Application of between- stand cooling in the production hot – rolled strips

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ABSTRACT. Medium grain size has been uneven over the length of hot-rolled strips of austenite of low-carbon steel during rolling on continuous mill. Assess the possibilities of metal microstructure of hot-rolled strip stabilization system between-stand refrigeration line. Rolling low carbon strips developed modes with increasing temperature end rolling along the length of the strips and rolling modes using between-stand cooling with variable flow cooling water.
Using this technology mode allows you to get a uniform cooling microstructure of metal strips and cut to length machine time rolling on 14 – 18%. Treatment with an increased acceleration stabilizes the metal microstructure on rolling strips on top of the thread speed and reduces the machine time rolling on 3-9%.

KEYWORDS. Hot rolling mills; Between-stand cooling; Microstructure; Increased cooling acceleration; Mathematical modeling.

INTRODUCTION

The most important indicators of the effectiveness of continuous strip hot rolling mills include performance and mechanical properties of the rolled strip. The use of cooling systems rolled strips, which include cooling between stands of finishing group and accelerated cooling in run-out roller table, to control capacity of the mill, and mechanical properties of hot rolled strips.
On the process of softening metal affect the extent and rate of deformation, temperature, chemical composition of the steel, grain size, time [1]. To ensure a uniform microstructure of the metal leaving the finishing group, the entire length of the strip should maintained the above parameters constant.
When hot strip mill generally accepted strategy for maintaining the temperature of the end of the strip rolling along at a constant level. This consistency provides accelerated finishing train, but there is heterogeneity of the microstructure of the metal from the front to the rear end of the band [2].
One way to stabilize the temperature and the speed limit, and therefore the microstructure and mechanical properties of the metal, is the application of installation Coil box, which requires significant capital investment and reduces the productivity of the mill.

Another way to stabilize the microstructure is the temperature increase by the end of the rolling length of the strip, which compensates for the temperature drop at the entrance to a peal finishing train. Temperature increase can be achieved by the end of rolling two ways that do not require additional capital expenditures:
1) using a rolling with between stands cooling mode for variable-speed distribution of cooling water;
2) rolling with an increased acceleration of finishing group.
Between stands cooling mode with variable flow rates is to reduce the supply of water along the rolled strip. This mode eliminates the rolling acceleration, thereby virtually eliminating the negative effects arising from its use.
Mode with high acceleration to stabilize the microstructure of the metal and reduce the computing time in the production of rolled strips, which increases the rolling speed cannot be applied because of the technical features of the mill. Application of the cooling capacity is limited only by the installation of accelerated cooling strip on the run-out roller conveyor and power parameters of the rolling process in the strips production.

TECHNIQUE TO STUDY THE THERMAL AND STRUCTURAL STATES OF THE METAL

Study of the thermal and structural states of the metal was carried out using mathematical modeling for the conditions of continuous broadband hot rolling mill 2000 "NLMK", Russia.
The mill includes 5 methodical furnaces, roughing group of stands, intermediate roller table with installing thermal screening lag, 7 stands finishing group, run-out roller table with installation of fast cooling strip and coiler area. The finishing group is equipped with a system of cooling the strip which can significantly increase its throughput. The maximum flow rate of cooling water in the cooling system is 1200 m3/h.
Calculation of the temperature strip mill line was carried out using the developed mathematical model of the thermal state of the metal from the issuance of a peal of roughing stands to strip winding into a roll. A mathematical model based on the solution of one-dimensional transient heat conduction Eq. (1) finite difference method.

$$\rho(T)c(T)\frac{\partial T}{\partial \tau} = \lambda(T)\frac{\partial^2 T}{\partial x^2} + q_V \tag{1}$$

where:
ρ is the density of the metal, kg/m^3;
c - specific heat capacity of the metal J/(kg.K);
λ - thermal conductivity of the metal, W/(m.K);
T - temperature of the metal, K;
τ – time, s;
x - coordinate of the strip thickness, m;
q_v - power density heat sources, W/m^3.
Mathematical model takes into account the effect of the screening device of roll, cooling strip in finishing group, heat generation due to plastic deformation of the metal, and polymorphic $\gamma \rightarrow \alpha$ transformation of super-cooled austenite on the thermal state of the metal [3,4]. The model also accounts for the effect of the phase state and chemical composition of the steel on the physical properties of the metal.
A mathematical model of the thermal state of the metal was adapted to the conditions of the mill 2000. Share lanes with an error calculating the metal temperature over 20°C was less than 2 %.
The calculation of the microstructure of the metal in the rolling mill finishing train carried by mathematical models recrystallized austenite low carbon steel grades set out in [4-8]. The calculation of the microstructure in finishing train was limited to the determination of the recrystallized volume fraction and the average grain size of austenite along the strip.

HOT STRIP ROLLING WITH USING THE BETWEEN STANDS COOLING

Influence of the cooling for formation of cooling metal microstructure

Investigation of the effect of cooling in finishing group on the structural state of the metal made in modeling for the strip 3x1250 mm of steel grade 08U of the mill in 2000 for four modes is shown in Tab. 3. The chemical composition of the steel is shown in Tab. 1. The deformation mode in finishing group is shown in Tab. 2.

Temperature-speed (t-s) mode and the water flow through the between stands cooling section for test modes are presented in Tab. 3.

Al	Cu	Mn	N	P	S	Si
0.045	0.037	0.186	0.003	0.008	0.10	0.015

Table 1: Chemical composition of steel 08U (%).

In Tabs. 2 and 3:
h*p*, h*sp*, h*6* -h*12* – metal thickness after: roughing group; descaler; stands of finishing group, acc.;
t*p* and t*f* – metal temperature before and after finishing group, acc.;
V*s* and a - thred speed and acceleration in finishing group, acc.;
Q*1* – Q*6* – finishing stands gaps acc.

	h_p	h_{sp}	h_6	h_7	h_8	h_9	h_{10}	h_{11}	h_{12}
Thichness,mm	34.7	34.0	20.3	12.5	8.4	5.89	4.45	3.45	3.00
Relative Reduction, %	-	9	0.3	8.5	32.8	29.9	24.4	25.5	13.1

Table 2: The deformation mode in finishing group rolling for strip 3x1250 mm, steel 08U.

№ of regime	Rolling parameters					Water slow, m^3/h					
	t_p, °C	t_f °C	Vs, m/s	a m/s^2	τ_m, s	Q_1, m^3/h	Q_2, m^3/h	Q_3, m^3/h	Q_4, m^3/h	Q_5, m^3/h	Q_6, m^3/h
1	1000	840	8.97	0.026	87.4	0	0	0	0	0	0
2	1000	840	11.95	0.026	68.8	200	200	200	200	200	200
3	1000	840	10.25	0.026	78.4	200	200	200	0	0	0
4	1000	840	10.25	0.026	78.4	0	0	0	40	200	200

Table 3: Technological parameters of studied rolling regimes with between stand cooling.

Length of hot-rolled strip is 884 m. The research results are presented in Fig. 1.
According to the study, the primary recrystallization process time to get fully only in the first three gaps [9] on all four modes (Fig. 1.a).
Recent the between standing cooling does not have time for fully recrystallizing of austenite grain and growth is difficult (Fig. 1.b). The share of the recrystallized volume and average grain size of austenite. Fig. 1 shows the entry point for the front end of the strip in the deformation and at the end of the pyrometer for the temperature of the end of rolling.
Application cooling (regime 3) reduces the average grain size of austenite at the exit of the stands and thus improve the mechanical properties of the metal. In regime 2 on the average grain size in the central layers of the band decreases from 18.1 to 16.9 mcm for the front end (Fig.1c) and from 15.9 mcm to 15.3 for the rear end (Fig.1.d) than with number 1. Reducing the size of the austenite grain from the front to the rear end of the strip associated with the use of acceleration in the finishing train (breaks are reduced in the process of rolling) and a constant temperature by the end of the rolling length of the bar in the presence of a temperature "wedge" at the entrance to the finishing group.
Application cooling mode at number 3 lowers the temperature of the metal in the last gap, which leads to a decrease in the average grain size at the exit of the mill.
As opposed to the regime number 3, in the last three cooling intervals (mode number 4) gives the average grain size of austenite grain size is close to rolling without cooling (mode number 1) at the same speed mode.

Thus, the cooling section should be included, since the last finishing stand. By increasing the thickness of the final sections of the rolled strip inclusion cooling should be transferred to the latter gap to the first, to minimize the heterogeneity of the austenite grain on the strip thickness and suppress the recrystallization process during long pauses.

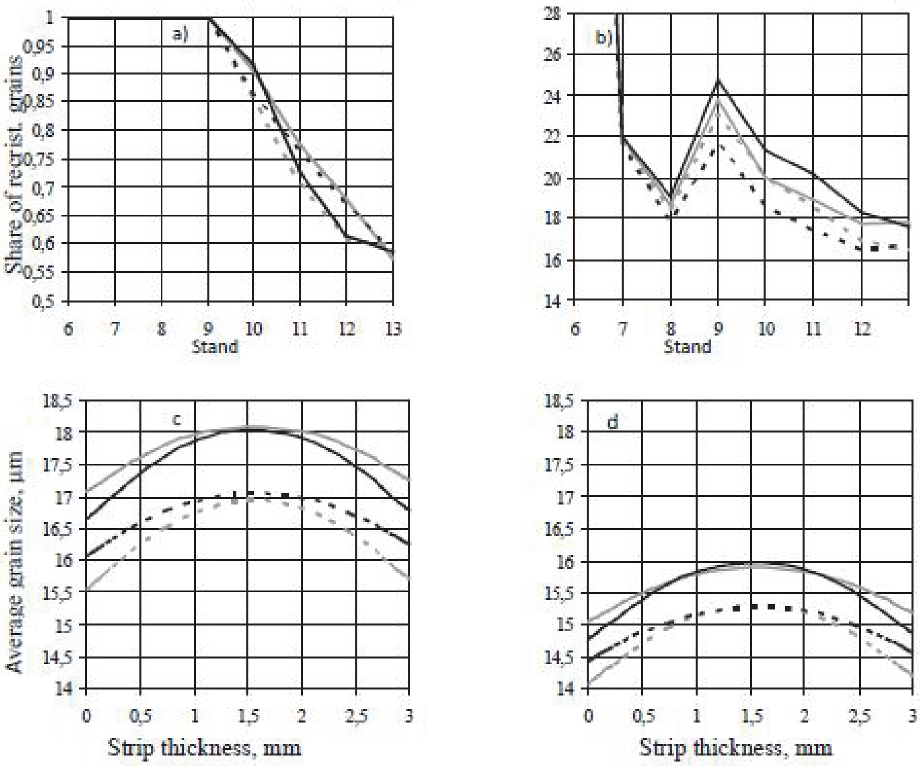

Figure 1: Comparison of the structural state of rolled strips using between standing cooling.

Development of hot strip rolling regimes

According to studies by rolling strips 3x1250 mm of steel 08U constant finishing temperature tf = 840°C, the temperature after roughing stands tr = 1000°C, thred speed Vth = 9 m/s and acceleration a = 0.026 m/s2 decrease in the average grain size of austenite along a strip in finishing train was 2.3 microns. Change the size of the austenite grain along the strip leads to uneven metal microstructure after winding into a roll. According to the Hall-Petch equation decrease in grain size increases the yield strength and ultimate strength along the length of finished hot-rolled strips.

In order to stabilize the microstructure of the metal strip along the rolling schedule is calculated using betweenstand cooling with variable flow of cooling water. Stabilization of the microstructure of the metal can reach the end of rolling temperature increase of 7°C during rolling acceleration without finishing group and with a rolling speed Ve = 11.2 m/s. The drop in temperature at the inlet to peal finishing in the rolling process is compensated by the change of the total water flow in the cooling system betweenstand band from 840 m^3/h to 0. Water flow in the system QMKO changes synchronously to each gap. Comparison of existing and design modes hot rolling is shown in Fig. 2.

Rolling without acceleration in the finishing train almost completely stabilize the cooling conditions of the band on the run-mill roller table. Temperature increase by the end of the rolling length of the bar and the stabilization conditions of accelerated cooling can solve the problem of a uniform microstructure of metal for a significant proportion of the bands mix mill 2000.

Application between stand cooling of size bands and temperature regimes rolling limited to a maximum filling rate band, which for the mill 2000 is 12.5 m/s. This level is the maximum speed of a gas due to the necessity of accident-free transportation of the front end of the strip to a discharge roller conveyor mill due to the aerodynamic effect.

Stabilization of microstructure metal along bands which use rolling betweenstand cooling impossible can be achieved with high values of acceleration of finishing group.

The task of rolling mode destination, depending on the thickness of the strip and the required temperature level to the end of the rolling mill 2000 mix resolved on the basis of the developed mathematical model of the thermal state of the metal.

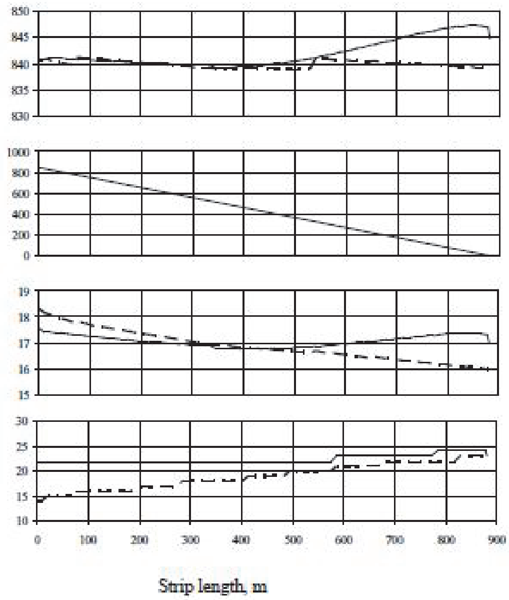

Figure 2: Calculated parameters of hot rolling and accelerated cooling. Strip 3x1250 mm of steel 08U (tr = 1000°C, Vth = 9 m/s, a = 0,026 m/s, tf = constant (840°C), cooling temperature (tc) + 640°C, QMKO = 0; tr = 1000°C, Vth = 11,2 m/s, a = 0, tf = constant, QMKO = constant, tc = 640°C; in Fig. 2A, - water slow in Fig. 2B, m^3/h; Fig. 2C – average grain size after finishing group, mcm, in Fig. 2C and number of cooling units in Fig. 2D).

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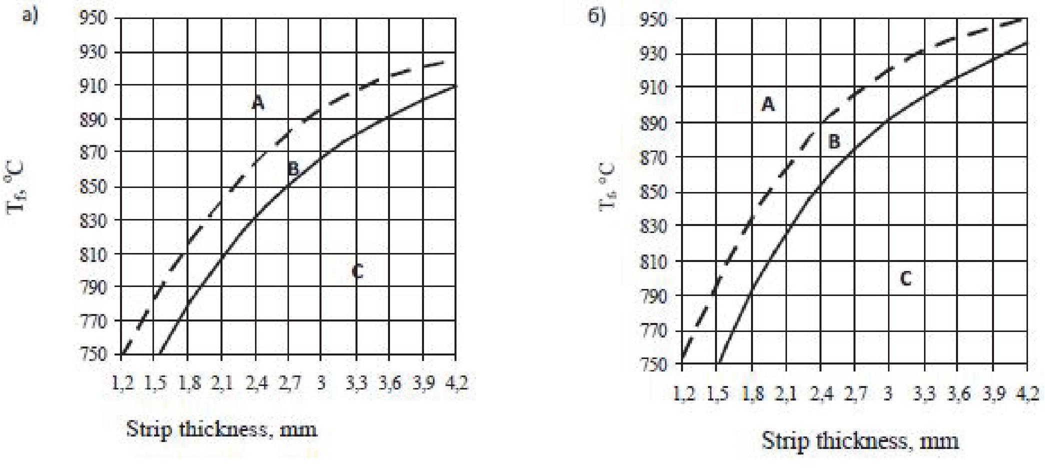

Figure 3: Assignment mode rolling strips in finishing group: a) tr = 1000°C; b) tr = 1030°C. (A - unreachable area, B - rolling with hither acceleration, C - rolling with QMKO = var).

In the rolling low carbon the strips thickness regime using cooling with variable flow water temperature increment of the end for rolling thin strips was 7-8°C and for thick strips thicker than 4.2 mm - 16-18°C. Machine time rolling of strip thickness over 2,7 mm decreased by 14-18 % compared to the rolling on the regime without cooling.
In the rolling strips of low carbon steel on the regime with an increased acceleration without screening peal at the intermediate roller table stabilizing metal microstructure at the exit of finishing train can reach the end of rolling temperature increment equal 13-17°C, with rolling of strip thickness less 2,5 mm using a screening of roll increment is 6-10°C. Rolling schedule with high acceleration can reduce the rolling machine time by 3-9 %, depending on the thickness of the strip.

CONCLUSIONS

A regime of hot-rolled strips of low-carbon steel with increasing temperature for the conditions of the end of rolling continuous wide 2000 hot rolling mill "NLMK" is developed that improve the performance of the mill and stabilize the microstructure of the metal along the hot-rolled strip, in contrast to the existing regimes.
Stabilization of the microstructure is achieved by increasing the temperature tf at 6-10°C when rolling of strip thickness less 2.5 mm, and at 13-18°C wen rolling of strip thickness over 2.5 mm.
The rolling of strip using between stands cooling with variable water flow leads to reduction of the rolling machine time by 14-18 %, according to the regime with an increased acceleration - by 3 - 9 %.

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