Analysis of the Microstructure Evolution in the Implementation of a New Macro Shear Rolling Technology

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Abstract: In the work on the basis of computer modeling, a comparative analysis of the rolling technology of a plate billet, which includes rolling in relief rolls with subsequent rolling in rolls with a smooth barrel to the desired size, compared with the existing rolling technology was performed. The results of comparison of deformation schemes using microstructure evolution indicate the advantage of the proposed technology compared with the current rolling technology.

The quality of sheet products depends on the mechanical properties of the material, and, consequently, the uniformity of distribution and dispersion of the granulated structure. It was noted in the works [1, 2] that the rolled structure formed after rolling through roughing stands – has a great impact on the further processes of structure formation and the formation of the final structure of a plate. At this stage, the control of the processes of structure formation pursues two main objectives: 1) obtain a fine austenite grain and 2) prevent the formation of a mixed structure of partial recrystallization. Moreover, it is known from works [3, 4] that, during reduction of a slab, there is a significant unevenness of deformation in the volume of the body being deformed - surface layers are more deformed, while the middle part of the strip is barely or not deformed at all, and this can lead to the formation of a heterogeneous structure. It is also known that the formation of the structure of heterogeneous austenite after rolling through roughing stands causes the formation of a heterogeneous ferritic structure and cannot be corrected during the rolling through finishing stands [4].

It is also known that it is impossible to completely eliminate the unevenness of deformation due to the monotonous nature of the metal flow, as a result of which, when rolling high strips, the molten structure of the slab’s axial zone is not sufficiently worked out, nonmetallic inclusions and liquids have node alignment in the metal along the rolling axis, which reduces the required level of physical and mechanical properties of products.

A promising solution to this problem is the development of new billet deformation schemes, which allow creating additional metal flows when rolling, i.e. to intensify the developed shear deformations not only in the longitudinal but also in the transverse direction.

Intense macro shears can be provided in a variety of technological and constructive ways. The most known and promising among them are the following: asymmetric rolling [5, 6]; the use of crossed rolls [7]; the use of rolls and billets with a corrugated or wavy surface [8–10]; the use of rolls with surface
asperities [11, 12]. All of the above mentioned methods have one thing in common - intense macro shears are achieved as a result of local deformation action on the rolled metal.

One of these technologies is the technology of rolling a plate, which includes the following: the use of rolls with a grooved surface [13], followed by rolling through the smooth rolls to the required size. The surface of the grooved rolls is made in the form of annular grooves forming a trapezoidal shapes along the entire length of the roll which are located at an angle of 90° to the rolling axis. When rolling through grooved rolls, trapezoidal segments are introduced into the body of the billet and due to the peculiarities of their shape, a part of the metal is displaced in-between these segments. As a result of this, shear deformation is intensified along the billet cross section with the formation of trapezoidal segments on the billet surface. During subsequent rolling of the billet in smooth rolls, conditions are created to ensure an alternating metal flow when leveling the transfer bar surface while maintaining the original geometry of the billet.

The objective of this work is to analyze the effectiveness of the proposed technology for rolling a plate, in comparison with the existing rolling technology (smooth rolls), based on the analysis of the evolution of the microstructure using computer modeling.

To build geometric models of the billet and tool, the KOMPAS software was used, in which 3D-models were created and exported to the compatible STL format. As a result, after importing the geometry files into the Simufact Forming software, a computer model was obtained (Figure 1), consisting of 3 pairs of rolling stands in series. The rolls of the first stand are grooved, in which the billet undergoes shaping and shear deformation. The second and third stands are equipped with smooth rolls, which serve to flatten the deformed billet in order to return its original geometric parameters.

![Figure 1. Plate rolling process model using new power saving technology.](image)

Based on previous works [14], when modeling a new technological rolling scheme, including rolling through grooved rolls, it was decided to use grooved rolls with an unequal up to down ratio, ensuring the same roll gap at different points.

The use of such rolls makes it possible to implement a simple shear scheme when rolling, which most favorably affects the preservation of the initial dimensions of the billet than the use of rolls with an equal ratio of up to the down, where, in addition to shear, reduction is also carried out on inclined sections of the rolls.

The billet is a rectangular sheet with the following dimensions: $h \times b \times l = 10 \times 140 \times 200$ mm. The material used for billet is brass of L63 brand.

In computer model of the process, the following technological parameters were used:
The rolling was performed at a room temperature of 20 °C;
- The billet temperature before rolling is 600°C;
- Heat conductivity coefficient is 7000 W/(m² · °C);
- Siebel friction model, i.e. contact stress exceeds yield strength;
- Friction coefficient is 0.7;
- Rolling speed is 1.25 rad/s.

Rolling process can be divided into three main stages (Figure 2).

At the first stage, the billet preheated to the rolling temperature is fed into the grooved rolls and during the first pass a single reduction by the rolls’ collars is carried out until the groove cavity is completely filled with metal (Figure 2 (a)). After rolling in the first stand, alternating ups and downs in the form of trapezoidal segments are formed on the surface of the billet. This stage is mainly characterized by shear deformation, however, there is also a height deformation at the junction of the ups, which contributes to the capture of the billet. In order to pre-flatten the surface of the profiled billet after rolling in the grooved rolls, rolling through the smooth rolls is carried out (Figure 2 (b)). As a result, conditions are created to ensure an alternating metal flow when flattening the surface of the transfer bar during rolling through smooth rolls, maintaining the original shape of the billet. In the third pass, the billet was also fed through the stand with smooth rolls (Figure 2 (c)).

Figure 3 presents the results of modeling the microstructure, the initial grain size is 60 μm (Figure 3 (a)). When rolling the billet through the grooved rolls (Figure 3 (b)), a significant refinement of the microstructure due to shear deformation is observed, the grain size reaches 35–45 μm.

From the cross section of the billet at the second stage (Figure 3 (c), it can be seen that the sections with the finest structure are the ups of the billet, the grain size is about 25–35 μm.
Figure 3. Evolution of the microstructure (grain size) when rolling: (a) – initial billet; (b) – the billet after grooved rolls; (c) – the billet after second pass (smooth rolls); (d) – the billet after third pass (smooth rolls).
This is due to the fact that the ups are the points of deformation concentration. In other parts of the billet the grain size varies from 40 to 30 µm (mkm).

At third pass stage (Figure 3(d)) the grain size reaches 30–25 µm. At the base of the ups the grain size is 25-20 µm.

For comparative analysis, two models were created and modeling was carried out using the Simufact Forming software. For the current technology the production technology of a thick sheet (made of copper alloys) at the Balkhash non-ferrous metal processing plant is taken. The model of the existing technology for rolling a plate includes 6 passes in a DUO-100 stand with smooth rolls. In our case, for the convenience of modeling, 6 passes of the billet through the DUO-100 stand were replaced by rolling in 6 consecutive stands with smooth rolls. The model of the proposed technology includes a stand with grooved rolls in the form of annular grooves along the entire length of the roll and 5 sequentially installed stands with smooth rolls.

The peripheral rolling speed in the stands was calculated from the condition of constant second volume (amount of metal going through the stand per second) in order to stretch the strip and ensure horizontal passage of the billet through the stands, as well as to exclude loop formation when rolling. The peripheral rolling speed in the stands is presented in Table 1.

| Table 1. Peripheral rolling speed (per stand). |
|------------------------------------------------|
| Technology | Stand 1 | Stand 2 | Stand 3 | Stand 4 | Stand 5 | Stand 6 |
| Existing, rpm | 30 | 35.42 | 40.48 | 43.97 | 47.2 | 51 |
| Proposed, rpm | 30 | 40 | 45 | 60 | 81.8 | 90 |

It is known that the temperature of the billet is an important technological parameter. The calculation results of the change in the temperature of the billet in each pass in each of the compared models are presented in Figure 4.

From this graph it follows that the billet rolled by the proposed technology cools down more than by the existing technology. This is due to the fact that when rolling according to new technology in the first three stands, there is no significant reduction of the billet, but only a change in its form and flattening.
In the last three stands, an increase in temperature is observed in both models. This phenomenon is explained by an increase in the rolling speed, as well as an increase in the degree of reduction.

In the framework of this model, a comparative analysis of the billet microstructure after rolling through the first stand was performed (Figure 5 (a)), which revealed that when rolling through a grooved stand, the microstructure has more even distribution and a smaller grain fraction than when rolling through the stand with smooth rolls. This is due to the large value of compressive strain in the proposed technology. The grain size reaches a value of 12–14 μm, while in the existing technology 14–16 μm.

![Figure 5 a](image)

**Figure 5.** The results of modeling the evolution of the microstructure: (a) – after rolling through the 1st stand, (b) – after rolling through the 3rd stand, (c) – after rolling through the 6th stand; A – existing technology; B – proposed technology.

After the last smoothing stand (the third one), a more uniform distribution of the structure is observed in the rolled billet by the existing technology (Figure 5 (b)). The grain size in both models reaches 8 μm. In billet “B”, the smallest grain size prevails near the grooves.

Figure 5 (c) shows the microstructure after the 6th stand. The billet “B” has a uniform distribution of structure with a grain size of 2–4 μm. The grain fraction in the billet “A” ranges from 5 to 8 μm, the microstructure has an inhomogeneous structure, which leads to anisotropy of the properties. It can be assumed that the use of the proposed rolling technology will help to avoid additional (excessive) metal loss in the form of side trimmings in order to equalize the mechanical properties of the sheet.

**Conclusion**

A comparative analysis of two deformation schemes: the proposed one, which includes rolling through grooved rolls followed by rolling of a billet through smooth rolls, and the current one (rolling only through the smooth rolls). Analysis results indicate the advantage of the proposed deformation scheme
compared to the existing one. Thus, the use of the proposed scheme of deformation in the first stand (with grooved rolls) contributes to a more intensive grinding of the initial grain size when rolling in all six stands.

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