Determination of temperature conditions for steel plate rolling at Vyksa Steel Works (AO VMZ)

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Abstract. This article describes the working process of OMK Heavy Plate Mill 5000. Based on the fabricator’s facilities capability, the technological production flow diagram of thick steel sheets of K60 (X 70) grades, for cold-working large diameter pipes has been developed. As the initial blank authors used a 310×2.100×3.170 mm plate slab. The controlled rolling process, described in the article, consists of two stages – roughing-down (when deformation and re-crystallization results in obtaining fine uniform austenite grains) and finishing rolling (when austenite is hammer-hardened and converted into fine-grain ferrite). As a result of the research has been selected and the optimal temperature conditions for rolling in the passes, which would reduce the waste of metal in furnace.

1. Introduction

There is a significant demand for the thick steel sheets in the modern-day mill products market. Thick steel sheets are used for high diameter gas pipes, which has special requirements for homogeneity of the structure, increased requirements for strength and surface quality. The main factor to attain the required quality specifications is the metallurgy production process [1-5].

Over the last 10 years modern plate mills have been built to completely cover the demand for the thick plates for large-diameter pipes, ship- and bridge-building industry needs. A vivid example of this is Heavy Plate Mill 5000 at Vyksa Steel Works. The Vyksa Steel Works Heavy Plate Mill 5000 manufactures the products for both internal and export markets. The rolled plates are mostly used to manufacture large-diameter pipes.

The Mill is capable of manufacturing flat products of different strength class pipes – К60, К65, К70 (X70, X80, X100, X120), including the pipes for seismic areas and underwater pipelines [6-8].

Steel manufacture process provides sequential execution of the following operations:
1. Scrap metal charging into the basic oxygen furnace in amounts of 18-22 % of the total heat metal charge.
2. Hot metal pouring into the basic oxygen furnace.
3. Metal lancing in the furnace using the process oxygen supplied through the lance with the simultaneous metal lancing with neutral gases (nitrogen, argon) through the bottom lances and addition of slag-forming materials to the furnace.
4. The temperature change and metal and slag sampling upon the lancing completion.
5. The heat tapping out of the furnace to the steel-pouring ladle with the addition of the decarburizing and de-oxidizing agents (ferroalloys ensuring the hot metal production with the chemical composition close to the average composition for this steel grade).

6. The hot metal treatment with argon in the steel-pouring ladle (out-of-furnace processing) is performed to average out and update the chemical composition and temperature.

The entire cycle of one liquid metal heat production using this method takes 40 to 60 minutes. The plate slabs are produced by means of liquid steel pouring at the steel continuous casting unit [9]. Requirements to the thick steel plates for large-diameter pipes for high-pressure main gas lines are defined by the pipe specifications defined in GOST 19903-74 Hot-rolled steel sheets. Dimensions [10].

2. Objects and methods of research

In this work to produce cold-resistant large-diameter gas line pipes 10Г2СФБ Steel was used. This Steel is brought in compliance with K60 strength class and GOST 10705-80 Electrically welded steel tubes. Specifications [11].

Chemical composition of this steel grade is provided in Table 1.

Table 1. Chemical Composition of 10Г2СФБ steel for cold-resistant large-diameter gas line pipes.

| Steel Grade | Element Contents, % |
|-------------|---------------------|
|             | C  | Si  | Mn  | Ni  | S   | P   | Cr  | V   | Cu  |
| 10Г2СФБ     | ≤ 0.13 | 0.25–0.5 | 1.3–1.8 | ≤ 0.3 | ≤ 0.02 | ≤ 0.025 | ≤ 0.03 | ≤ 0.01 | ≤ 0.3 |

The main tasks of pre-rolling heating are metal strength properties’ reduction, process plasticity improvement and uniform temperature field provision. The mode of the plate slab pre-rolling heating shall be selected based on the steel chemical composition, its quality specifications, furnace heating power and equipment power specifications. As per the conventional ideas low-carbon steel plate slabs must be heated to 1220–1250 °C [12-15].

Mechanical properties of steel are provided in Table 2.

Based on the conventional technology thick plate rolling from low-alloy carbon steels is finished in austenite region, however, as the technology of micro-alloy steel controlled rolling is implemented it has become possible to reduce the heating temperature to 1150–1180 °C. Besides, the heating temperature reduction promotes the reduction of the metal wastes in the furnace [16, 17].

Proceeding from the above, let us admit the plate slab pre-rolling heating temperature equal to 1180 °C.

Table 2. Mechanical properties of 10Г2СФБ steel for cold-resistant large-diameter gas line pipes.

| Steel Grade | Strength Class | Pipe Diameter, mm | σu, MPa | σt, MPa | δ5, % |
|-------------|---------------|-------------------|---------|---------|-------|
| 10Г2СФБ     | K60           | 1420              | 590     | 460     | 20    |
Let us select the initial blank weight and dimensions. Steel used for the calculation: 10Г2CФб, strength class – K60. The transverse rolling pattern was selected
Finished plate geometrical dimensions:
− plate thickness −23 mm;
− plate width −4,500 mm;
− length − 20,060 mm;
− weight (cut off) −17.0 ton.
The plate slab weight is calculated using the following equation (1):
\[ G_{sl} = I_c \cdot G_{fp} \] (1)
where
\( I_c \) – consumption index;
\( G_{fp} \) – finished plate weight, t.
\[ G_{sl} = 1.099 \cdot 17.0 = 18.7 \text{ t} \]

As per the data for Russian and foreign companies, to produce preset thickness plates as-cast slabs with the thickness of min. 250 mm are used.
As the initial blank we use a 310×2.100×3.170 mm plate slab. Now let us determine the rolling temperature mode.
The controlled rolling process consists of two stages – roughing-down (when deformation and recrystallization results in obtaining fine uniform austenite grains) and finishing rolling (when austenite is hammer-hardened and converted into fine-grain ferrite). Recommended rolling temperature ranges for K60 strength class steel are provided in Table 3.

**Table 3. Recommended rolling temperature ranges.**

| Pre-rolling heating temperature, °C | Roughing-down end temperature, °C | Finishing rolling start temperature, °C | Rolling finish temperature, °C |
|-----------------------------------|-----------------------------------|----------------------------------------|-------------------------------|
| 1150 – 1180                       | 1150 – 1180                       | 820 – 850                              | 780 – 800                     |

The temperature variation temperature is calculated in stages, separately for each thickness value.
The temperature before each pass is calculated using the equation provided by G.P. Ivantsov [12]:
\[ T_i = \frac{100}{1000 + 0.055 \cdot \tau_{i-1}} - 273 \text{ ,} \] (2)
where \( T_{i-1} \) – is absolute temperature, °K.
The temperature before the first pass is determined based on the pre-rolling heating temperature and the time of the plate slab transportation to the mill, it is calculated using the following equation (3):
\[ \tau_0 = \frac{L_0}{v} + \tau_p, \] (3)
where
\( L_0 \) – the length of the rolling table between the furnaces and mill, \( L_0 = 105 \text{ m} \);
\( v \) – rolling table speed, rolling table speed, \( v = 2 \text{ m/s} \);
\( \tau_p \) – pause time before the mill, \( \tau_p = 2 \text{ s} \).
The time of the plate slab transportation to the mill:

\[ t_0 = \frac{105}{2} + 2 = 54.5 \text{ s}. \]

We will determine the temperature at the moment when half of the hot-rolled piece is in the point of the metal roller exit, therefore:

\[ \tau = \tau_s + \tau'_i, \]

\[ \tau'_i = \frac{l_{i-1}}{2 \omega_{i-1}}, \]

\[ \tau_i = 54.5 + \frac{2.82}{2 \cdot 1.9} = 55.3 \text{ s}. \]

Temperature in the first pass:

\[ T_1 = \frac{100}{100 + \frac{0.055 \cdot 0.553}{250 \sqrt{1423} / 100}} - 273 = 1150.3 \text{ °C}. \]

The time in the subsequent passes is calculated using the following equation (6):

\[ \tau_j = \tau'_i + \tau'' + \tau_p + \tau_t, \]

where \( \tau'_i = \frac{l_{i-1}}{2 \omega_{i-1}}; \)
\( \tau'' = \frac{l_{i}}{2 \omega_{i}}; \)
\( \tau_p \) – pause time (for Heavy Plate Mill 5000 \( \tau_p \approx 4 \text{ s}; \))
\( \tau_t \) – tilting time (for Heavy Plate Mill 5000 \( \tau_t \approx 13–15 \text{ s}; \))

The temperature in the second pass:

\[ \tau'_2 = 3.287 / 2 \cdot 1.9 = 0.8 \text{ s}; \]
\[ \tau''_2 = 3.858 / 2 \cdot 2.2 = 0.9 \text{ s}; \]
\[ \tau_p = 4 \text{ s}; \]
\[ \tau = 0.8 + 0.9 + 4 = 5.7 \text{ s}. \]

\[ T_2 = \frac{100}{100 + \frac{0.055 \cdot 5.7}{182.8 \sqrt{1394} / 100}} - 273 = 1123.8 \text{ °C}. \]

Similarly we will calculate the temperature in the subsequent passes. The results of the rolling temperature mode in the roughing-down and finishing stages are provided in Table 4.

The Table shows that the temperature ranges by stages match the recommended values (see Table 3). The temperature distribution chart (by passes) is provided in ‘Figure 1’.
**Figure 1.** Chart of the rolling temperature distribution by passes.

**Table 4.** Rolling temperature mode results.

| Pass No. | $h^a$, mm | $L^b$, mm | $\tau^c$, s | $T^d$, °C |
|----------|------------|------------|--------------|------------|
| 0        | 310.0      | 3170.0     |              | 1150.0     |
|          |            |            | Roughing-Down Stage |
| 1        | 279.0      | 3522.1     | 55.3         | 1123.3     |
| 2        | 248.3      | 3958.8     | 5.7          | 1121.8     |
| 3        | 216.0      | 4550.3     | 5.9          | 1117.5     |
|          |            |            | Tilting 90 ° |
| 4        | 181.5      | 2543.2     | 20.8         | 1108.1     |
| 5        | 152.5      | 3027.4     | 5.5          | 1103.4     |
| 6        | 125.0      | 3691.2     | 5.7          | 1099.4     |
| 7        | 102.3      | 4513.1     | 5.9          | 1093.3     |
| 8        | 83.0       | 5564.5     | 6.1          | 1088.1     |
| 9        | 66.8       | 6912.2     | 6.5          | 1079.6     |
|          |            |            | Cool-Down    |
| 10       | 56.8       | 8277.6     | 272.0        | 845.3      |
| 11       | 48.4       | 9466.2     | 7.0          | 840.1      |
| 12       | 41.4       | 11177.7    | 7.4          | 834.3      |
| 13       | 35.4       | 13085.3    | 7.7          | 826.5      |
| 14       | 30.5       | 15217.8    | 8.2          | 817.8      |
| 15       | 26.4       | 17590.6    | 8.6          | 806.2      |
| 16       | 24.2       | 19018.8    | 8.6          | 793.4      |
| 17       | 23.0       | 20060.1    | 9.0          | 779.0      |

$^a$ hot – rolled piece thickness.  
$^b$ hot – rolled piece length.  
$^c$ rolling time.  
$^d$ rolling temperature.
3. Conclusions
This work highlights the operation of Heavy Plate Mill 5000 at Vyksa Steel Works. Based on the equipment capabilities at this Company a process flow diagram for the fabrication of thick plates (strength class K60, steel grade 10Г2СΦБ) used for cold-resistant large-diameter pipes was developed and an optimum rolling temperature mode by passes was selected which promotes the reduction of the metal wastes in the furnace.

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