# Steel casting speed in suspended cast-rolling with roll-mold for thin bars production

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Abstract
This article is devoted to the research of suspension casting speed dependence on reduction value and gripping angle under conditions of cast-rolling of thin steel bars production. In order to determine the casting speed, we used foundry and rolling mill of improved design. It enabled us to increase the rate of metal crystallization and to diminish metal loss. The operations were performed with suspension, made from particulate low carbon steel chips. In the research, the impact of the reduction value and gripping angle on the speed of steel casting in the process of casting-rolling was analyzed and the reasonable reduction ratio of 15% with the steel casting was found. The dependence of the suspension casting speed in the foundry and rolling mills on the exit thickness of bar and the gripping angle was defined. The dependency graphs allowing us to trace the change of steel casting speed with different gripping angles for thin bar manufacture by cast-rolling method were developed. This dependence was defined as the exponential one. In order to determine the speed of steel casting under conditions of suspension casting, we expressed the dependency in the form of an equation. This permitted us to determine reasonable modes of thin bars manufacturing.
Keywords: SUSPENDED STEEL CASTING, CAST-ROLLING, FOUNDRY AND ROLLING MILL, MOLD, CASTING SPEED, GRIPPING ANGLE, REDUCTION VALUE, THIN BAR, PRODUCTION PROCESS, LIQUID STEEL

**Introduction**

The modern metallurgical industry places high requirements for the performance of machines and production units, for saving of materials and energy resource and for the quality of manufactured products. Meeting these requirements becomes possible thanks to the development of cast-rolling with roll-molds. Manufacturing of bar by continuous casting-rolling process enables us to increase productivity, to reduce energy consumption and to improve the quality of the product. Therefore, further improvement on the manufacture processes of the cast-rolling and the choice of optimal modes are crucial tasks, which open up new opportunities in the steel industry.

**Analysis of recent researches and publications**

The unit of continuous direct casting of liquid steel into thin sheets is an important step forward in innovations in metallurgy. The main advantage of this process is the elimination of the hot rolling operations in the production scheme and the corresponding reduction in equipment, as well as decrease in labor and energy costs [1 – 6]. In the units of the direct casting of a thin sheet, the mold is composed of two rolls, which are arranged directly beneath the intermediate ladle and rotate in opposite directions. During the casting, liquid steel enters the space between the rolls and crystallizes in contact with the surface of the rolls. At that, the cooled solid layers are formed, they move together with the surface and exit from the rolls in the form of the sheet. The sheet thickness is determined by the distance between the rolls and the width is made by the side walls of the mold [1].

In cast-rolling, there are two combined processes employed: crystallization of the liquid steel and plastic deformation carried out first for the crystallized part of the metal and then for the whole mass of metal [5]. Soft reduction takes place while crystallization [6].

Compared against the conventional rolling, we would like to note that in cast-rolling, molten metal serves as the initial product and the parameters of plastic deformation zones are formed as a result of a complex interaction of the material with the tool [7].

The most important parameter of the cast-rolling technology, which determines the quality of the bar and the roll performance, is the rotation speed of the roll-molds and the speed of steel casting. According to the commonly established ideas[8, 9], there are three zones distinguished for the metal in the gap between the rolls in the casting-rolling process (Figure 1).

The process of cast-rolling with roll-mold involves a lot of complex interactions of physical phenomena such as fluid flow, heat exchange, solidification, air gap between the rolls for bar forming and mechanical deformation. A very important task is to evaluate the influence of these process parameters on the production rate and quality of the final product.

Moreover, if we discuss the production of 10 mm thick bar from low-melting metals with low resistance to deformation, for example, aluminum [8], the deformation area length is 0.6-0.8 of the total three zones length due to the lowered casting speed. The reduction of the bar reaches 40-60% in the deformation zone.

Furthermore, when casting steel bars, the roll-molds are not able to provide greater reduction because of the insufficient strength and stiffness of the roll-molds. Therefore, the speed of steel bars casting is practically much higher than that of aluminum bars. Increased speed of steel bars casting leads to the reduction of the relative length of the deformation zone down to 10%, and the reduction of bar in the deformation zone does not exceed 15%.

An important characteristic of the bar forming process in the roll-mold is position of solidification final point regarding to the plane of the rolls axis («S» point) [9].

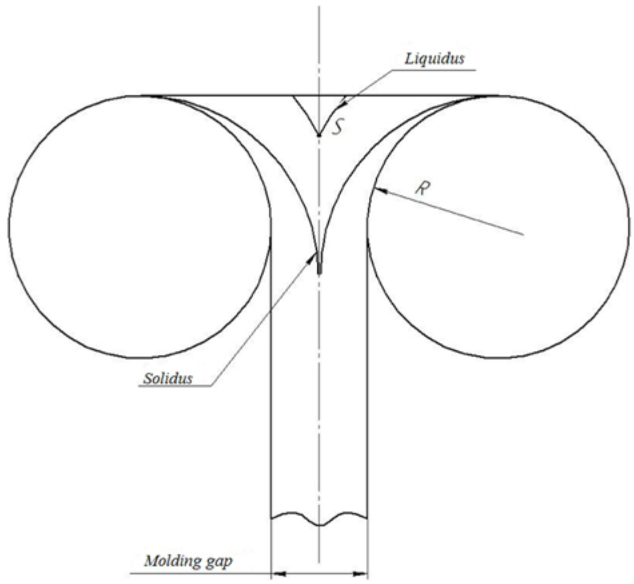


**Figure 1**. Scheme of the gap between the rolls in cast-rolling for the thin bars manufacturing: *R* – radius of roll-molds

The research results were analyzed and evaluated with A. Kasama's research data and the co-authors [8], while those for the steel cast-rolling – with the data obtained by S. Berkovich [10] and for aluminum cast-rolling – with A.Y. Gridin's results [11]. Utilizing the outcomes of the earlier researches [12], we accept that the degree of deformation able to provide a good quality of steel during its processing is to be not less than 15%.

There is the suggestion to apply a new design of foundry and rolling stand with the objective to reduce metal consumption during casting [13]; in order to decrease the overheating of steel coming between the rolls, we can use the additional crystallization centers in the form of steel chips which are able increase the speed of liquid steel casting.

**The purpose** of the current work is to make the research on the steel casting speed increase in suspended cast-rolling for thin bars manufacturing.

To achieve the stated purpose, it is necessary to perform the following **tasks**:

- to analyze the impact of gripping angle and reduction value on the speed of steel casting in the foundry and rolling stands in order to select the optimal mode of casting;
- to determine the dependence of suspension casting speed for the liquid steel on the bar thickness and its gripping angle; to develop the dependency graphs and to determine the formula for the casting speed calculation.

**The Research Methods**

Low-carbon constructional steel was used as the material for the research of the suspension casting speed of metal into roll-mold. The rolls had a radius of 500 mm while the degree of deformation was equal to 15 %. The experimental production resulted in manufacture of bars with the width of 2 mm, 3 mm and 4 mm. The angle of gripping was equal to 10°, 20° and 30°. The rolls were with collars. [13]. For creating suspension, steel chips were used.

Based on the experiment, we carried out a research analysis on dependence of predicted maximum speed of steel bar casting (4 mm/s) on the crystallization-deformation angle α for the rolls with radius of *R* = 500 mm. The research was made with varying bars thickness and deformation degrees. [6].

**Research results of steel casting speed with suspended cast-rolling**

The research results of steel cast-rolling in thin bars production without the suspension are shown in Table 1.

Table 1. The research results of influence of the gripping angle on the casting speed without suspension use (original development by the article author).

| .α,° | υ, m/min | | |
|---|---|---|---|
| | *h*=2, mm | *h*=3, mm | *h*=4, mm |
| 10 | 42 | 20 | 10 |
| 20 | 91 | 43 | 15 |
| 30 | 160 | 80 | 40 |

The table 1 marks: α – gripping angle; h – exit thickness of a bar; υ – steel casting speed.

As the research results evidence, with the exit bar thickness increase, we observe the casting speed decrease, while with the gripping angle increase allows the casting speed increase.

In accordance with technology [13], the use of suspended casting is provided where it is obvious that the crystallizing and cooling rate of the metal increases up by 20 % with the use of suspension. Owing to this, we offer to increase steel casting speed into roll-mold up by 20 %. The corresponding research results are given in Table 2.

Table 2. The research results of the gripping angle influence on the casting speed with the use of suspension (original development by the article author).

| .α,° | υ, m/min | | |
|---|---|---|---|
| | h=2 mm | h=3 mm | h=4 mm |
| 10 | 50.4 | 24 | 12 |
| 20 | 109.2 | 51.6 | 18 |
| 30 | 192 | 96 | 48 |

To follow up more precisely, the gripping angle influence on the steel casting speed in the foundry and rolling stand on condition of suspension use, we consider it is necessary to build up dependency graphs (Figure 2).

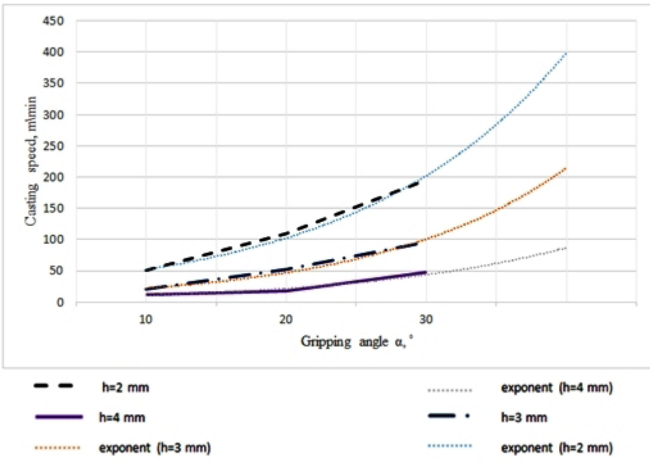


**Figure 2.** The influence of the gripping angle on the casting speed when suspended cast-rolling of carbon steel (original development by the article author)

It is clear from the graph that with increasing the gripping angle it is possible to increase the steel casting speed under conditions of suspended cast-rolling. For the experiment reported in the current paper, the maximum steel casting speed was achieved with the exit bar thickness of 2 mm and the gripping angle of 30°.

The research results show that there is an exponential dependency of steel casting speed on the gripping angle which is reflected in an equation below:

$y = a \cdot e^{kx}$ , (original development by the article author),

where *a* and *k* are coefficients, which depend on the following conditions of steel casting: the bar thickness, the gripping angle, *e* – exponent, *e*=2.718.

Thus, the above written can prove that the equation of dependency of steel casting speed on the gripping angle under suspended cast-rolling is found.

**Conclusions**

The researches on the stated theme resulted in the analysis on the influence of the gripping angle and percentage reduction of product cross-sectional area on the steel casting speed in foundry and rolling stand. This analysis has been performed with the aim of choosing the optimal casting modes, defined as those where the optimal reduction for a steel bar is 15 % while the gripping angle is 10-30°.

The dependency of liquid steel suspension casting speed on the exit bar thickness and the gripping angle is defined; this dependency is expressed in the graphical form. Moreover, it has been found out that there is an exponential dependency between the bar gripping angle and the steel casting speed. The dependency equation has been made, which allows us to define the steel casting speed provided by the conditions of suspended casting for thin bars production.

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