

TESTING OF HOT ROLLED STRIPS WITH THE INVERSE TEMPERATURE WEDGE

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ABSTRACT

It is theoretically possible to increase the productivity of a hot rolling mill due to a greater acceleration in the finishing train at a constant initial rolling speed. This will increase the rolling end temperature along the strips. Changes in deformational, speed and temperature modes require research into changes in the rolled stock mechanical properties along the strips. The article presents the results of industrial research on the way the rolling end temperature increase influences the mechanical properties of St3 hot-rolled steel.

***Keywords:** strip, hot rolling, productivity, mechanical properties.*

INTRODUCTION

Increased productivity of existing hot rolling mills with multistand roughing is an important and urgent task. This problem can be solved in several ways: increasing the thickness of the workpiece; increasing the initial rolling speed; reducing the time for rolling individual strips.

Increasing the thickness of the workpiece causes an increase in weight which requires design changes of transport machines, heating furnaces, bearing structures. Compression and processing time increase while maintaining the rolling range and the length of hot-rolled strips. The distance between the stands or trains imposes additional restrictions on the length and weight of the strips. Therefore, increasing the thickness of the workpiece involves high costs, and in some cases it is impossible to reconstruct the equipment in the existing production.

The increase in the initial rolling speed is achieved through the modernization and reconstruction of equip-

ment which can be implemented in the existing production with relatively small investments. In this way the runoff table of NLMK 2000 hot rolling mill was modernized [1]. The start-up of the equipment after the step-by-step reconstruction of the mill will provide an increase in the mill's productivity by 1 - 3 % a year. Increased productivity is achieved through reliable and stable operation of the equipment with the increase of the threading speed of the strip.

Further increase of productivity due to the increase of the threading speed of the strip is limited by both the stability of the equipment's operation and the conditions for transporting the strip along the runoff table. The length of the runoff table in some cases exceeds 200 m. At a high rolling speed a thin strip can become unstable. The aerodynamic effect will lead to a jam or shift of the strip on the runoff table. Emergency situations both reduce productivity and increase the metal loss.

The reduction of machine time for rolling individual strips does not require significant investments and is

achieved through changes in the production technology. This way is the most promising after the reconstruction of the mill, when other options at this stage of developing the equipment have been exhausted. Machine time for rolling a strip on the mill as a whole is limited by the productivity of the continuous finishing train.

The productivity of the continuous finishing train and of the mill as a whole can be increased only by providing quality indicators of the strip. Quality is understood as a set of properties of rolled products, including the mechanical properties of the material of the strips. Moreover, it is important to ensure both the desired combination of mechanical properties and their stability along the length of the strip.

INFLUENCE OF ROLLING MODE ON THE FORMATION OF MECHANICAL PROPERTIES ALONG HOT-ROLLED STRIPS

On broadband hot rolling mills, slabs heated in furnaces are rolled in the roughing mill to an intermediate thickness of roll. The rolled strip is transported to the continuous finishing group along the intermediate table. Then the strip is fed into the finishing train, where it is compressed into a strip of a given thickness. The rolled strip is transported along the runoff table to a group of coilers where it is coiled.

When moving along the intermediate table the strip cools. The rear end of the strip cools longer than the front one, which leads to a reduction in the rolling end temperature from the front end to the rear end along the length of the strip. This reduction in the rolling end temperature over the length of the strip from the front to the rear end is called “temperature wedge”. The temperature wedge leads to changes in the properties of rolled strip along its length. When rolling slabs of large mass to eliminate the temperature wedge a widely used method is rolling in the finishing train with acceleration.

In order to obtain stable mechanical and metallographic characteristics along the length of the strip the rolling end temperature is maintained constant along the length of the strip during rolling. Initially, rolling is performed at the initial speed as to obtain the desired value of the rolling end temperature at the front end of the strip. After the front end of the strip exits the finishing train or after the strip is put into the coiler, the rolling speed gradually increases with a certain accel-

eration providing the rolling end temperature which is constant along the length of the strip [2, 3].

Rolling with the fixed rolling end temperature under certain conditions can lead to a difference in mechanical properties along the length of the strip. The difference of the mechanical properties along the length of the strip is caused by the difference of the microstructure of the strip material. At the constant temperature and degree of deformation of the strip in the last stands, as the rolling speed increases, time during which strip portions remain in the interstand spaces of the continuous train decreases from the front end to the rear end of the strip. Less time is required for the recrystallization of the deformed structure of the strip's material. Accordingly, the degree of the recrystallization of the strip's material at the entrance into the next stand changes. Recrystallization may be incomplete, and the structure of the strip's material may enter the next stand partially recrystallized. The unhomogeneity of the microstructure formed along the strip at the exit from the mill can lead to the unhomogeneity of the mechanical properties of the strip's material (Fig. 1).

At hot rolling mills with a continuous subgroup in the roughing train there is a possibility to change the rolling speed in the stands. It is suggested to ensure the homogeneity of the mechanical properties along the fin-

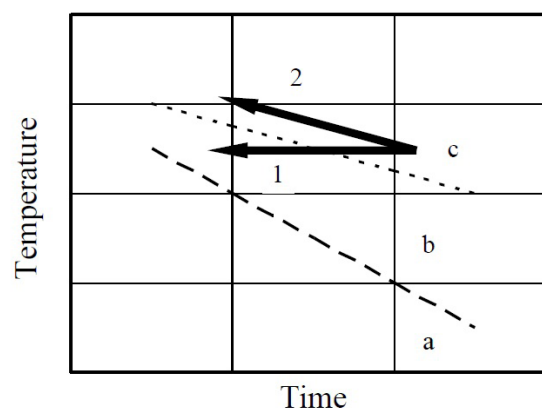


Fig. 1. Temperature - time recrystallization diagram.

a - area of unrecrystallized metal structure; b - partially recrystallized metal; c - recrystallized area; 1 - change of metal condition along the strip at the constant rolling end temperature and complete recrystallization of metal at the front end of the strip; 2 - change of metal condition along the strip at the increasing rolling end temperature and complete recrystallization of metal at the front end of the strip.

ished strip at these mills due to rolling with acceleration in the roughing train. Rolling in the finishing train is carried out at a constant speed, providing a quasi-permanent temperature of the rolled stock at the entrance into the finishing train which is achieved by rolling in the roughing continuous subgroup with acceleration and subsequent screening of the rolled stock [4].

It is impossible to use such a technology at mills with a sequence group of roughing stands. In this case, a different approach can be used which involves changing the existing temperature deformation mode in the finishing train. In order to obtain the same degree of recrystallization over the length of the rolled strip at the reduction of time for the pause between deformations, the metal temperature along the strip can be increased. Rolling should be carried out with the increase of temperature along the strip, providing a constant recrystallization rate along the strip at the entrance to the last stand. Technically, this is achieved by using acceleration to ensure the “inverse temperature wedge” at the exit from the continuous train.

Rolling with the “inverse temperature wedge” will both increase the stability of the mechanical properties along the strip and enhance the productivity of the continuous finishing train, particularly in the manufacture of thin strips.

When rolling a strip with a cross section of 2.0×1250 mm of low-carbon steel, the rolling end temperature equaling 810°C is obtained at the initial speed of 10.1 m s^{-1} . The constant rolling end temperature along the strip is provided at the acceleration of 0.025 m s^{-2} . The maximum rolling speed reaches 12.9 m s^{-1} at the strip's length of 1288 m. When accelerating the strip when it is leaving the last stand of the continuous train the overall strip rolling time will be 112 seconds. Conventional productivity (excluding pauses) will be $807.3 \text{ tons h}^{-1}$. If we assume that the inverse temperature wedge along the strip, at which mechanical properties remain stable along the strip and equal 50°C , is provided at the acceleration of 0.051 m s^{-2} , then in this case, the conditional productivity is $889.8 \text{ tons h}^{-1}$, i.e., increases by 10 %. When rolling thicker strips, the increase in productivity will be lower and, taking into account the pauses, should be 2 - 3 %.

The proposed modification of the hot rolling mode is only theoretically grounded. In fact, rolled stock properties may not meet the requirements for the stock

on strips' length or the existing equipment cannot ensure the rolling mode. Therefore, the change in the temperature or speed modes at a continuous hot rolling mill requires a practical confirmation of the feasibility of the modes and of obtaining the required properties along the rolled stock. In laboratory conditions, it is impossible to simulate the deformation and cooling of metal in a multistand train. With a view to the practical implementation of the proposed rolling mode requires experimental research is required directly at a continuous broadstrip hot rolling mill.

EXPERIMENTAL

For experimental testing of the possibility to provide stable mechanical properties along the length of the strip at hot rolling with the inverse temperature wedge steel Cm³ is selected. Rolled steel is sent to be cut into sheets, which makes it easier to select the samples along the length of the strip during research.

Strips of selected steel are rolled on the 2000 hot rolling mill according to the following temperature conditions:

Strip thickness, mm	Tf, °C	Tr, °C
2.50 - 4.00	790 - 830	610 - 650

Finish temperature (Tf) and reeling temperature (Tr) are retained in a constant value.

During research the Tf of the beginning of the strip was equated to the current one and then Tf was attained to be increased by 30 - 50°C along the length of the strip.

T_f increasing from the minimum to the maximum value along the length of the strip was achieved by using an increased (in comparison with commonly used) amount of acceleration of the finishing train. The reeling temperature was set up at a constant value of 630°C .

According to the Tf real value, the rolling conditions can be divided into four versions:

Version A - the finish temperature along the length of the strip is set up at a constant value of 810°C .

Version B - with inverse temperature wedges, i.e. when the finish temperature increases with 30 - 50°C against the set up value of 810°C from the beginning to the end of the strip.

Version C - with inverse temperature wedges, i.e. when the finish temperature increases with 30 - 50°C against the set up value of 830°C from the beginning to

Table 1. Heats constitution.

Heat number	Elements, %									
	C	Si	Mn	S	P	Al	Cr	Ni	Cu	N
1	0,191	0,22	0,48	0,013	0,013	0,042	0,05	0,03	0,03	0,007
2	0,176	0,26	0,51	0,017	0,018	0,051	0,03	0,02	0,06	0,008

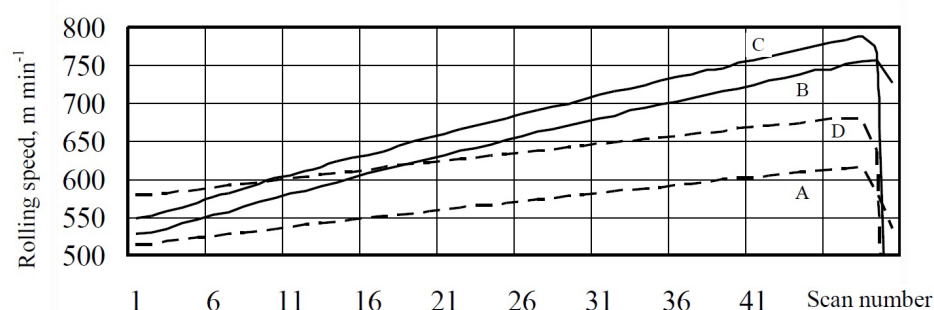


Fig. 2. Rolling speed change along the length of the strips.

the end of the strip.

Version D - the finish temperature along the length of the strip is set up at a constant value of 830°C.

According to these versions, the rolling of 21 strips made of steel Cm3 with the C-section 3.0×1250 mm each for further cutting into sheets was performed. For the lack of metal the rolling according to versions A and B was made through one heat and according to versions C and D it was performed through the other with the same constitution. The same constitution of the heats eliminates its effect on the final mechanical properties of the strips.

The used slabs had the 240×1290 mm C-section. The breakdown thickness was 34 mm. The breakdown temperature before the finishing train was 1034 - 1008°C. Shielding arrangement on the intermediate table was not used. The required finished strip thickness was 3.00 mm, the thickness allowance was ± 0.13 mm. The thickness deviation was under AGC system control. Table 1 presents the chemical composition of the bottoms.

In the process of rolling the following were registered: the distribution of breakdown on the stands, the values of power parameters along the length of the strip, the strip thickness after the twelfth stand, the speed and temperature rolling modes, the sprayer mode.

According to the results of the temperature mode analysis of rolling strips, which were rolled through

each version, the test strips on which the rolling temperature conditions by T_f and T_r were mostly close to the required conditions were selected.

The length of test strips is almost the same (727, 734, 730 and 722 m), which allows the correct comparison of the rolling conditions through scans every 3 m along the length of the strips. During the rolling of the test strip on the version B the acceleration was 0.060 m s⁻², which is 2.3 times higher than when rolling with the T_f along the length of the strip is set up at a constant value (Fig. 2). The T_f increase was 35°C against the set up value of 810°C (Fig. 3). During the rolling of the test strip on the version C the acceleration was 0.066 m s⁻², which is 2.1 times higher than when rolling with the T_f along the length of the strip is set up at a constant value ($a = 0.031$ m s⁻²). The T_f increase was 30°C against the set up value of 825°C with the constant value of T_r (Fig. 4).

The T_r constant along the strips was achieved due to the operation of more semisections of the sprayer (Fig. 5). At the end portion of the strip rolled in mode B 33 semisections of the sprayer were operating, which is 1.7 times more than at rolling with a constant T_f along the strips. Accordingly, on the strip rolled in mode B 38 semisections were operating, which is 1.4 times higher. It should be noted that the technical capabilities of the sprayer were not fully employed. The maximum number of operating semisections was 38 out of 80. The AGC system provided the thickness of strips in the

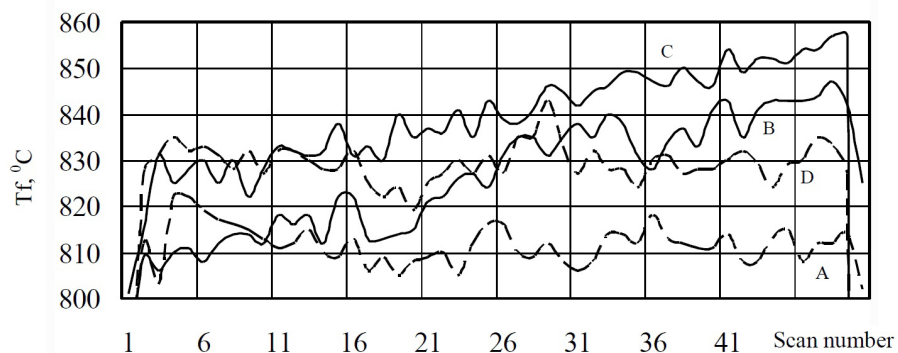


Fig. 3. The temperature distribution along the length of the rolling strips end.

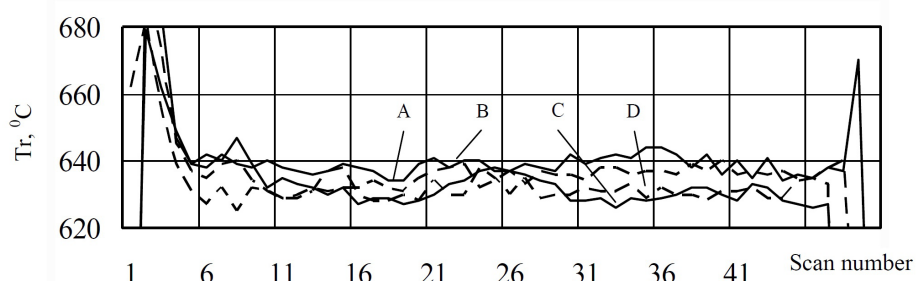


Fig. 4. The temperature distribution along the length of the winding lanes.

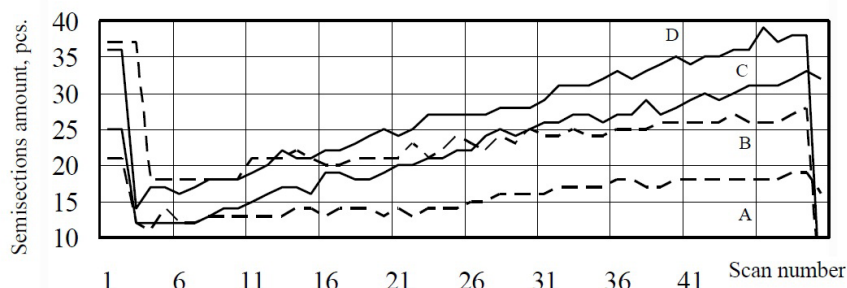


Fig. 5. The amount of included semisections along the length of the strips.

specified range throughout their length (Fig. 6).

RESULTS AND DISCUSSION

It is considered that the main reason for rolling at the constant T_f along the strips is to ensure constant mechanical properties. In order to determine the mechanical properties of the strips on the transverse cutting unit five samples were selected along each test strip. The strip was cut into sheets of 2.5 m long. The samples were taken from the front and rear ends of the strip, and from the middle - after cutting 60 sheets. The distance between the samples was approximately 150 m. The mechanical properties of the material samples

were determined in a certified laboratory.

The pattern of distribution and the yield stress, tensile strength and elongation values along the strips do not depend on the rolling modes during the experiment (Fig. 7). Consequently, the use of increased acceleration values for increasing T_f by 30-50°C from the front end to the rear end of the strip does not lead to significant changes in the mechanical properties.

CONCLUSIONS

On the existing equipment of the hot rolling mill, rolling is carried out with the “inverse temperature wedge” when the rolling end temperature increases

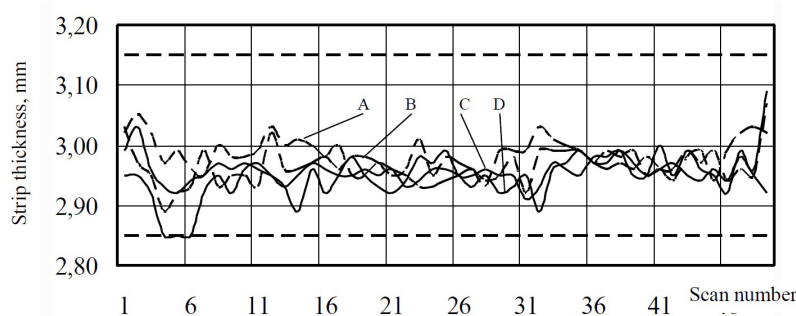


Fig. 6. Longitudinal strips thickness deviation. (--- - thickness allowance).

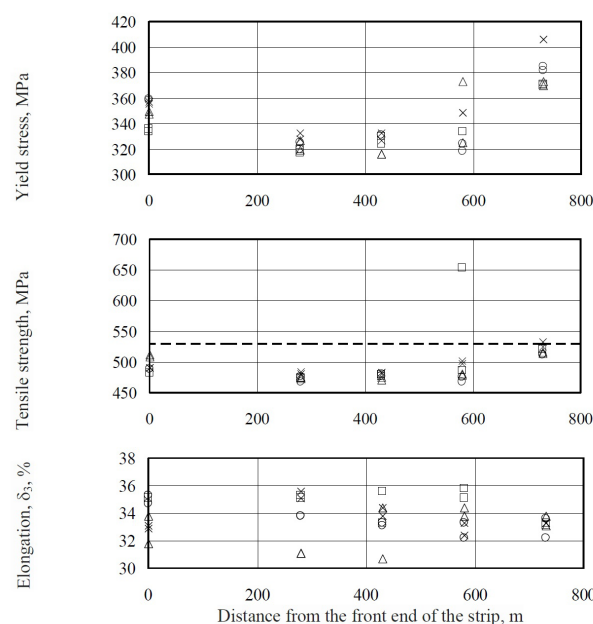


Fig. 7. Mechanical properties of sample strips. (× - rolling mode A; o - rolling mode B; D - rolling mode C; δ - rolling mode D; --- - upper limit of rupture strength for OK360B and OK370B strength groups according to GOST 16523-97).

from the front end to the rear end of the strip.

When rolling with the “inverse temperature wedge” the desired coiling temperature, thickness and non-uniform thickness of strips are provided.

It is not necessary to correct the coiling temperature and the sprayer’s operation mode to provide the required complex of mechanical properties of rolled stock 3.0 mm thick of St3steel.

The use of increased acceleration values to increase T_f by 30 - 50°C from the front end to the rear end of the strip does not lead to significant changes in mechanical properties: yield strength, tensile strength, elongation, and their distribution along the strip.

Rolling with the «inverse temperature wedge» improves the productivity of the finishing train by 2 - 3 % without capital investments.

The rolling technology with the «inverse temperature wedge» is introduced at NLMK 2000 mill.

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