Study of cooling rate, crystallization duration and metal discharge coefficient in case of continuous casting into foundry and rolling mills

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Abstract
The new technology of the continuous casting of liquid steel into foundry and rolling mills is developed. The rate of cooling and crystallization, metal discharge coefficient in case of the continuous casting of metal into upgraded facilities for production of thin strips are determined. The studies showed that under conditions of steel suspension casting use, the cooling rate increases, time of crystallization and coefficient of metal discharge decrease in comparison with roll casting without suspension use.
Key words: ROLL CASTING, CONTINUOUS CASTING OF STEEL, STRIPS PRODUCTION, COOLING RATE, CRYSTALLIZATION, METAL DISCHARGE, FOUNDRY AND ROLLING MILL, SUSPENDED CASTING OF STEEL

Introduction

Increase of competitiveness of modern metallurgical enterprises is provided with a complex of actions, among which minimization and optimization of energy consumption and resources expenditure, improvement of production quality etc. are the most important.

This is achieved by combination of processes of casting and rolling in case of strips production. Obvious advantages of such processes, as a rule, are low capital intensity, low level of ecological pollution, minimum equipment downtime, rather short production cycle with the maximum productivity and profitability. Especially noticeable results are achieved by implementation of the continuous roll casting of metal in rolls crystallizers which achieved essential positive results now.

Therefore, improvement of process of roll casting of liquid metal for strips and roll foundry and rolling machines production for implementation of this method of strips production is relevant task which solution will allow increasing labor productivity and reducing energy consumption and production cost.

Analysis of last researches and publications

Energy consumption in ferrous metallurgy is connected with high temperature of processes, need of repeated heating and cooling of processed products, losses in the form of emission and convention. Therefore, for reduction of such expenditures, it is necessary to reduce temperature of processes and quantity of stages of temperature changes [1].

Important innovation of metallurgy is experimental-industrial aggregates of direct continuous casting to the thin strip directly. Basic advantage of direct casting of thin strip is exclusion of some operations of hot rolling from the technological diagram with reduction of equipment, and also energy and labor input [1].

Unlike normal continuous casting and rolling of steel products, in case of roll casting, two combined processes take place: crystallization of melt and plastic deformation at the part which was crystallized, and then the whole mass of metal [2].

The technological diagram of thin strips using two-roll continuous-casting machines allows reduction of energy consumption and resources expenditures by 8 - 10 times, reduction of metal losses to the scale by 40 - 50 times, increasing of labor productivity by 5 - 10 times, and also provides economic expediency of further development and improvement of technological processes [3].

The general view and layout chart of the experimental plant for carrying out investigations of roll continuous casting are given in Figure 1, where it is seen how liquid steel is poured from ladle into rolls crystallizers [3]. Further, soft reduction of steel takes place; in case of output from crystallizer mill, the strip undergoes further cooling and passes to rolling mill.

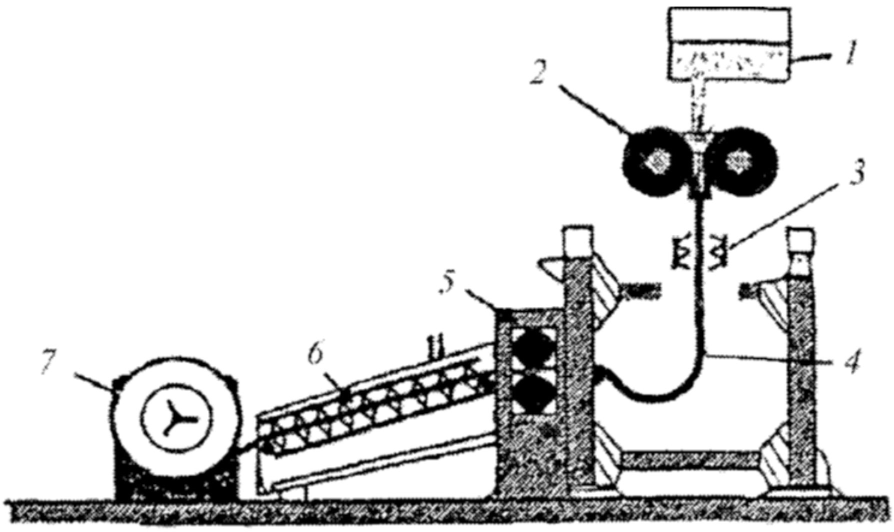

Figure 1. Diagram of experimental plant: 1 - liquid steel in a ladle; 2 - roll crystallizer; 3 - zone of ingot cooling; 4 - loop; 5 - rolling mill; 6 - refrigerator; 7 - coiling apparatus

Studies [3] have shown advantages of use of roll foundry and rolling units over foundry and rolling units: reduction of capital expenditure by 68%, reduction of relative capital investments by 35%, energy consumption decreases twofold. But the new technology also has shortcomings, namely, width of strips is not regulated and fluctuates throughout the length.

There are technologies where liquid steel is suggested to be poured directly into overhang rolls, which are crystallizers [3], and to reduce quickly overheating of metal before casting using suspended casting [4].

Opportunity to recover metal waste (shaving, trimming, short pour, scrap) is one of advantages of suspended casting. The most essential distinguish feature of suspended casting in comparison with other methods is implementation of the internal heat sink by heat flows of inoculators for intensification of heat transfer in a liquid phase with superimposing of external effect. If metal does not crystallize at certain temperature that is lower than equilibrium temperature of melt, then it is possible to initiate crystallization by increase in overcooling in one way or another with reduction of formation of critical nucleus.

By researches it has been proved [4] that rate of crystallization of melt from steel 35 in case of introduction of ferriferous components increases from 0.15 mm / s (when casting without components) to 0.2 – 0.8 mm / s (when adding iron powder).

The patent search concerning improvement of foundry and rolling modules [5] that allowed studying dynamics of development and implementation of foundry and rolling units in Ukraine and Russia from 2000 to 2013. This analysis gives the opportunity to determine advantages and disadvantages of development of such units and to reveal the further direction of research on reduction of overheating of metal in case of the continuous casting of steel into rolls crystallizers that provides a possibility of combination of casting and rolling processes.

The perspective of intensification of continuous casting of steel is limited, mainly, by limitation of solidification speed of cast ingot. This process is connected to complexity of extraction of physical and latent crystallized metal heat; therefore, it is defined by its thermal physical properties: heat conduction, heat diffusivity, heat capacity etc. [1, 4].

One of disadvantages of steel casting into rolls crystallizers is that it is difficult to retain liquid steel in the space between rolls because it has high level of liquid flowability in the melted condition and is capable to flow out that leads to losses of finished products. Therefore, it is necessary to improve construction of rolls crystallizers for the purpose of prevention of pouring out of liquid steel when casting, and also to provide actions for reduction of metal overheating in case of space between rolls that is possible in case of formation of additional crystallization centers in the metal in case of roll continuous casting.

Objective and tasks of research

The objective of this paper is to increase the speed of cooling of liquid steel, to reduce time of crystallization and coefficient of metal discharge in case of continuous casting in foundry and rolling mills for strips production.

For achievement of the objective it is necessary to carry out the following tasks:

1. To analyze possibility of introduction of additional crystallization centers and to use an optimum inoculator for increase in cooling rate, reduction of time of crystallization and coefficient of metal discharge into rolls crystallizers in case of roll continuous casting of steel.

2. To study cooling rate, crystallization of liquid steel, coefficient of metal discharge in case of continuous roll casting with use of suspended casting of steel into suggested equipment.

2. Technique of research of cooling rate, duration of crystallization and coefficient of metal discharge in case of continuous casting in foundry and rolling mills

When studying of continuous roll casting, carbon steel (Steel 20), which was poured from ladle directly into horizontal cylindrical rolls, which rotate in opposite directions, was used. Working rolls in this case simultaneously serve as crystallizers coolers and crimping tools where processes of cooling and rolling of steel are combined with pressing that provides material extraction. Rolls are arranged horizontally as it is shown in Figures 2 and 3 and are continuously cooled with water. Metal shavings are poured out from bunkers from both sides at the end face of rolls crystallizers. Working rolls are made of copper and are covered with nickel, collars are pressed-on with tension at an end face of rolls crystallizers (Fig. 3) [6, 7].

Construction of roll is provided in Figure [6, 7] where its connections with collar is shown. Collars serve for holding of crushed shaving and prevention of pouring out of liquid steel between working rolls that allows increasing of finished-product output.

Diameter of the rolls crystallizers used in researches is equal to 500 mm, length is 1000 mm.

When studying, temperature of liquid steel was measured by thermocouple and fixed by means of thermal sensors.

In researches, suspended casting of liquid steel was used in rolls crystallizers that allows reduction of duration of ingot solidification and reduction of utilization coefficient of liquid metal and to improvement of quality of obtained product.

The equipment, which was used for research, is foundry and rolling mill, which includes two cylindrical horizontal rolls crystallizers arranged in bearings of stand. Disks are pressed on barrel of each roll on both sides with warranted tension; at that, distance between right and left disks of roll is equal to width produced plate and disk thickness, distance between rolls is equal to thickness of produced plate, at the same time, collars of neighboring rolls cover each other.

As a result of researches it was determined the speed and time of cooling of metal, crystallization and coefficient of liquid steel discharge in case of strips production under the conditions of roll continuous casting of steel with use of suggested equipment. As a comparison, casting with use of suspension and without it was investigated. During researches, value of a gap between rolls was changed that allowed obtaining several strips of different thickness. Temperature of casting remained constant and was equal to 1580 °C.

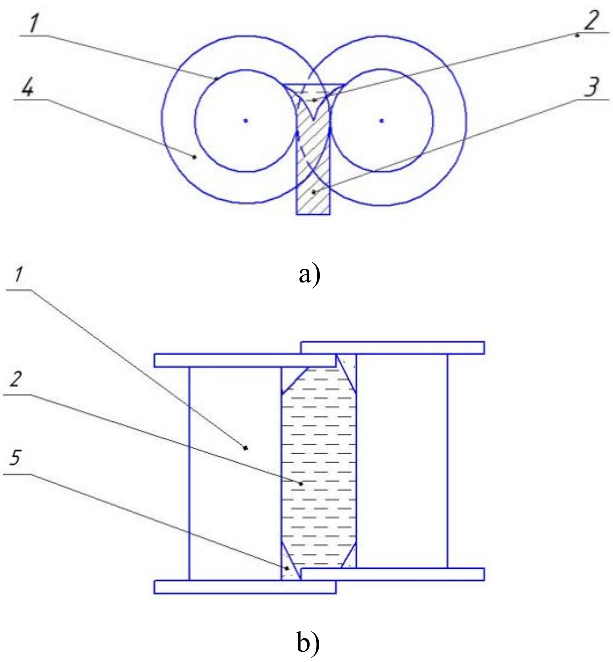

Figure 2. Foundry and rolling mill [6]: a) view from the side, b) top view
1 - mill rolls crystallizers; 2 - liquid steel; 3 - starting bar; 4 – pressed-on collars; 5 - crushed shaving

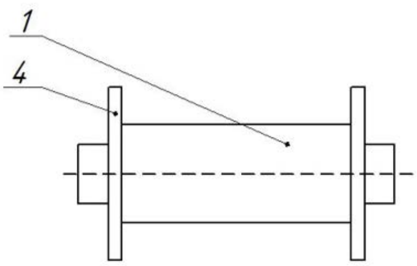

Figure 3. Casting roll with collars [6]: 1 - mill roll crystallizer; 4 - collars

In course of researches, the crushed metal shaving, which was poured from the bunker to the side faces of rotating rolls crystallizers, was added for formation of suspension in liquid metal. Collars have stabilized it in the form of a trihedral pyramid that kept liquid steel reliably and allowed it to crystallize quickly.

Researches were conducted by the following technique: liquid steel (2) was poured from a ladle to horizontal cylindrical rolls crystallizers (Figure 3), which rotate (1); along with it, a layer of the crushed shaving (5) in the form of a trihedral pyramid was put on rolls crystallizers from the bunkers arranged in both sides of rolls. For stabilizing of this pyramid, collars (4) are pressed-on in the ends of rolls, the starting bar (3) which prior to casting of liquid steel was added into working space of crystallizer, was used for maintenance of steel in liquid state.

The equipment suggested for carrying out experiments provides holding of liquid steel by mill rolls prior to solidification: liquid steel interacts with shaving, which is held on rolls due to collar that holds back pouring out of liquid steel from space between rolls and allows finished products output to raise. Thus, the technique of carrying out research of strips production efficiency of continuous roll casting of liquid metal has been provided. According to this technique, new technology of the continuous roll casting of steel into rolls crystallizers is suggested, new design of equipment for its implementation is determined and material for implementation of suspended casting of liquid metal in crystallizers is selected.

3. Results of study of cooling rate, duration of crystallization and coefficient of metal discharge in case of continuous casting in foundry and rolling mills

The method of intensification of solidification of continuously cast billet is the most perspective; this method is based on removal of overheating warmth of liquid metal by means of internal heat flows.

Side thickening of a liquid bath is of great importance. Experiments have shown that when using such condensation, liquid steel is held well by mill rolls: liquid metal interacts with shaving, is held well on the rolls crystallizers due to collar and crystallizes quickly from the side surface that prevents its pouring out into space between rolls.

For determination of inoculator composition, that is particles of crushed shaving from different iron carbon alloys appear; their thermal physical properties are analyzed.

In course of researches, crushed shavings of low-carbon steel were used as inoculators.

As a result of experiments, researches of 2 - 4 mm strips production, with casting speed of 50 - 70 m/min were conducted, time of solidification of liquid steel was 0.8 – 1.0 s.

Results of experiments are presented in Table 1 where time of crystallization of liquid steel, speed of cooling and coefficient of metal discharge are compared in case of the continuous roll casting of steel for strips production with and without use of suspension.

Table 1. Results of research of cooling rate, time of crystallization and coefficient of metal discharge in case of the continuous casting of steel into foundry and rolling mills

No	h, mm	Without suspension				With suspension use			
		υ_c, m/min	T_{cr}, s	Y_{cool}, °C/s	K_{dis}	υ_c, m/min	T_{cr}, s	Y_{cool}, °C/s	K_{dis}
1	2	72	1,0	950	1,05	72	0,8	1300	1,02
2	2,5	75	1,1	920	1,04	75	0,9	1280	1,015
3	3	81	1,2	900	1,03	81	1,0	1230	1,01
4	4	82	1,25	880	1,02	82	1,0	1200	1,008

Symbols in Table 1: h – strip thickness; υ_c – speed of continuous casting of liquid steel; υ_{cool} – cooling speed; t_{cr} – time of liquid steel crystallization; k_{dis} - metal discharge coefficient; this coefficient was determined by the ratio of metal amount at the inlet of foundry and rolling mill to amount of metal at the output from foundry and rolling mill.

For vivid observation of indices changes of casting by continuous casting roller machines, the comparative diagrams of dependence of crystallization duration on strip thickness when casting without and with suspension use (Figure 4).

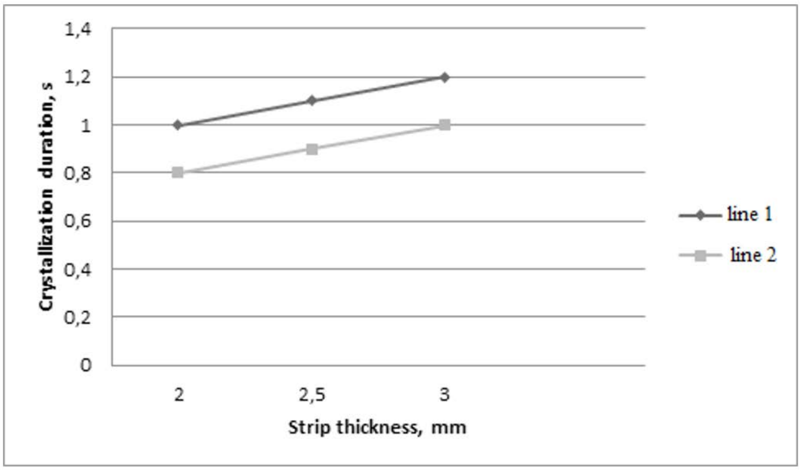

Figure 4. Dependence of cooling duration on strip thickness: line 1 - without suspension use; line 2 - with suspension use

From Figure 4 it is seen that crystallization duration in case of thickness growth increases in both cases with and without suspension use, but in case of using suspension, duration of crystallization of liquid steel when casting in rolls crystallizers is reduced that demonstrates acceleration of time of crystallization when using suspension.

Diagrams of dependence of relative cooling speed on strip thickness when casting without and with suspension are developed (Figure 5).

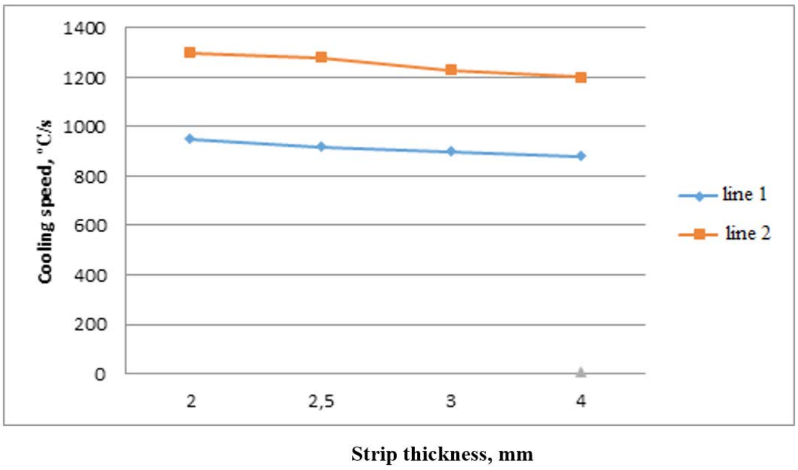

Figure 5. Dependence of cooling speed on strip thickness: line 1 - without suspension use; line 2 - with suspension use

From Figure 5, it is seen that the relative cooling speed in case of increase in strip thickness decreases. In case of suspension use, from Figure 5 it is seen that the relative cooling speed increases that proves positivity of use suspended castings of steel in roll foundry and rolling mills.

For analysis of coefficient of metal discharge, the diagrams of dependence of coefficient of liquid steel discharge on strip thickness without and with suspension use (Figure 6).

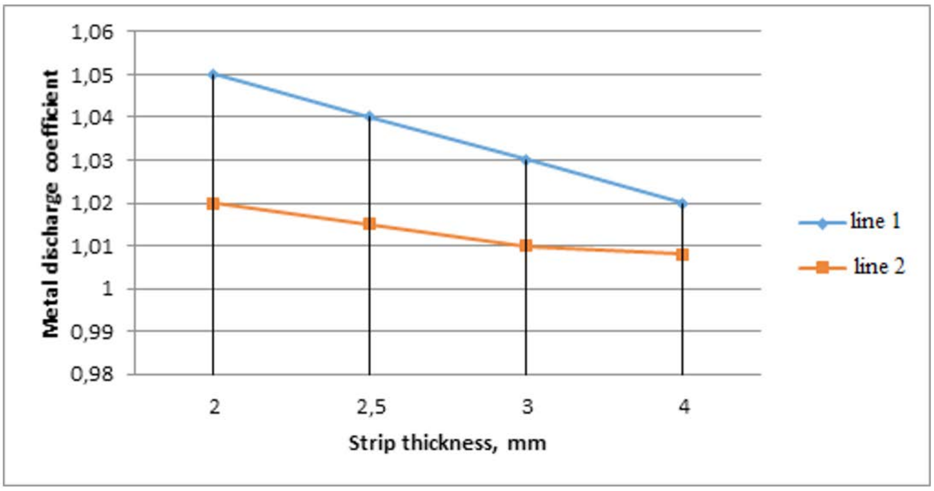

Figure 6. Dependence of metal discharge coefficient on strip thickness: line 1 - without suspension use; line 2 - with suspension use

From Figure 6, it is seen that in case of increase in thickness of strip, the coefficient of metal discharge decreases. The use of suspended casting allows reduction of discharge coefficient almost to unit; it demonstrates that almost all liquid steel is able to become crystalized, but not to be poured out.

Results of researches have shown that the speed and time of metal cooling in rolls crystallizers depends on strip thickness: the thicker strip is, the more slowly its cooling will be.

From results of research, it is seen that in each experiment irrespective of strip thickness, the speed of metal cooling in case of roll casting with use of suspension increases, and time of crystallization decreases when using suspension. In our research, the suspension is crushed steel shaving, in comparison with the same experiment, but without suspension. Data of researches confirm that in researches with use of suspension, the metal extension increases by 20% approximately under the conditions of roll casting with suspension use.

Conclusions

1. Possibilities of introduction of additional crystallization centers are analyzed and crushed steel shaving is used as inoculator that allows increasing of speed and reduction of crystallization time of liquid steel in case of continuous roll casting in foundry and rolling mills in case of strips production.

2. Speed of cooling and crystallization of metal, coefficient of liquid steel discharge are determined by new technology with use of suggested equipment, the speed of metal cooling in case of roll casting with use of suspension increases, and time of crystallization decreases when using suspension. In our research, the suspension is crushed steel shaving, in comparison with the same experiment, but without suspension.

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Experimental studies of complex influence of temperature and deformation parameters of rolling on the mechanical properties of metal

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