гии пилигримовой прокатки качественных труб из металла непрерывной разливки : дис. на соискание учен. степ. д-ра техн. наук в форме научн. Доклада : 05.16.05. Днепропетровск, 1989. 36 с.

8. Спосіб гарячої пілігримової прокатки тонкостінних труб: пат. 129752 Україна: МПКВ21В. № U 2018 05077; заявл. 08.05.2018; опубл. 12.11.2018, Бюл. № 21.
9. Спосіб зміни дорна з дорновим кільцем для пілігримової прокатки труб: пат. 100527 Україна: МПК В21В 21/00, В21В 25/06, № U 2015 01778; заявл. 27.02.2015; опубл. 27.07.2015, Бюл. № 14.
10. Спосіб гарячої пілігримової прокатки труб: пат. 86284 Україна: МПК В21В21. № U 2013 07664; заявл. 17.06.2013; опубл. 25.12.2013, Бюл. № 24.

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STRESS STATE STUDY DURING ROLLING IN A BOX CALIBER WITH A CHILLED SURFACE

Introduction. Modern pipe production is characterized by a wide range of hot-deformed pipes and various schemes for their production. Some of the pipes are made from rolled billets, others from continuous cast billets. Rolling of pipe billets is used in cases where it is necessary to ensure a high quality of the inner surface of the pipes. In this regard, issues related to the study of factors affecting the quality of pipe billets are of considerable interest to metallurgists.

Formulation of the problem. A significant number of scientists at various periods of time were engaged in the issue of the quality of pipe billets.

Due to the complexity of the processes occurring in the deformation zone during rolling of a pipe billet, most of the research in this area has been carried out experimentally. Thus, a whole range of experimental studies is combined in monographs [1 and 2]. There are also separate studies, for example, the study [3], which combines both an experimental approach to the study of the flow of metal in a caliber, and a theoretical analysis of the results.

The experimental studies described in [1] were carried out in a production environment. These studies were carried out using screws that were screwed into various sections of the strip and then rolled. The processes taking place in the caliber were investigated by the modification of the screws after rolling. In this regard, the authors of this work carried out only a qualitative analysis of possible stress state that leading to the formation of one or another defect.

In contrast to the work [1], the authors of the study [3] used a technique in their research, which is based on the study of the metal flow by deformation of the coordinate grid applied to the lead plates of which the experimental sample consisted. In relation to the dimensions of the strip rolled on an industrial mill, the experimental section was reduced by a factor of 2.4.

As a result of research [1, 3], many interesting facts were obtained. Unfortunately, in the described studies, there is no information on the modification of longitudinal and vertical stresses, and there is also no complete information about all dangerous zones of the deformation zone, in which the occurrence of regions with an unfavorable stress state pattern for the quality of the metal is possible. This is, of course, related to the difficulty of conducting a comprehensive experimental study.

At the same time, at the time of the described works, the technique of mathematical modeling was still insufficiently developed. In this regard, there was no possibility of constructing a mathematical model of the metal flow in the deformation zone with the correct consideration of non-contact deformations in the plane of the entry and exit of the strip from the rolls. There were also problems with the issue of accurately accounting for the unevenness of the deformation in the caliber itself, which in our case is significant due to the fact that the studied deformation zone has a big height. In addition, the shape of the caliber leaves its mark on the flow of metal. This form leads to the fact that in reality we have a complex deformation zone and, accordingly, a complex modification of the velocity field, and, consequently, a complex stress field. The situation is even more complicated when taking into account the influence of temperature fields on the flow of the metal and the stress state.

In this regard, at the present stage, it is of interest to study the volumetric stress state when rolling a rectangular strip in a box caliber under conditions of an uneven distribution of the temperature field over its cross section.

At the same time, the question of the appearance of zones with tensile stresses not only in the geometric zone of deformation, but also in non-contact zones is interesting.

Results. As a mathematical apparatus, the finite element method was used to approximate the fields of metal flow velocities and the variational principle of continuum mechanics. The general modeling technique is described in [4].

In the simulation, the actual calibration of a pipe billet with a diameter of 150 mm was used. The shape of the caliber is shown in Fig. 1.

The simulation was carried out for rolls with a diameter of 700 mm, the number of rolls rotation was taken equal to 80 rpm. The billet material is steel 20. The roll opening was 7 mm. The thickness reduction was 30 mm. The billet was divadet into 4673 prismatic elements with a quadrangular base.

Billet surface temperature 850. The temperature of the inner part of the billet was 1050. The temperature field is shown in Fig. 2.

The metal flow was considered in 6 cross sections along the deformation zone.

Section 1 is located at a distance of 187 mm from the plane of the strip exit from the rolls (vertical section passing through the axis of the rolls) and at a distance of 29 mm from the plane where the first contact of the strip with the rolls occurs. Here, an almost uniform distribution of all stresses is observed, with the exception of the corner sections, where significant compressive stresses are present.

In this section, there is an uneven distribution of velocities and a significant asymmetry of the metal flow relative to the vertical and horizontal axes of symmetry. The reason is the point contact of the strip with the roll at the initial stage of deformation, which leads to an unstable behavior of the billet.

In section 2, located at a distance of 158 mm from the plane of the exit from the rolls, where the metal touches the side walls of the caliber, the stress distribution is no longer so uniform, since here the corner sections begin to deform by the rolls. In this section, in the middle part of the future

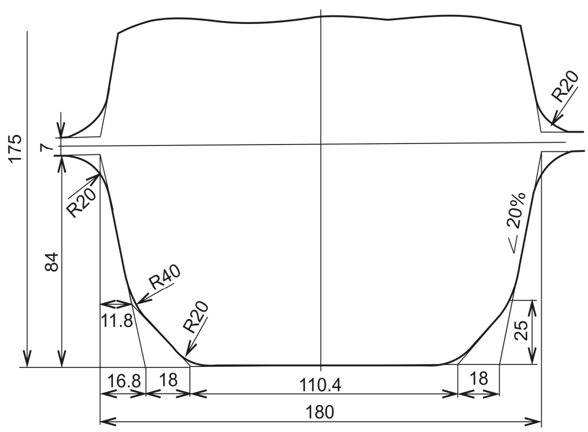

Figure 1 - Caliber used in the study

horizontal contact surface, compressive transverse and longitudinal tensile stresses develop. Compressive stresses arise due to the fact that here the metal is displaced by the side walls of the caliber in the transverse direction just in the region of the area under consideration. Longitudinal tensile stresses appear here due to the fact that the metal, displaced at the corners of the workpiece, moves not only in the transverse direction, but also in the longitudinal direction. As a result, the corner parts try to extend the middle parts. In the area under consideration, this process is most developed. However, the resulting tensile stresses do not exceed 43 MPa.

As the strip moves along the deformation zone, this surface penetrates deeper into the caliber and at the same time receives significant compression from the side walls of the caliber. As a result, the deformation penetrates the entire width of the future horizontal contact surface. This leads to a decrease in the value of longitudinal tensile stresses in this area. At the same time, there is an increase in transverse compressive stresses in this zone.

Along with this, a flow section appears in the strip in the region of the initial corners of the workpiece. This is accompanied by the appearance of tensile stresses here, the maximum of which reaches 78 MPa.

The presence of vertical tensile stresses (no more than 50 MPa) in the area of the workpiece corners is explained by the significant non-uniformity of deformation.

At the same time, some parts of the strip move at a higher speed, and some at a lower speed. Interaction arises between them. Sections with higher speed tend to stretch out sections with less speed. This becomes the reason for the appearance of tensile stresses in such places. The greater the velocity gradient between such areas, the greater tensile stresses arise.

In the central part of the billet, in section 3, located at a distance of 99 mm from the plane of the exit from the rolls, small (about 10 MPa) longitudinal and transverse tensile stresses arise. The occurrence of longitudinal tensile stresses is understandable.

The occurrence of transverse tensile stresses requires some explanation. In the section under consideration, the main deformation develops in the lateral sections of the billet located in the region of the initial profile angles. This leads to the fact that the metal is displaced mainly in the lateral region of the strip. Part of the displaced flow is initially directed to the vertical axis of symmetry of the strip, and then, meeting with the opposite metal flow on the other side, turns towards the side surface of the strip. That is, in a certain place on the strip, the velocity vectors turn almost 180 degrees. As a result, these metal flows, heading towards the side surface of the strip, try to stretch the central axial zone of the workpiece. This leads to the appearance of small tensile stresses here (12 MPa).

In section 4, located at a distance of 67 mm from the plane of the exit from the rolls, the middle horizontal part of the strip comes into contact with the caliber. As a result, there is a significant change in the deformation pattern, and, consequently, in the stress state. Here, the part of the metal is displaced in the middle section and a smaller part is displaced in the area of the corner sections. Therefore, the middle parts of the strip begin to move at a higher speed than the corner ones. As a result, zones of longitudinal tensile stresses with a value of about 58 MPa appear in the region of the corner sections. Zones of transverse and vertical tensile stresses develop significantly here. Their appearance is due to uneven deformation. So, in this zone, a significant volume of metal is displaced from

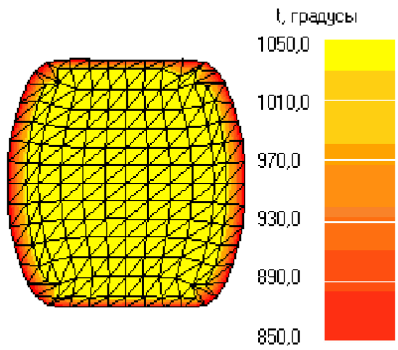

Figure 2 - Temperature distribution over the profile section

the side of the middle part of the strip, which is directed to the horizontal axis of symmetry and towards the roll clearance. However, in this direction, these metal flows meet with flows coming from the side walls of the caliber, where deformation also occurs. As a result, the flows coming from the horizontal contact surface slightly change their direction and try to bypass the compression zone formed by the side walls of the caliber. This leads to the formation of a dead zone in the area of the caliber walls and the adjacent zone with an increased speed of movement of metal particles. This becomes the reason for the occurrence in the place of the highest velocity gradient of transverse and vertical tensile stresses (Fig. 3).

The development of this process leads to the fact that in the region of the horizontal axis of symmetry, the main part in the formation of metal flows going for broadening is taken by the metal volumes displaced by the side walls of the caliber. As a result, the metal going for broadening tends to pull along the central (axial) volumes of the metal. This again leads to the occurrence of transverse tensile stresses in this part of the strip. Their value is insignificant.

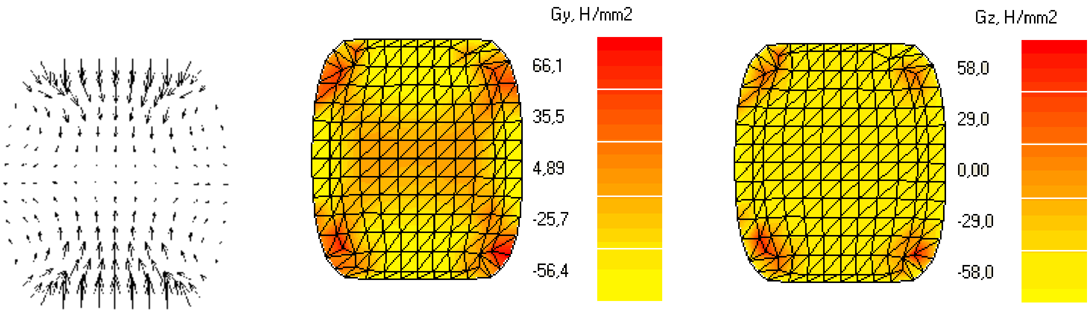

Figure 3 - Metal flow and stress

In section 5 (the plane of the billet exit from the rolls), we observe the most complex of the considered stress distribution patterns (Fig. 4).

Here, the processes occurring in the caliber are combined, and the processes occurring in the non-contact zone behind the deformation zone are superimposed. Obviously, in section 5, the processes of equalizing the velocities of longitudinal motion began to develop. As a result, those parts of the strip that had a high speed of movement in the contact zone of deformation will be shortened here, and sections with lower speeds will be stretched. This means that compressive longitudinal stresses will arise in the shortening sections, and tensile longitudinal stresses will appear in the lengthening sections. In addition, a reduction in the length of individual sections leads to an increase in the transverse dimensions of these sections, which is accompanied by the appearance of tensile stresses.

Since in the deformation zone, before the strip leaves the rolls, the most compressed areas were the middle horizontal contact areas near the vertical axis of symmetry of the groove and the areas in the region of the caliber walls, then, naturally, longitudinal compressive stresses arise here.

As we noted earlier, the corner regions are less deformed at the last stage of deformation. Therefore, in section 5 and 6, these sections are under tension. Section 6 is located at a distance of 14 mm behind the exit plane from the deformation zone.

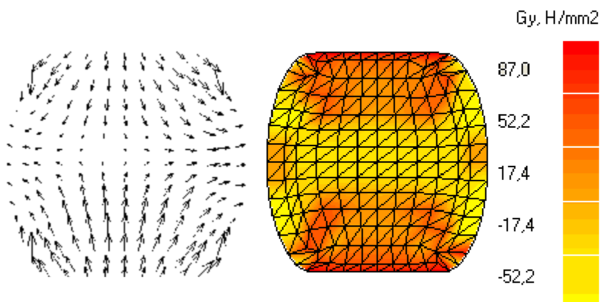

Figure 4 - Metal flow and stress

Attention is drawn to the occurrence of a zone of tensile transverse stresses in the part of the strip located under the horizontal contact surface (see Fig. 4). The reason for the appearance of this zone is that with a reduction in the length of the part of the strip strongly compressed by the side walls of the caliber, it tends to expand. Naturally, not in the direction of the vertical axis of symmetry of the caliber, but in the opposite direction. In addition, the central part of the strip tends to expand. This leads to the fact that compressive transverse stresses arise in the lateral parts, and tensile stresses occur in the near-contact central part. It should be noted that the process of equalizing the velocities is accompanied by the appearance of significant tensile stresses with a value of about 87 MPa.

Conclusions. With this deformation pattern, from the point of view of defect formation, the most severe stress state pattern occurs in places corresponding to the horizontal part of the strip contact surface after the strip leaves the rolls.

In accordance with the conditions for rolling out defects, it can be concluded that there are no conditions favorable for rolling out surface defects in this area. If there is a non-metallic inclusion in this area, it will be a stress concentrator. As a result, this will facilitate the formation of deep surface defects.

Another dangerous place is the part of the strip located on the side surface, slightly below its corners. Although the tensile stresses are not very high here (about 66 MPa), when stress concentrators hit this zone, these stresses may be sufficient for the formation of surface defects.

In the central part of the profile and in the area of caliber clearance, tensile stresses are present in some areas of the deformation zone, but their value is too small to make the surface defects.

LITERATURE

1. Beda N. I., Kancelson G. M., Konovalov V. S. Production and quality of pipe billets. K. : Technics, 1966. 243 p.
2. Chekmariov A. P., Mashkovtsev R. A., Nosadze A. D. Pipe billet production. M. : Metallurgy, 1970. 304 p.
3. Litvinenko Y. P., Yakovlev A. I. Deformations and stresses when rolling oval bars in a round caliber. *Steel.* 1972. №. 3. P. 246-249.
4. Ilyukovich B. M., Ogurtsov A. P., Nekhaev N. E., Yershov S. V. Theoretical foundations of metal forming: in 2 volumes. Dnepropetrovsk : RIA «Dnepro-VAL», 2002. Volume 2. 485 p.

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ВЛИЯНИЕ ПЕРЕДНЕГО НАТЯЖЕНИЯ НА ДЕФОРМИРОВАННОЕ СОСТОЯНИЕ ПРИ ПРОКАТКЕ КРУГЛЫХ ПОЛОС В ОВАЛЬНОМ КАЛИБРЕ

Введение. Способ непрерывной прокатки в настоящее время является самым часто используемым при производстве длинномерной металлической прокатной продук-