STUDY OF STRESS-STRAIN STATE AND TEMPERATURE FIELD DURING ROLLING UNDER THE NEW SCHEME WITH ALTERNATING AND SHEAR DEFORMATIONS

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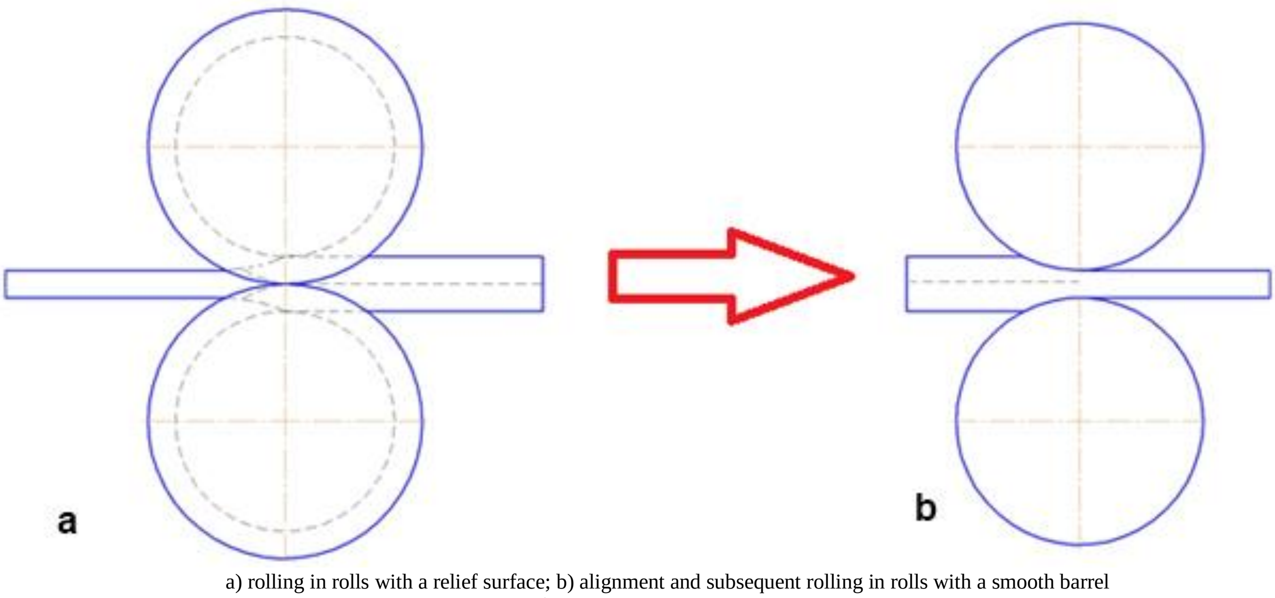
Abstract: *In this paper, a computer simulation of a new technology of thick-sheet rolling, including rolling in rolls with a relief surface followed by rolling on rolls with a smooth barrel to the desired size. The analysis of effective plastic deformation, hydrostatic pressure and temperature field was carried out according to the results of modeling. According to the results of the analysis of effective strain, maximum of processing in the first pass receives the ridge area, but after the second pass observed alignment distribution of this parameter over the cross section. The study of the temperature field showed that the greatest temperature difference in the cross section occurs when rolling in relief rolls, in the future when rolling in smooth rolls due to the increase in the contact surface area, this difference decreases. Analysis of hydrostatic pressure showed the presence of both compressive and tensile stresses in the deformation zone. Such distribution is caused by the presence of a relief surface after 1 pass in the further alignment of the strip profile, which occurs both in the longitudinal and transverse directions.*

Keywords: ROLLING, SHEAR DEFORMATION, SIMULATION, TEMPERATURE, STRESS-STRAIN STATE.

1. Introduction

Obtaining high-quality products, i.e. products that fully meet the needs of the consumer, realizing the greatest economic effect and having the highest technical, economic and operational indicators, in metallurgical and machine-building production is mainly associated with the development of new technological processes. Thus, one of the primary and most urgent tasks of metallurgical production is to obtain high-quality cast billets, as well as the modernization of existing and development of new technological schemes of rolling capable of providing the study of the cast structure, a high level of mechanical properties and performance of the finished product. Currently, the use of technological processes of rolling with the use of classical tools and existing deformation schemes do not fully provide the required level of mechanical and operational properties due to the uneven distribution of the degree of deformation in the metal volume. Therefore, a promising direction to improve the quality of finished products is the development of new deformation schemes, including those implementing intensive shear or alternating deformation in the entire volume of the processed metal.

For introduction into production, a new technological scheme for rolling thick-sheet blanks was proposed, which implements intensive shear deformation without significant changes in the geometric parameters of the original workpiece. This technological scheme includes rolling in rolls with a relief surface followed by rolling of relief blank in rolls with a smooth barrel to the desired size. The technological scheme is presented in figure 1.



a) rolling in rolls with a relief surface; b) alignment and subsequent rolling in rolls with a smooth barrel
Fig. 1 *Scheme of rolling according to the proposed technology*

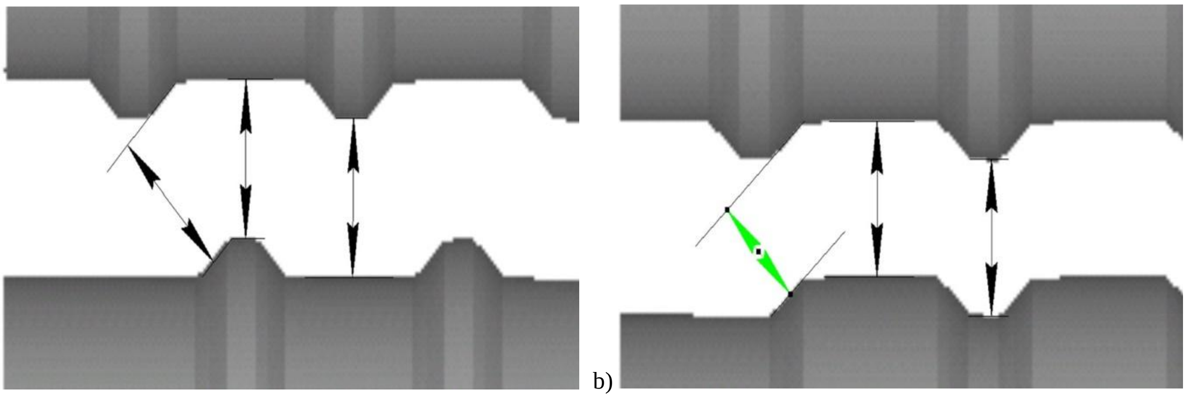
The surface of the relief rolls is made in the form of annular grooves forming projections and depressions of trapezoidal shape along the entire length of the roll barrel and located at an angle of 90° degrees to the rolling axis [1]. At rolling in rolls with a relief surface there is an introduction of trapezoidal segments of protrusions in the workpiece and due to features of the form there is a displacement of a part of metal in deepening of hollows. As a result, the intensification of shear deformation along the section of the workpiece is carried out with the formation of alternating protrusions and depressions on the surface of the workpiece in the form of trapezoidal segments. During the subsequent rolling of the workpiece in smooth rolls, conditions are created to ensure the alternating flow of metal when alignment the surface of the roll with the preservation of the original geometry of the workpiece.

The purpose of this work is to study the influence of the proposed deformation scheme on the stress-strain state of the metal and the distribution of the temperature field over the cross-section of the workpiece.

2. Computer model of process

The use of only theoretical methods of analysis of technological processes can not be effective for a number of reasons. To implement an objective and more accurate analysis, in addition to theoretical calculations, it is necessary to resort to new innovative technologies. One of the most effective technologies productive in the development and research of materials processing pressure is computer modeling. One of the most productive and popular is the Simufact Forming software package - a specialized software package designed to simulate the processes of metal forming.

Based on previous studies [2], when modeling a new technological scheme of rolling, including rolling in relief rolls, it was decided to use relief rolls with an unequal ratio of the protrusion to the cavity, providing the same values of the roll gap at different points (figure 2a). The use of such rolls allows to implement a simple shift scheme, which most favorably affects the preservation of the original dimensions of the workpiece than the use of rolls with an equal ratio of the protrusion to the cavity (figure 2b), where in addition to the shift is carried out and compression on the inclined sections of the rolls.



a) b)

a) unequal ratio of the protrusion to the cavity; b) equal ratio of the protrusion to the cavity.

Fig. 2 *Variants of ratio of the protrusion to the cavity*

When constructing the geometry of relief rolls for modeling, the following dimensions were adopted:

- diameter of the proposed roll-embossed surface for the clamps is 200 mm;
- barrel length 380 mm (these values correspond to the geometric dimensions of rolls for existing laboratory mill DUO 200);
- depth of the depression is equal to the height of the protrusion is 10 mm.
- bevel groove on the projections and depressions is 45°.

The design of the gap in the relief rolls is shown in figure 3. The total gap between the two opposite cavities of the roll was 20 mm. Smooth rolls were made with geometric dimensions: the diameter of the barrel rolls is 200 mm, barrel length is 380 mm.

After importing the geometry files into the Simufact Forming, a computer model was obtained (figure 4) consisting of 3 consecutive rolling stands: the first stand with relief rolls, where the workpiece undergoes shaping and shear deformation, the second and third - with rolls with a smooth barrel. The second and third stands serve to align the relief shape of the workpiece obtained in the first pass to its original geometric shape (flat form), while the alternating deformation is realized in the metal, contributing to a more intensive study of the original metal structure.

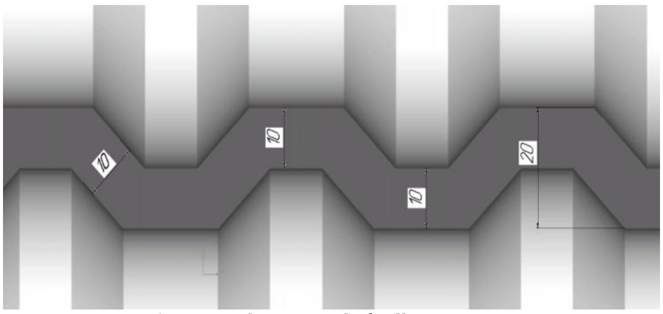


Fig. 3 *Gap design in relief rolls*

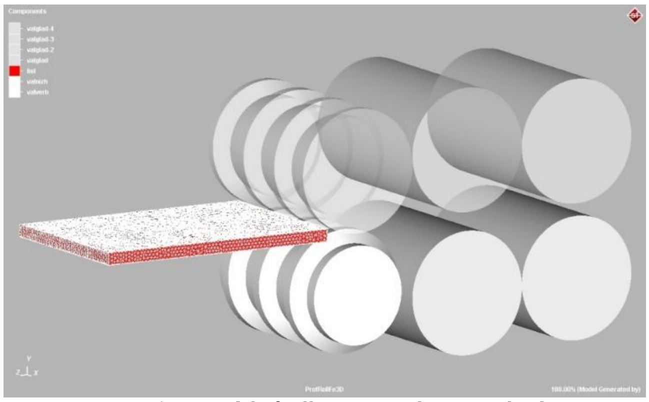


Fig. 4 *Model of rolling process by new technology*

The following technological parameters in computer modeling of the process were used:

Rolling was carried out at room temperature (20°C);

The temperature of the workpiece before rolling was 1000°C;

The thermal conductivity coefficient was 7000 $W/(m^2 \cdot ℃)$;

The Siebel friction model (the contact stress exceeds the yield strength);

Friction coefficient was 0.7;

The rolling speed was 1.25 rad/s.

The initial blank is a thick sheet of rectangular shape with dimensions h x b x l = 10 x 140 x 200 mm. Material for the workpiece the steel AISI 1015 was selected.

3. Simulation results

The whole rolling process can be divided into three main stages. At the first stage, the preheated to the temperature of rolling beginning the workpiece is fed into the roll gap of the proposed design and a single compression in the first pass is carried out until the cavity of the rolls is completely filled with metal (figure 5a). After rolling in the 1st stand on the workpiece surface the alternating protrusions and depressions in the form of trapezoidal segments are formed. This stage is characterized mainly by shear deformation, but there is also a high-altitude deformation at the junction of the projections, contributing to the capture of the workpiece. In order to align the surface of the profiled workpiece after rolling in relief rolls, it is rolled in stands equipped with rolls with a smooth barrel (figure 5b-c) (second and third stage). In this case the conditions are created to ensure the alternating flow of metal when alignment the metal surface when rolling in smooth rolls with the preservation of the original shape of the workpiece.

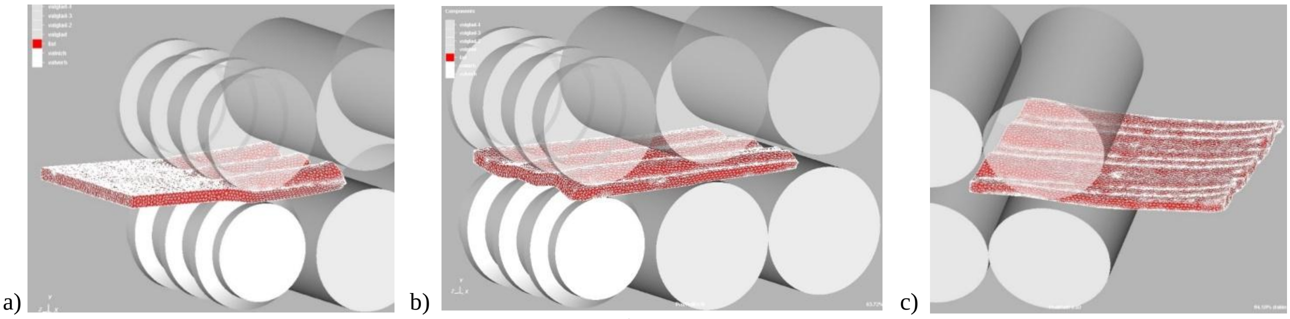


Fig. 5 *Stages of the rolling process*

In the study of any metal forming process, the key step before laboratory or industrial testing is the study of the stress-strain state (SSS). It will allow to reveal distribution of stresses and strains in the considered process, and also to define their critical values that will give the chance to check the working tool on durability.

Effective plastic strain shows the intensity of the workpiece throughout its cross-section. This parameter also allows you to track the degree of accumulated deformation, which is cumulative. When studying the strain state, it is necessary not only to provide a high level of equivalent strain required for the formation of a fine-grained structure, but also a uniform distribution of this parameter over the section of the workpiece.

At the first stage (figure 6a) deformation develops during rolling in the deformation center in relief rolls. From the results obtained, it was revealed that the maximum value of effective plastic strain is concentrated at the junction of the roll ridges and is 0.4. Also, the cross-section of the workpiece is observed shear deformation, its value is in the range of 0.25-0.35. The difference in equivalent strain values was 62.5 %. At the second stage (alignment of the workpiece in smooth rolls) there is a further increase in the equivalent deformation (figure 6b). There is also a cross-section alignment of the deformation, as evidenced by a decrease in the difference in the values of the equivalent deformation to 50 %. From the results at stage 3, it can be said about the uniform distribution of accumulated deformation (figure 6c). The difference in equivalent strain values is less than 20 %.

Also, in the SSS study, it is very useful to study the temperature conditions of the process, since the change in the temperature of the deformed metal significantly affects the energy-power parameters of deformation.

Figure 7a shows the temperature distribution on the surface and in the cross section of the workpiece when rolling in relief rolls. In the center of deformation during the process there is an increase in temperature to 1070°C, which improves the plastic properties of the workpiece. In other parts of the workpiece is maintained uniform temperature distribution. According to the laws of thermodynamics, the cooling of the surface layers is faster than the internal, so the temperature of the end parts of the workpiece has decreased to 970°C.

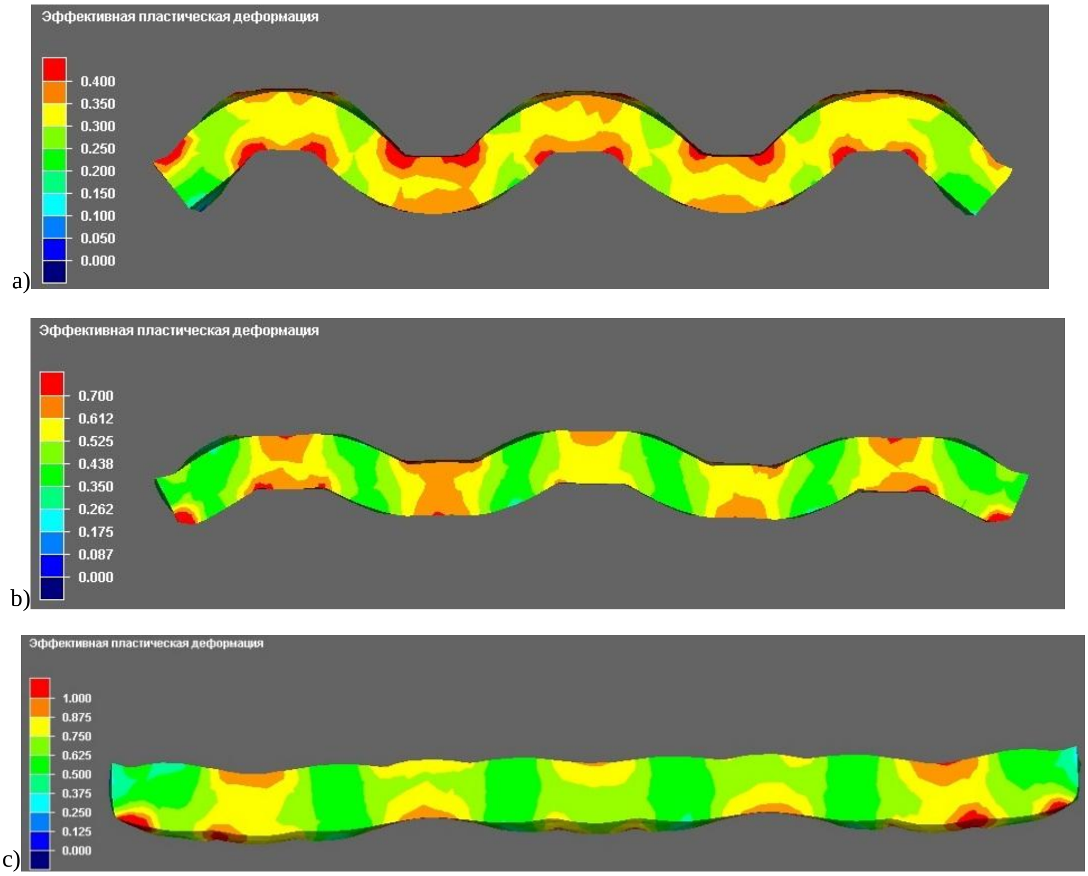


Fig. 6 *Effective plastic strain of the workpiece by passes*

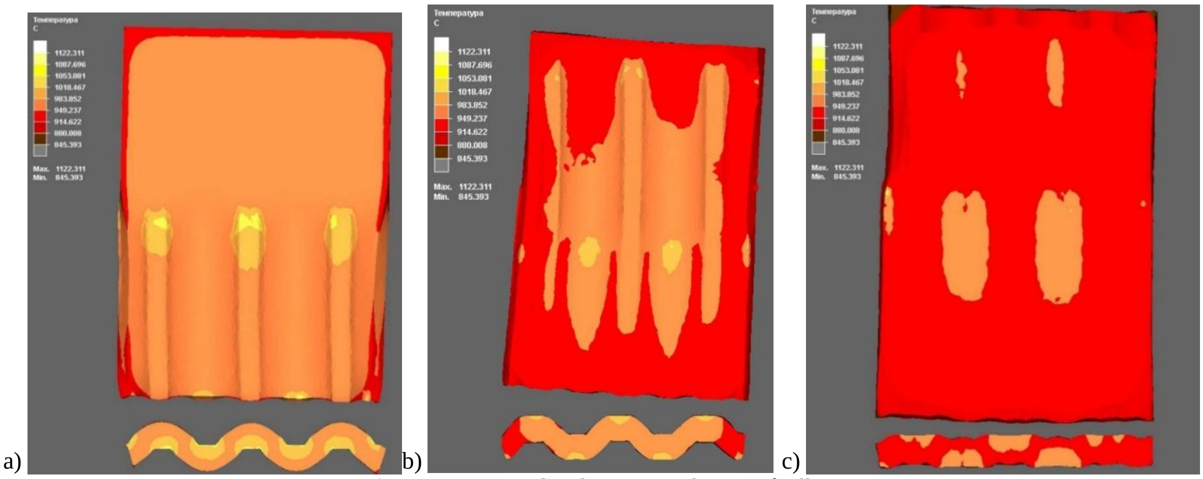


Fig. 7 *Temperature distribution at each stage of rolling*

In the second stage (figure 7b), most of the surface cools to temperatures of 950°C and only in the deformation center the temperature reaches 1040°C. At the third stage of rolling (figure 7b), almost the entire surface of the workpiece, in addition to the deformation center, cools to 920°C. On the cross section, the temperature difference of the workpiece layers can be clearly observed.

Another important component in the SSS study is hydrostatic pressure. Hydrostatic pressure shows the intensity of compressive and tensile stresses across the workpiece section, i.e. the value of the stress can take both positive and negative values. By analyzing this parameter, it is possible to identify those zones that are exposed to tensile stresses, i.e. are the most dangerous from the point of view of defects. From the results obtained, it can be concluded that at the first stage of rolling (figure 8a) at the point of contact of the roll with the workpiece, the hydrostatic pressure fluctuates between -150÷-100 MPa. The compressive nature of stresses is due to the fact that in addition to shear deformation in the place of formation of ridges and troughs, a certain proportion of high-altitude deformation occurs. In the undeformed zone of the workpiece, a pressure value within 30÷50 MPa is observed. The tension of the central layers of the workpiece remained unchanged.

At the second stage (figure 8b) in the process of the workpiece alignment on smooth rolls in the zone of the deformation center, a hydrostatic pressure within -350÷-300 MPa is created. In places the top of the ridge there are tensile stresses.

In the center of deformation at the secondary alignment of the workpiece on smooth rolls (figure 8c), the value of hydrostatic pressure reaches -450÷-500 MPa. The cross-section of the workpiece clearly shows the accumulation of compressive stress at the base (origin) of the ridges, this is due to the occurrence of backpressure during the lateral flow of the metal (there is a collision of the lateral flows of the metal flow during the alignment of the ridges). The voltage in this area reaches 130 MPa.

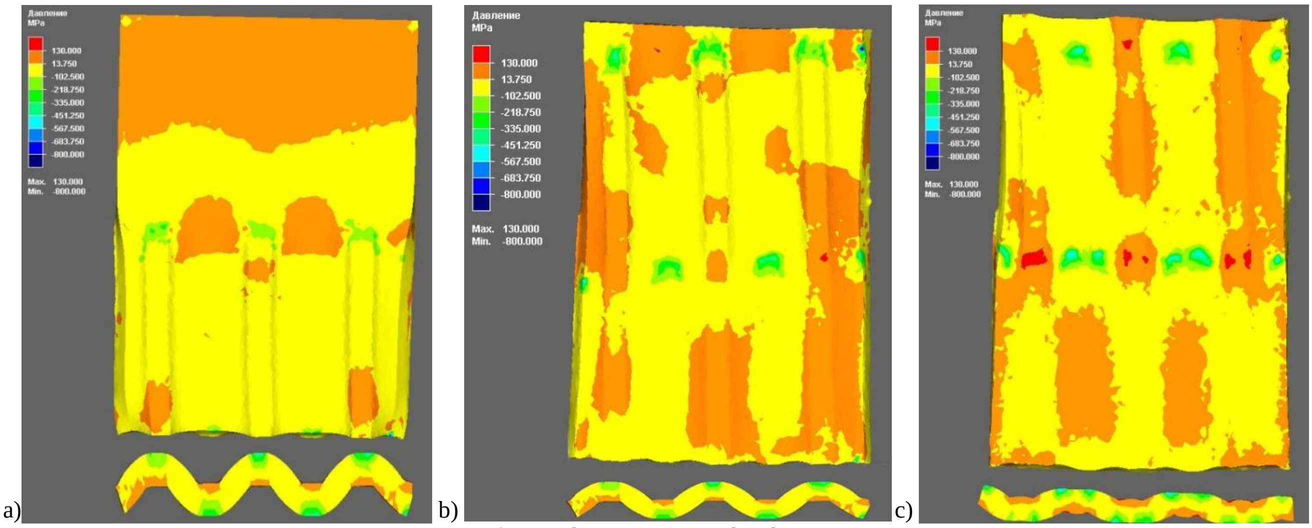


Fig. 8 *Hydrostatic pressure distribution*

Conclusions

In this paper, a computer simulation of a new technology of thick-sheet rolling, including rolling in rolls with a relief surface followed by rolling on rolls with a smooth barrel to the desired size. The analysis of effective plastic deformation, hydrostatic pressure and temperature field was carried out according to the results of modeling. According to the results of the analysis of effective strain, maximum of processing in the first pass receives the ridge area, but after the second pass observed alignment distribution of this parameter over the cross section. The study of the temperature field showed that the greatest temperature difference in the cross section occurs when rolling in relief rolls, in the future when rolling in smooth rolls due to the increase in the contact surface area, this difference decreases. Analysis of hydrostatic pressure showed the presence of both compressive and tensile stresses in the deformation zone. Such distribution is caused by the presence of a relief surface after 1 pass in the further alignment of the strip profile, which occurs both in the longitudinal and transverse directions.

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