings [7], on which barrel disks are pressed, have been conducted. Liquid low-carbon steel (of grade Steel 20) was poured from ladle in horizontal cylindrical rotating rolls-crystallizers. At the same time, layer of the crushed steel cuttings in the form of triangular pyramid was poured to the rolls-crystallizers from two bunkers arranged at both sides of rolls for reduction of liquid metal overheat; for maintenance of steel in liquid state, dummy bar, which at the beginning of liquid steel casting had been introduced into working space of crystallizer, was used. In rolls-crystallizers, soft reduction was carried out that has allowed obtaining strips of 2 ÷ 4 mm in thickness.

Researches results

Particles of disperse inoculator accumulate hardened melt heat, which is spent for their heating and melting. A shift of process of crystallization towards lower overheats takes place. Decrease in overheat of liquid metal leads to reduction of total heat (both hidden and physical) that must be be taken away from melt when hardening strip in rolls-crystallizers; in turn, it causes reduction of hardening time of a cast strip under equal conditions. For achievement of the maximum thermal-physical effect, it is necessary to control parameters of disperse inoculator, so that particles completely melted by a moment of achievement of liquidus temperature. Therefore, the important parameter of technological process of suspended casting of steel is the quantity of share of disperse inoculator [6]. The optimum size of particle can be established by determination of duration of heating and melting of particles and comparison of them with time of reaching of liquidus temperature by strip edges. For this purpose, processes of heat exchange and kinetics of particles melting depending on their shape and size, mass of additives and temperature of overheat of liquid steel have been studied.

Researches have shown [6] that at the first moment of insertion of particle into liquid metal as a result of intensive absorption of heat by the cold body, sharp fall of temperature of neighboring layers of liquid metal is observed. This period is characterized by the maximum temperature gradient on the edge particle-liquid metal and corresponds to process of hardening of liquid metal on inoculator particle. Heat of liquid metal overheat is spent for heating up of inoculator particle. Process of hardening is completed after achievement of balance between heat flows on external and internal surface of frozen layer. Further having of overheated particles together with frozen layer takes place due to heat flow from liquid metal where reduction of an overheat of the following layers of liquid metal happens. Melting of frozen layer begins after reaching liquidus temperature on external surface of a layer. During melting of frozen layer, external layer of particle is heated to the temperature of melting and temperature is leveled by the particle section. Melting of heated part begins when temperature of surrounding layers of liquid metal exceeds temperature of its melting. After full melting of share, gradual leveling of temperature takes place by local volume of liquid metal. In a case when material of share and crystallizing phases have close thermal-physical characteristics (heat conductivity, thermal capacity) in dynamics of melting, the second and third periods can be considered as uniform process of melting of particle of big diameter. If particles distinguish by chemical composition, process of melting is caused not only by heat exchange, but also by mass transfer. When studying thermophysics of suspended casting of ingots, it was determined that [6] duration of hardening increases at increase in particles mass; it allowed determination of technological areas of obtaining cast materials with use disperse inoculators, close to the processed material by physical-chemical and thermal-physical properties. If it is considered that liquid steel is being continuously cooled, depending on specific conditions of casting, local overcooling can exist a long time that is enough for formation of critical size germs which are stable at the following constant equilibrium temperatures of system.

In calculations, let us consider that particles have spherical shape of radius R.

Duration of the first period (heating up period) from the moment of introduction in melt to melting [6]:

$$\tau_1 = \frac{R^2}{a_s + \mu^2} \ln\left[b_1 \mu \frac{\lambda_l (T_l - T)}{\lambda_l (T_l - T_c)} \right], \qquad (1)$$

where T_l – temperature of liquid steel; T_o – initial temperature of particle; T_c – crystallization temperature; R – size (radius) of particle; μ – coefficient of body massiveness; λ – heat conductivity of body; α – linear expansion coefficient.

Duration of the second period from beginning of melting to disappearance of hard phase [6]:

$$\tau_2 = \frac{0,493 L R^2}{a_l c_l (T_l - T_c)}, \qquad (2)$$

where c – specific heat; L - hidden heat of melting.

The total time of existence of metal layer in melt is determined by formula:

$$\tau = \tau_1 + \tau_2 . \quad (3)$$

Having substituted formulas (1) and (2) we obtain:

$$\tau = \frac{R^2}{a_s + \mu^2} \ln\left[b_1\mu \frac{\gamma_s (T_l - T_o)}{\gamma_l (T_l - T_c)} \right] + \frac{0,493LR^2}{a_l c_l (T_l - T_c)}. \quad (4)$$

For convenience of calculations, let us transform a formula (4) to the form:

$$\tau = R^2 \left\{ \frac{1}{a_s + \mu^2} ln\left[b_1\mu \frac{\lambda_s (T_l - T_o)}{\lambda_l (T_l - T_c)} \right] + \frac{0,493L}{a_l c_l (T_l - T_c)} \right\}. \quad (5)$$

In this case, $\tau = R^2 A,$ (6)

where A=const, which is equal to:

$$A = \frac{1}{a_s + \mu^2} ln\left[b_1\mu \frac{\lambda_s (T_l - T_o)}{l (T_l - T_c)} \right] + \frac{0,493L}{a_l c_l (T_l - T_c)}. \quad (7)$$

From a formula, it is see that duration of particle existence is directly proportional to its radius squared. The size of particle, which allows regulating time of crystallization of liquid steel, is changed.

The strips of 2 ÷ 4 mm in thickness were made of low-carbon steel in course of research. The particles made of the same low-carbon steel and of steel cuttings were used for suspension formation. A liquid steel, which was poured into casting and rolling mill, had temperature T_l=1600^{0}C.

Thermal-physical coefficients for such material have the following values:

$\lambda_s = \lambda_l$=25.5 W/m·K; $c_s = c_l$=6,7·10^2 J/(kg·K);
$\alpha_s = \alpha_l$=2.5·10^4 W/(m^2·K); L=2.74·10^5 J/kg;
T_c=1500^{0}C; A=const=2.73

Results of calculations are presented in Table 1.

Table 1. Results of calculations of time of steel share existence in melt depending on its size

R, mm	0,2	0,3	0,5	1,0	1,5	2,0
.τ, s	0,11	0,23	0,75	2,37	6,14	10,92

For more detailed idea of time of hard phase existence in melt, let us compose dependence diagram (Figure 1).

From calculations, it is seen that time of existence of solid phase in liquid depends on the size of a particle and is from 0.11 to 10.27 seconds for particles equal to 0.2÷2.0 mm. In case of increase in share quantity, time of its existence increases in proportion to size squared.

In accordance with results of research [3], 1 second is enough for crystallization of liquid phase in casting and rolling mills. Therefore, it is suggested to apply low-carbon particles for suspended casting into casting and rolling mills. Particles size is 0.3 ÷ 0.5 mm that will allow providing instant crystallization of melt in space between rolls.

Conclusion

- inoculator behavior in case of its addition to liquid steel at roll continuous casting is investigated that has allowed determination of its impact on the rate of crystallization of liquid metal when steel casting in rolls-crystallizers for the purpose of thin strips obtaining;
- inoculator material, which must be added when continuous casting of low-carbon Steel 20 has been determined; material must be the same or close to composition of liquid steel, which is poured out into rolls-crystallizers;

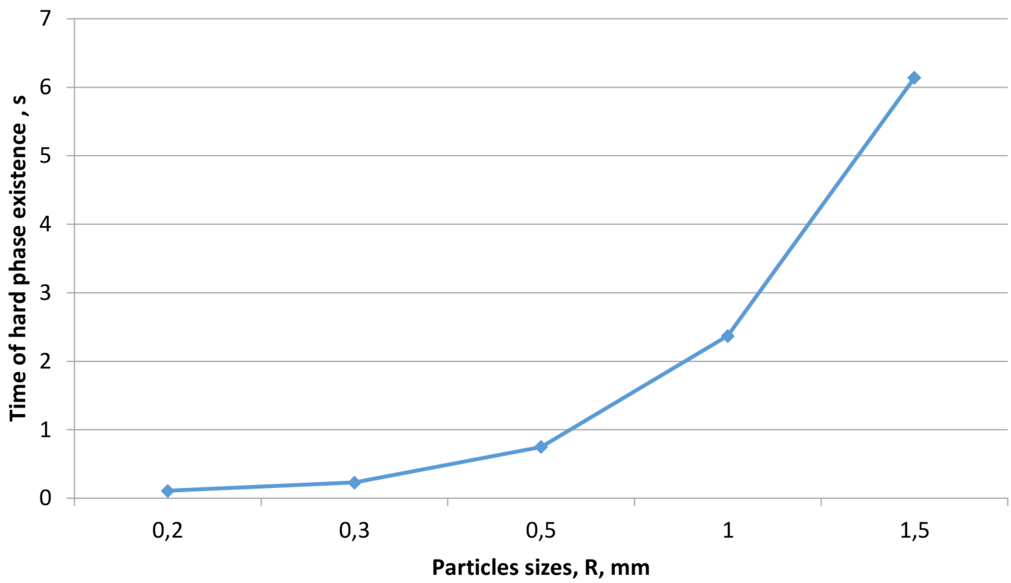

Figure 1. Time of hard phase existence depending on particles sizes

- new formula is suggested and dependence of time of inoculator melting on the quantity of its share is determined and its optimum size equal to 0.3÷0.5 mm is established.

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