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# THERMOMECHANICAL TREATMENT OF REINFORCING STEEL

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## Abstract

*The work deals with application of interstand and afterdeformation cooling of coiled (∅10, 12 mm) and reinforcing (∅14,16 mm) bar steel in the accelerated cooling installations behind the prefinishing and finishing stands of the light-section mill which provides the formation of the even fine-grained ferrite-perlite structure and reduces grain growth in the mid section of the coil. The application of the roll stock interstand cooling behind the 11$^{th}$ stand together with the afterdeformation accelerated roll stock cooling to 800-850$^{0}$C enabled us getting reinforcing bar steel diameter ∅14mm with high impact strength..*

*Keywords:* thermomechanical treatment, reinforcing steel

## 1. Introduction

Some research works [1 - 4] demonstrate that even fine-grained structure and increase in steel mechanic properties can be achieved in two ways:

a) Introduction of the powerful carbide-forming elements and microalloying additions during steelmaking in combination with strict cycles of plastic deformation and braking of austenite recrystallisation at the expense of it;

b) Rolled stock cooling in interdeformation pauses for reducing the temperature at the end of rolling and a controlled afterdeformation cooling, impeding recristallisation.

The main advantage of the second method are economical reasons and a possibility to increase perfomance characteristics of low-carbon steels.

The main condition of realization of the technological process of thermal strengthening is working-out of coolers providing intensive rolled stock cooling combined with its hydrotransportation on the site where the coolers have been installed at the rolling speed up to 20 m/s.

The purpose of this work is to find ways of obtaining looping reinforcing steel diameter ∅10-16mm St3sp (GOST 380-71) with even fine-dispersed structure and increasing the mechanical properties by interstand rolled stock controlled cooling.

## 2. Experimental

For this purpose accelerated cooling installation has been worked out consisting of injecting funnel 1, cooling stand 2, injector 3 (Fig.1). In the case of direct-flow cooling, a cutter 4 is used.

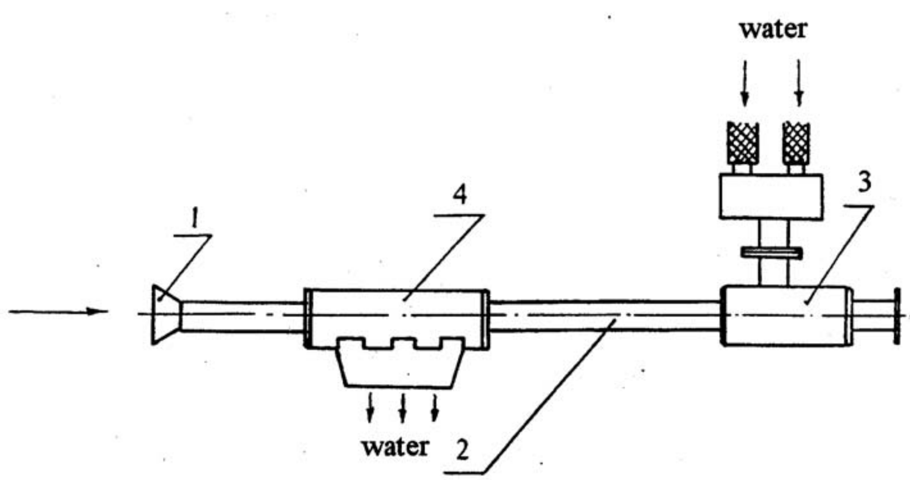



*Fig 1. Accelerated cooler scheme*

It is installed in the place of the outlet pipe behind the 11$^{th}$ stand and attached to the outlet bar. A cooling stand is a pipe with the inner diameter 40 mm and 1500 mm in length, which provides required cooling of rolled-stock to the calculated temperature and its safe hydrotransportation.

Injector is a sealed case inside of which a roll cone with two cams moves its purpose is generation of required water blow velocity in the cooling stand.

The passing hole diameter for the metal inside the case is 40 mm. A ring-shaped gap is installed on the injector depending on the rolled-stock diameter and for the required cooling rate in the cooling zone. It provides the necessary water consumption at the continuous pressure at the injector's inlet.

An inlet roll cone is used for rolled-stock reception and directing it to the cooling zone. It is a funnel-shaped hole changing into a cylindrical one (diameter is 40mm).

The cutter is used to reduce the water flow velocity and for water dascharge. It's a pipe with conical wires inside. There are holes at the bottom of the pipe for water discharge.

One side of the cut-off chamber is attached to the cooling stand, another one is attached to the inlet roll cone. The counter flow device for accelerated cooling is used for after-deformation cooling. It consists of an injector (like the one described above), a cooling chamber (length – 480 mm) with the inner diameter 40 mm; and the injecting funnel.

The cooling device is installed behind the $13^{th}$ finishing stand when rolling reinforcing bar steel 14-16mm in diameter.

The rolled stock accelerated cooling installation is connected with the high-pressure pipe by means of flexible hose and lock-device.

## *2.1. Process flow diagram*

Process flow diagrams of making coiled and reinforcing bar steel have been developed and tested. Diameters are 10, 12, 14, 16 mm respectively.

Metal rolling to the $11^{th}$ stand was made according to the existing technology. From the 11 stand, a process workpiece (diameter 16 mm) goes to the cooling chamber, then to the stands 12, 13, 17, 19, where is deformed with drawing $\lambda$=1.17; 1.18; 1.17; 1.18 respectively (for ∅10). For ∅12 mm diameter drawing in stands is 1.2; 1.168; 1.203; 1.17 respectively. Total drawing is $\lambda_{10}$=1.938 and $\lambda_{12}$=1.954. Later rolled stock is being coiled. When making steel 10 mm in diameter, two rates of stand's cooling were investigated: the first - to cooling temperature of 920°C, the second - to the temperature of 950°C and the third  hot-rolled state (for comparison). The temperature of hot-rolled steel is 1050°C. The coiling temperature is 1010°C in the first case and in the second one 1010-1020°C.

Reinforcing bar steel 12 mm diameter was thermal strained – under two rates: the first – to 950°C, the second – to 980°C, which were compared to hot-rolled state (without cooling) rolling temperature of 1050°C.

The coiling temperature is 1020°C in the first case in the second one -1030°C and of hot-rolled coil - 1050°C.

The conditions of production of reinforcing bar steel enable putting into practice the most perspective kinds of thermal strain. It means that accelerated steel cooling in interdeformation pauses and after deformation to the initial temperature of phase transformations. This method decelerates process of deformed austenite recrystallisation and results in production of fine-grained structure, defining the high level of mechanical properties including impact strength at low temperatures.

Reiforcing bar steel's rolling rates (∅14 mm), with controlled inferstand and after-deformation cooling, were investigated using two accelerated cooling devices; the first counter flow installation 1500 mm length is behind the 11$^{th}$ stand; the second counter-flow (480 mm) is behind the prefinishing stands (12$^{th}$, 13$^{th}$). Process workpiece have been cooled in the counter flow accelerated cooler after deformation in the 11$^{th}$ stand to certain temperature, then it passed to 12$^{th}$ and 13$^{th}$ stands and was deformed with drawing $\lambda$=1.2; 1.68 respectively.

Steel was directed to the second cooler from stand 13$^{th}$ with three cooling rates 840 → 750-770°C; 920 → 840-820°C; 950 → 940°C (under this rate water was not directed into the second cooler).

A controlled afterdeformation cooling to temperature 800-780°C may be used at reinforcing bar steel production 16mm in diameter. These temperatures prevent recrystallisation processes at full rate.

By means of the device described above the conditins of fittings (∅16 mm) rolling were investigated to minimum possible temperatures (from 870 to 970°C).

Utilization of reinforcing steel technology using counter flow accelerated coolers behind stands 11$^{th}$ and 13$^{th}$ affords to reduce metal temperature and to equalize it according rolled stock's length and plane.

### *2.2. Metallographic examination of reinforcing steel*

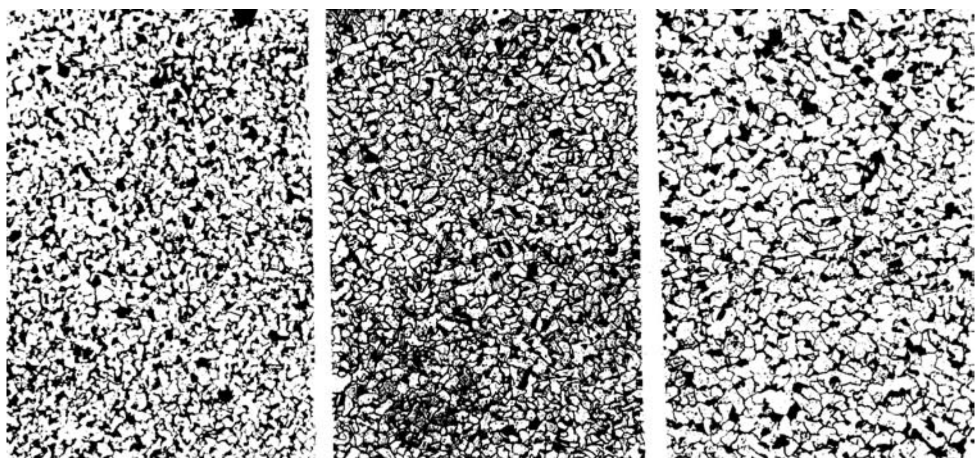
The structure of hot-rolled reinforcing steel St3sp diameter 10, 12, 14 mm is ferrite- globular perlite grains corresponding to scale number 8-9 GOST 5639-82 (Fig.2). Ferrite-perlite percentage is F-90% P-10%.

Perlite is thin-plated (distance between cementite is 0.3-0.8 μm) and placed on ferrite grains joints.

Interstand steel cooling (diameter ∅10-14mm) to temperature 950°C results in slight perlite phase growing (F-85%, P-15%) (Fig.3).

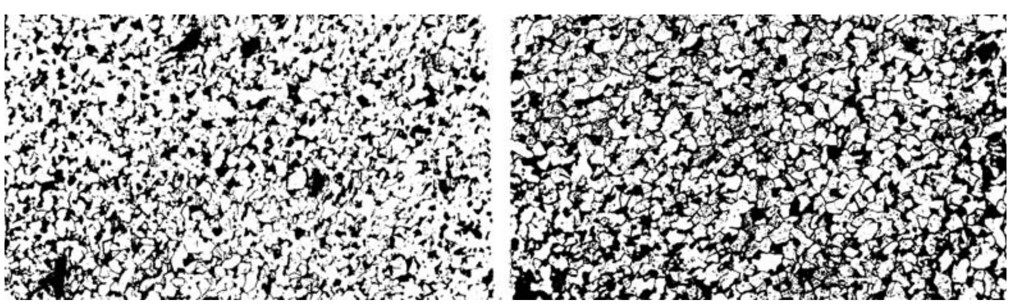
Perlite grains are placed on joints and partly on ferrite grains boundaries. Grain size corresponds of scale number 9 GOST 5639-82. Perlit dispercity is 0.3-0.5 μm (GOST 3443-87 at 500- multiplegrowth ).

Interstandand afterdeformation reinforcing steel cooling (cooling temperature in injector $1^{st}$ 920°C, in injectior $2^{nd}$ – 820-840°C), steel diameter ∅14 mm changes greatly perlite dispersity to 0.3 μm (Fig. 4a,b). Grain size corresponds of scale number 9 GOST 5639-82. The sharp cooling (cooling temperature in injector $1^{st}$ is 840°C, in the other one is 750-770°C) results in steel structure grinding (Fig. 4c,d).



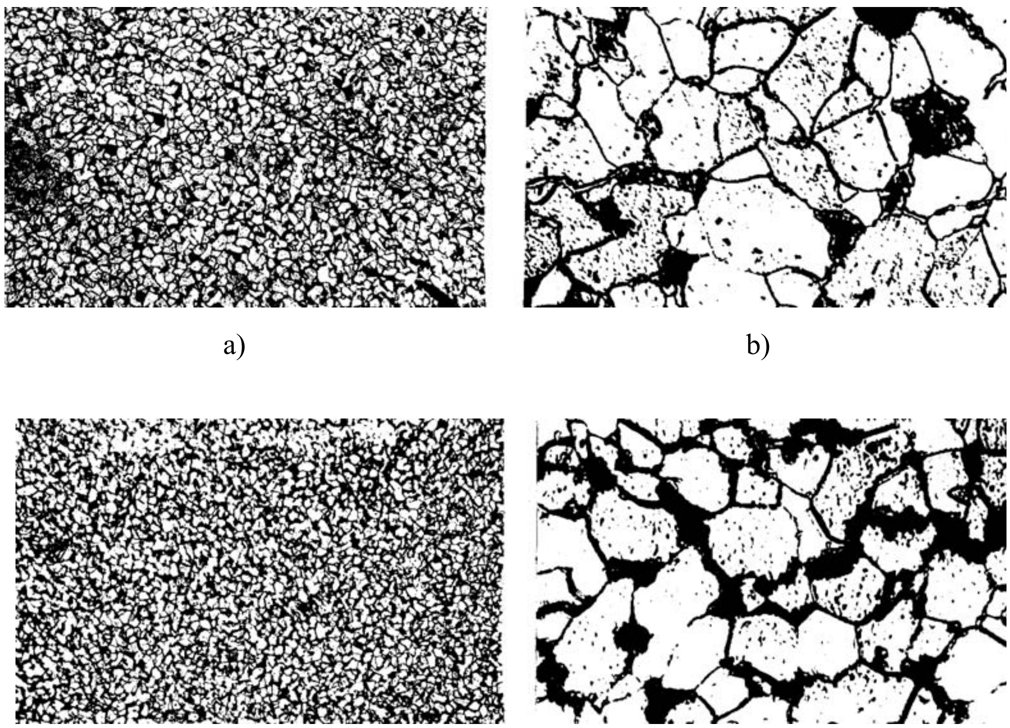
a) b) c)

*Fig. 2. Steel microstructure St3sp diameter ∅10 (a), ∅12 (b), ∅ 14 (c) in hot - rolled state. Magnification x100*



a ) b)

*Fig. 3. Steel microstructure St3sp diameter ∅10(a), ∅12(b) mm rolled with interstand cooling to 950°C. Magnification x100*

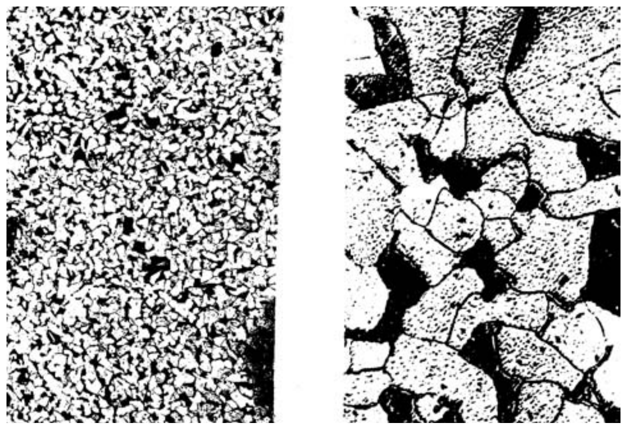


a) b) c) d)

*Fig 4. Steel microstructure St3sp diameter ∅14mm rolled by means of inferstand and afterdeformation cooling (Magnification: a, c - x100; b,d - x800):*
*a, b - interstand cooling to $940^0$C and afterdeformation accelerated cooling to $840^0$C.*
*c, d - interstand cooling to $840^0$C and afterdeformation accelerated cooling to $740^0$C.*

Even-grained ferrite - perlite structure can be observed on the polish section plane. Graine size corresponds to scale number 10-12. Perlite grains are placed along ferrite grains' boundaries. Ferrite percentage is 80%, perlite percentage is 20%. Perlite component dispercity increases (less than 0.3 mm at increase 500)

Steel cooling (∅ 16mm) after deformation to the temperature 920-980$^O$C results in slight grain grinding (Fig 5). Perlite-ferrite grain size corresponds to scale number 8-9.Perlite placed on ferrite grains joints is thin-plated (to 0.3 μm). Ferrite percentage is 85%, perlite is 15%.



a) b)

*Fig 5. Steel microstructure St3sp diameter ∅16mm after rolling and accelerated cooling to $920^0$C (Magnification: a - x100, b - x 800)*

## 3. Conclusion

Interstand and afterdeformation cooling of hot-rolling steel St3sp diameter 10-16 mm affords to influence greatly the quality of rolled stock at the expense of reducing of metal temperature and equalizing on the process workprice length and plane. The high level of mechanical properties and impact strength at low temperatures is achieved as a result of even fine-grained structure formation.

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