Study of the microstructure of the pipe steel after rolling in the plate mill 5000

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Abstract. The article is devoted to an experimental study of the influence of thermo-mechanical processing parameters on the microstructure of pipe steel. Rational temperature-time modes of hot rolling and parameters of accelerated cooling, which allow obtaining a structural state that ensures the achievement of the required complex of consumer properties were determined.

1. Introduction
Currently, the main trend in the ferrous metallurgy is to reduce alloying and achieve the required properties of products due to precise control of the material structure [1-3]. The distribution of velocities and modes of reduction, rolled stock cooling and other factors are little used for normalization during the production of ordinary grades of steel in the hot rolling mills. This normalization is important because the processes of structure formation occur in almost all parts of the rolling mill, and for the implementation of the defined structural states, strictly regulated thermo-mechanical processing of the material is required [4-11].

The controlled low-temperature rolling is used to increase the blow toughness and to improve the surface quality of pipe steels. At a regulated rolling process, pauses are widely used in rolling modes. The use of regulated cooling between deformations allows approaching to the modes of thermomechanical processing and two-phase rolling in the finishing block of deformations, which significantly expands the capabilities of the rolling mill in obtaining high consumer properties of products. According to the set of the required consumer properties of pipe steels, it is necessary to have microscopic structures in the finished product obtained at high cooling rates: upper and lower bainites and martensite. Since the temperature field of the rolled product is very uneven during cooling, the task of obtaining the required structural state in certain parts of the finished product, for example, in the surface layers, can be set.

The aim of the work is to study the possibilities of the equipment of a rolling mill 5000 to achieve temperature and deformation modes, allowing obtaining the required properties of the final product by ensuring a rational cooling path.

2. Methodology
A series of experimental rolling of 5 slabs to a final thickness of 27 mm were performed. For further
research samples were taken from each of the rolled sheets. Mechanical properties were determined and the structural condition of the specified volumes of finished rolled product was certified. Mill process analysis system operates with two main electronic documents containing technological information about rolling [15]. To check the reliability of the data included in the passport, the information stored in the Level 1 database of the APCS system was used. This information is the initial, formed by processing the data of the first level on the basis of specialized algorithms. The Level 1 database records the system information about the metal tracking. The dependence of the coordinates of the head part of the metal on time for each unit located on the mill line is being recorded.

The temperature and time modes of experimental rolling on a thick plate rolling mill 5000, starting with the issuance of the metal from the furnace and ending with its exit from the accelerated cooling line, are presented in the table. The process of the pipe steel rolling includes the following operations: heating of the plates to a temperature of 1172-1178 °C.; their excerpt at the roller table during 80-160 s.; 6-pass roughing rolling on a reversing rolling mill; pause between deformation (BDP) during 500-1750 s.; finish rolling with 18-20 passes during 170-300 s; exposure of the workpiece on a roller conveyor 2 and accelerated cooling in a specialized line within 30-60 s.

Table 1. Temperature-time modes of experimental rolling

| Operation               | The surface temperature of the rolled metal, °C | Duration, s | Cooling rate, °C/c |
|-------------------------|-----------------------------------------------|-------------|-------------------|
|                         | Beginning | End       |                  |
| Mode 1                  |           |           |                  |
| Warming                 | 15        | 1177      | 4597             | 0,25              |
| Rough rolling           | 1037      | 990       | 63,30            | 0,74              |
| Pause                   |           |           | 1662,60          | 0,15              |
| Finish rolling          | 748       | 764       | 337,35           | 0,05              |
| Accelerated cooling     | 740       | 548       | 33,62            | 5,71              |
| Mode 2                  |           |           |                  |
| Warming                 | 15        | 1175      | 5331             | 0,22              |
| Rough rolling           | 1044      | 992       | 61               | 0,85              |
| Pause                   |           |           | 1716             | 0,15              |
| Finish rolling          | 742       | 780       | 200              | 0,19              |
| Accelerated cooling     | 736       | 521       | 60,50            | 3,55              |
| Mode 3                  |           |           |                  |
| Warming                 | 15        | 1178      | 4452             | 0,26              |
| Rough rolling           | 1036      | 977       | 63,40            | 0,93              |
| Pause                   |           |           | 534,57           | 0,17              |
| Finish rolling          | 885       | 918       | 177,55           | 0,19              |
| Accelerated cooling     | 867       | 679       | 40,08            | 4,69              |
| Mode 4                  |           |           |                  |
| Warming                 | 15        | 1172      | 4285             | 0,27              |
| Rough rolling           | 1045      | 984       | 66,23            | 0,92              |
| Pause                   |           |           | 1198,77          | 0,15              |
| Finish rolling          | 799       | 853       | 178,87           | 0,30              |
| Accelerated cooling     | 805       | 637       | 33,59            | 5,00              |
| Mode 5                  |           |           |                  |
| Warming                 | 15        | 1172      | 4328             | 0,27              |
| Rough rolling           | 1025      | 969       | 60,55            | 0,92              |
| Pause                   |           |           | 1112,83          | 0,15              |
| Finish rolling          | 800       | 831       | 185,83           | 0,17              |
| Accelerated cooling     | 777       | 602       | 61,60            | 2,84              |
3. Results and discussion

The structure of the rolling sheets for 90-95% consists of ferrite (F), upper and lower bainites (UB and LB) and martensite (M). The remaining volume is perlite (P), carbides, nitrides, carbonitrides and martensite-austenite. The volume fractions of M and LB decrease from the surface to the centre of the sheets, while the volume fractions of F and P increase in this direction.

The metal of all five experimental modes is characterized by a different-grain ferrite component, which may be due to the partial implementation of the conditions of the process of recrystallization of austenite in the rolling mill line. A common feature of the structural state is that the average size of F grains in the metal layers located at a distance of up to 4 mm from the upper and lower surface of the sheet is 1.2–1.4 times smaller than the average size of ferrite grains located in deeper layers.

The metal, rolled in all modes, except the third, is characterized by a striped structure, expressed in significant elongation areas, containing M, UB, LB and carbides. These regions have a visually distinct boundary with a ferrite matrix. It should be noted that the striped structure is much less pronounced in the central layers of the rolled products. The sheet rolled according to regime No.3 is characterized by a higher temperature of finish rolling; the striped structure is weakly expressed already in the near-surface layers, and in the central layer it is practically absent.

An important experimental result is that the increase (about 2 times) of the time of passage of the line of accelerated cooling, with a constant mode of heat removal from the metal surface (the scheme of inclusion of nozzles) leads to an increase in the volume fractions of UB and, especially, LB throughout the cross section of the sheet, thereby increasing the average value of microhardness (see figure 1).

![Figure 1. Structural state of rolled sheets mode No. 3, 1 mm from the bottom surface of the sheet (a), Hv$_{100}$=206, F+P; mode No. 5, 1 mm from the bottom surface of the sheet (b), Hv$_{100}$=244, F+P+UB+LB; mode No. 3, the central layer (c), Hv$_{100}$=214,F+P+UB; mode No.5, the central layer (d), Hv$_{100}$=214, F+P+UB.](image)

The increase in the volume fraction of LB is due to the more complete flowing of the process of austenite disintegration during accelerated cooling. This is confirmed by the dimension of the values $t = \frac{\Delta T}{\tau_o}$, where $\Delta T$ is the decrease in the temperature of the layer surface as a result of accelerated cooling, °C/s; $\tau_o$ is the time of passage of the accelerated cooling line, s.
For mode No. 5 $t=2.82$, while for mode No. 2 with almost the same $\tau_0=60c$ (see table), $t=3.55$. The decrease in the cooling rate in the case of mode 5 is explained by the heating of the metal layers as a result of the thermal effect of the process of austenite decay [12].

4. Summary
According to the results of a series of experimental rolling of plates to the final thickness of 27 mm, the values of a number of significant technological parameters are set, compliance with which allows obtaining the required mechanical properties of the strips:

- the surface temperature of the metal at the beginning of the finish rolling is 800-820 °C;
- the time of passage of the line of accelerated cooling is 60–63 s;
- the surface temperature of the sheets at the exit of the line of accelerated cooling is 600-620 °C.

Compliance with these parameters leads to an increase in the volume shares of the upper and, in particular, the lower bainite throughout the section of rolled products.

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