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RESEARCH AND DEVELOPMENT OF TECHNOLOGY FOR ROLLING OF HIGH-QUALITY PLATES OF NON-FERROUS METALS AND ALLOYS IN RELIEF ROLLS

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ABSTRACT

Studies on deformation of a plate workpiece in rolls with a surface relief in the form of annular grooves forming a trapezoidal ledges and cavities alternating each other along the entire length of the barrel (the first pair with unequal ratio of the ledge to the cavity and the second pair with equal ratio of the ledge to the cavity) have been carried out. Computer simulation of the rolling process in the rolls with unequal and equal treatment of the ledge to the depression showed the advantage of the first scheme, because in this case is implemented pure shear without compression, which is beneficial to the uniformity of distribution of accumulated plastic deformation, which, in turn, affects the forming of the workpiece. Laboratory studies have confirmed the simulation results. The analysis of the intensity of shear strain proved the superiority of the first scheme and the analysis of rolling load showed the advantage of using the relief rolls instead of smooth.

Keywords: *rolling, relief rolls, simulation, laboratory experiment, effective strain, load, shear strain.*

INTRODUCTION

The obtaining of rolled product with high mechanical properties is one of the main goals of any metallurgical production, including the production of rolled metal products made of brass and copper alloys. Currently, the industrial enterprises of Russia and Kazakhstan for the production of metal from brass and copper alloys, which include the Balkhash processing factory of non-ferrous metals, improving the mechanical properties of these alloys most often is achieved by using special alloying additives in the melting alloy or heat treatment of finished steel. However, in the works [1, 2] is described the possibility of obtaining the required properties using simpler and far more cost-effective ways. One way of increasing the strength of the metal is to create additional streams of metal flow during rolling, i.e. localization of shear deformation developed not only in longitudinal but also in transverse direction [3].

It is known that to improve the quality of products at rolling of thick sheets of ferrous and non-ferrous metals use the system of alternating projections and depressions, when applied to the surface of the wide faces of the slab or on work rolls [4, 5]. In this case, along with the deformation in the longitudinal direction, which is characteristic for rolling on thick-sheet and wide-strip mills, there are conditions for deformation of the metal in the transverse direction, which has a positive effect on the reduction of anisotropy of properties.

Although there are currently a number of technologies allowing to realize the shear deformation in both the longitudinal and the transverse direction, but the manufacturers of rolled plates of non-ferrous metals and alloys, still have the task of developing such a rolling process in which it was possible to get plates with specified quality with little change in the cross-sectional dimensions of the workpiece. This will allow to save metal, reduce the required deformation force, costs of labour and energy due to reduced number of passes of the metal through the working stands.

Therefore, knowing the advantages of rolling with additional shear deformations, we have developed energy-saving technology of rolling thick-sheet metal, allowing to solve this problem and designed two new designs of the pair of work rolls with a relief surface in the form of annular grooves forming a trapezoidal protrusions and depressions alternating each other along the entire length of the barrel [6] (the first pair with unequal ratio of the ledge to the cavity – «the first scheme» (Fig. 1a); and the second pair with equal ratio of the ledge to the cavity - «the second scheme» (Fig. 1b) to implement this technology in practice.

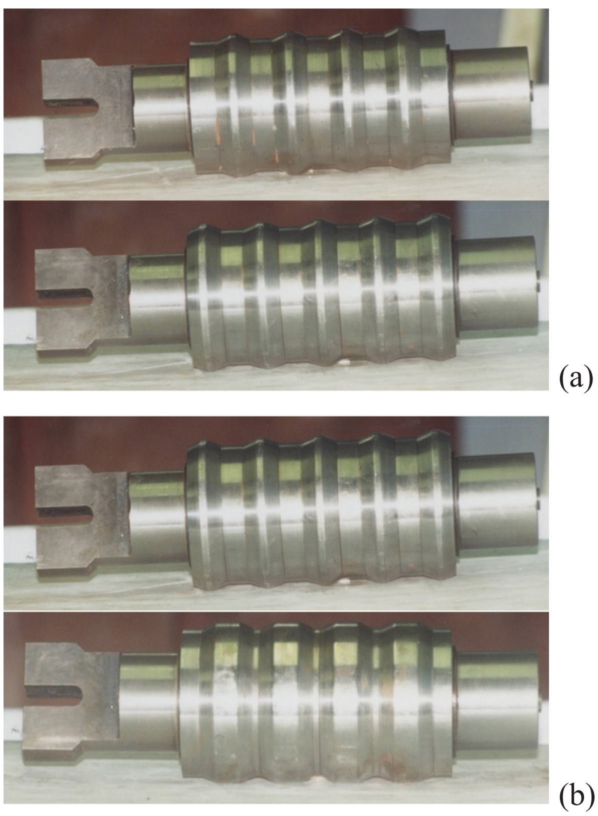


Fig. 1. Relief rolls: (a) - relief rolls with unequal ratio of the ledge to the cavity; (b) - relief rolls with equal ratio of the ledge to the cavity.

In the first case, in the gap between the rolls in all directions is stored the value of the distance between the rolls, i.e. the deformation in these rolls is that only the scheme of pure shear (Fig. 2a). In the second case, the distance between the horizontal and sloping areas is different - on sloping area it is significantly less (Fig. 2b). So here, along with a shear on the horizontal areas are also implemented compression on sloping areas.

COMPUTER SIMULATION

For a comparative analysis of the effectiveness of the proposed technology of rolling was performed a computer modeling in the program DEFORM-3D (Fig. 3). Because rolling in relief rolls is the initial activity for localization of the metal flow and intensification of the deformation of the inner layers, after the first pass were installed 2 pairs of smooth rolls for subsequent straightening of the workpiece. The initial workpiece had dimensions of 25 x 100 x 200 mm. The gap between both pairs of relief rolls was set at 25 mm. In smooth rolls, due to the lack of possibility of realization of shear deformation, the gaps

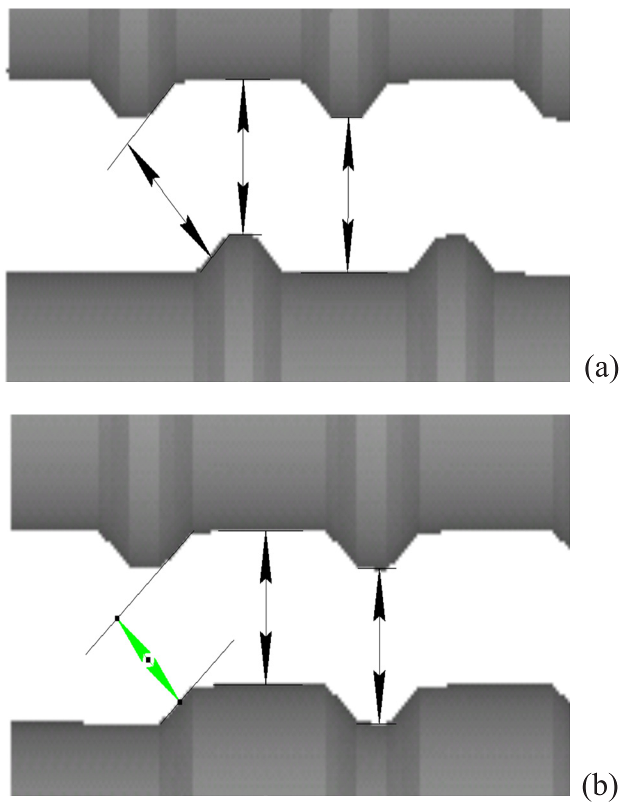


Fig. 2. The design of the gaps in relief rolls: (a) the first scheme; (b) the second scheme.

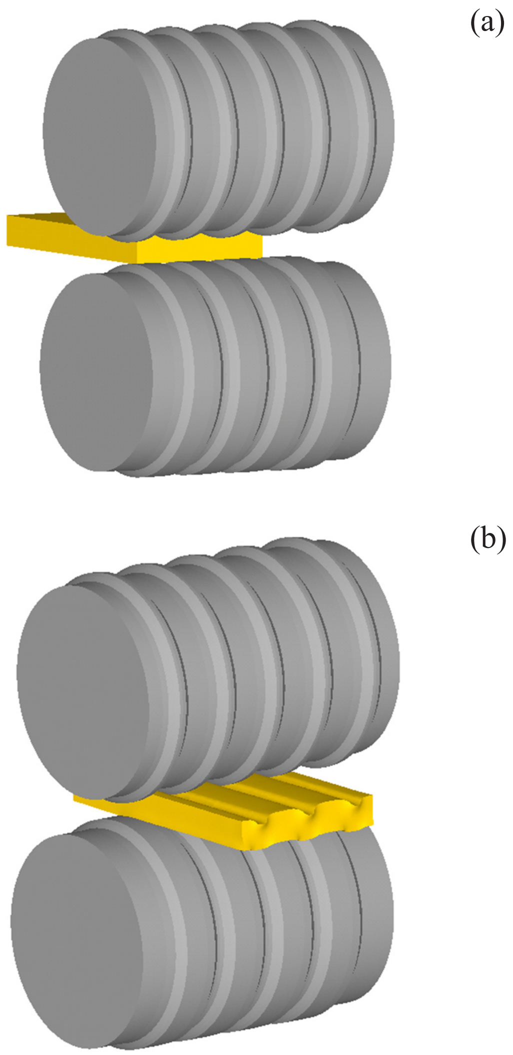


Fig. 3. Model of rolling in relief rolls: (a) - filing of work-piece in the roll gap; (b) - process of rolling.

were exposed for sequential compression 2 mm per pass (23 mm in the first pair of rolls; 21 mm in the second pair). Copper alloy grade M1 was chosen as material. Since the solidus temperature of this alloy is equal to 1083°C, the mode of heating was chosen to 900°C. Roll rotation speed was equal to 64 rpm, in accordance with the specification of laboratory mill DUO-120, available in the rolling laboratory of the University. The friction coefficient was taken equal to 0.4, as recommended by the program for copper alloys.

The results of modeling of the deformation are shown in Figs. 4 and 5.

After rolling according to the first scheme across the entire width of the workpiece appear cavities of the same shape and size. In this case, the depth of the cavity

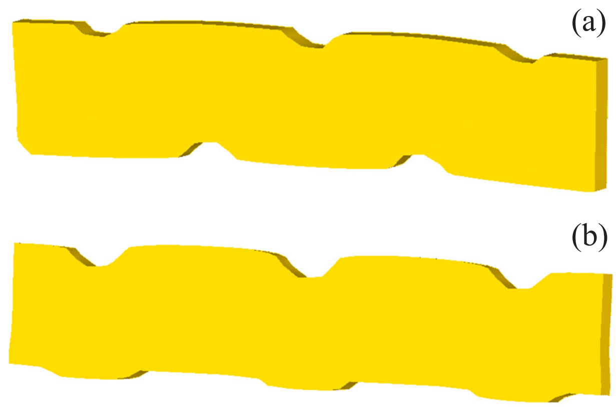


Fig. 4. The profile of the workpiece after rolling in relief rolls: (a) the first scheme; (b) the second scheme.

equal to 3.5 mm and a height of the ledge on the roll of 5 mm. The incomplete filling of the gap between the rolls is due to the lack of compression (Fig. 4a).

After rolling according to the second scheme across the entire width of the workpiece appear cavities of different shapes and sizes. Because of the equality of the sizes of ledges and cavities on the upper face of the workpiece arise deep and narrow cavities with a depth of 5 mm. On the bottom face appear wide cavities with a depth of 2 mm (Fig. 4b). This uneven metal flow can be explained by the presence of compression on sloping areas, which creates zones of local inhibition. Therefore, the upper area of the gap is completely filled. The lower zone is not completely filled, because of the particular construction the lower cavities have a relatively large width, which leads to significant friction forces which retard the metal flow in the transverse direction.

After two passes of rolling on smooth rolls in the first scheme, the workpiece had a small cavities with a

Fig. 5. The profile of the workpiece after rolling in smooth rolls: (a) the first scheme; (b) the second scheme.

depth of 0.5 - 0.7 mm on both faces (Fig. 5a). After two passes of rolling in the second scheme, the workpiece had cavities with a depth of 2.8 - 3 mm on the upper face, while on the bottom face the cavities completely leveled out after the first pass in smooth rolls (Fig. 5b).

To determine the minimum required compression for perfect straightening the simulation was continued with a reduction of gap as 1 mm per pass.

Subsequent modeling showed that full straightening of the workpiece in the first scheme occurred when the thickness of the workpiece was 20 mm; in the second scheme, when the thickness of the workpiece was 17 mm. Thus, after full straightening the workpiece had the following dimensions:

A) the first scheme: 20 x 105 x 238 mm;

B) the second scheme: 17 x 106 x 277 mm.

Also for a comparative analysis of the effectiveness of the proposed technology of rolling has been studied strain state of metal. As the strain state analysis allows us to study the distribution of accumulated plastic deformation throughout the volume of the workpiece during the deformation, to identify those areas that are more susceptible to deformation, and based on this to determine rational parameters of deformation.

In common case all components of the deformation tensor is not zero and must be calculated. However, since the strain tensor is an object that is very difficult to visualize, for practical purposes was used a simple measure of the intensity of deformation, effective strain, which includes the components of deformation in the following form:

$$\varepsilon_{EFF} = \frac{\sqrt{2}}{3}\sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_3 - \varepsilon_1)^2} \quad (1)$$

where ε_1, ε_2 and ε_3 are the main strains.

In the first scheme after relief rolls the deformation is localized around the cavities, going deeper into the workpiece. The average value of effective strain in the central layers is 0.15; in the surface layers it is 0.65 (Fig. 6a).

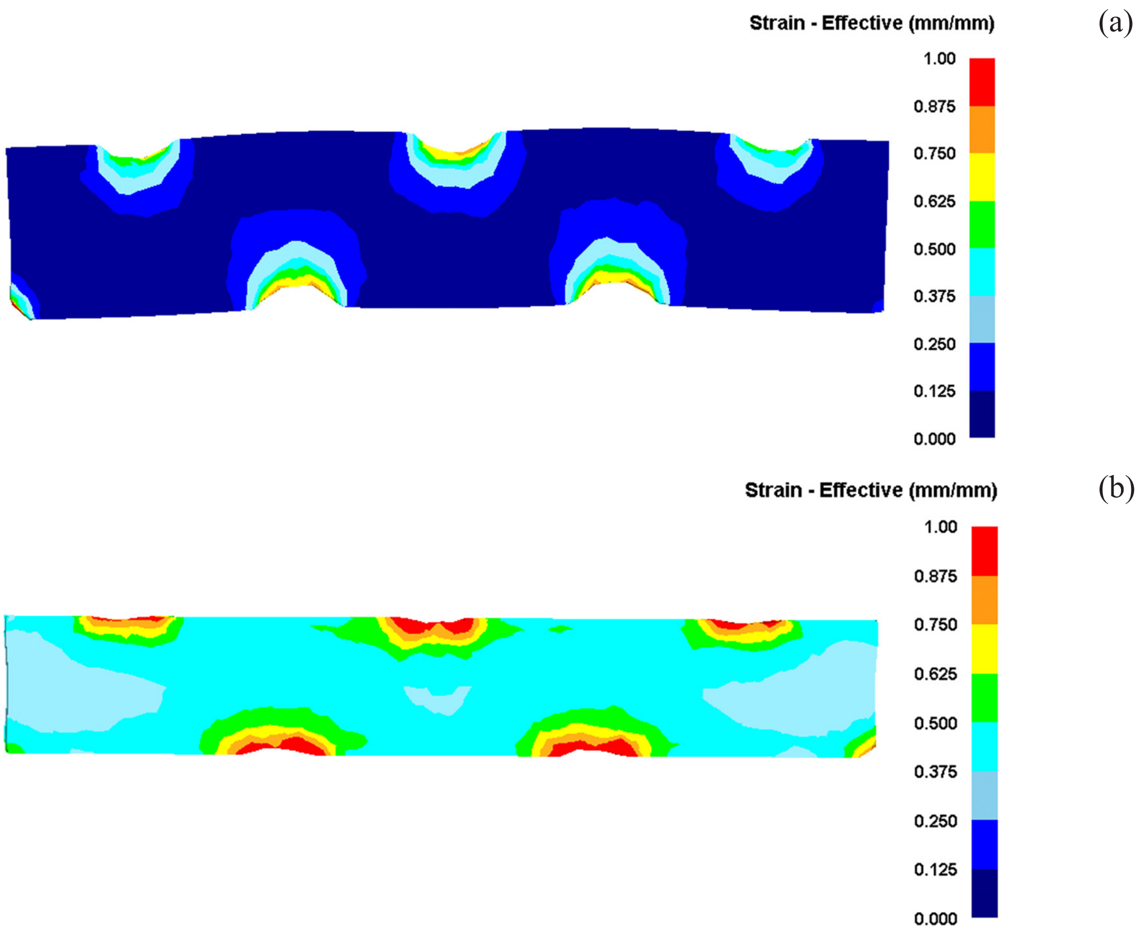


Fig. 6. Effective strain after rolling in the first scheme: (a) - after relief rolls; (b) - after two pairs of smooth rolls.

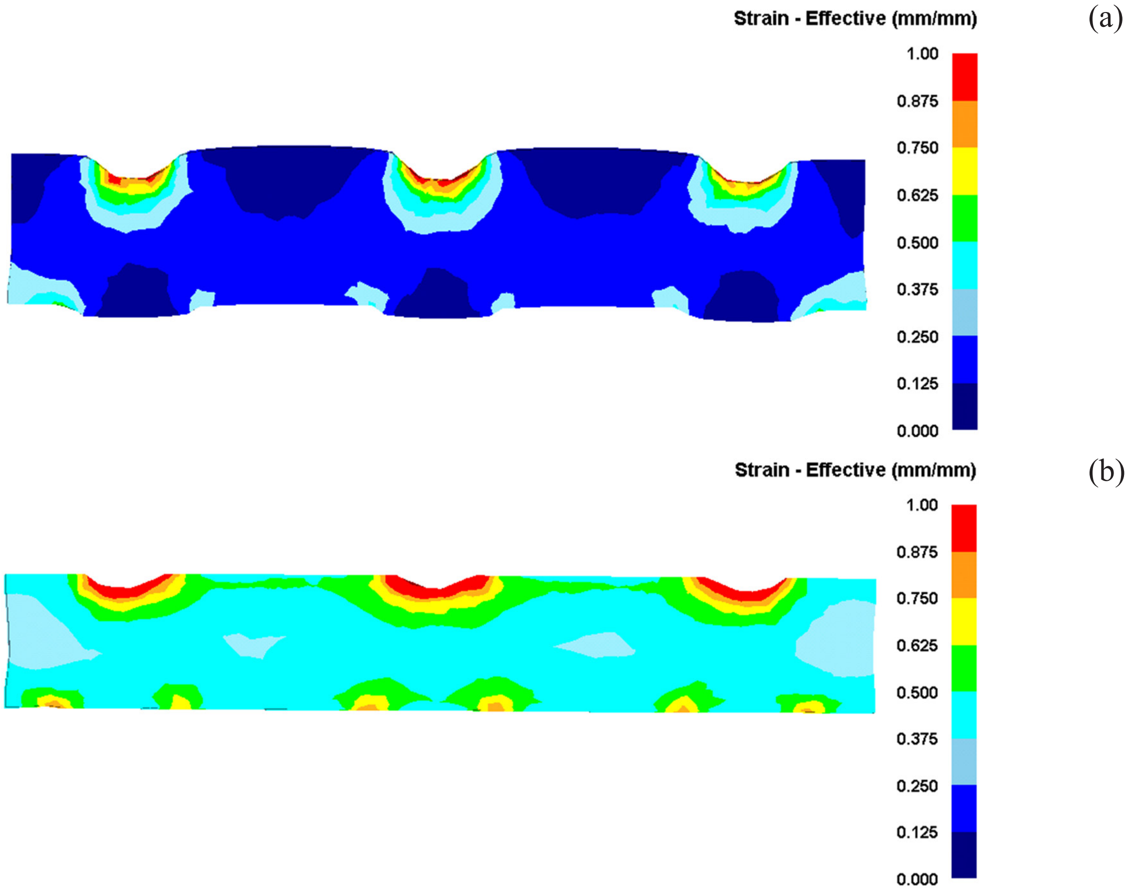


Fig. 7. Effective strain after rolling in the second scheme: (a) - after relief rolls; (b) - after two pairs of smooth rolls.

After two passes in smooth rolls, the development of deformation throughout the volume of the workpiece takes place. Zones of the cavities with a maximum value of deformation are stretched in the transverse direction. The average value of effective strain in the central layers is 0.5; in the surface layers is 0.95 (Fig. 6b).

In the second scheme, after relief rolls the deformation is localized around the cavities of the upper face, going deeper into the workpiece and merging with the deformation areas of the cavities of the bottom face. This is possible because of the additional compression deformation. The average value of effective strain in the central layers is 0.1; in the surface layers of the upper face - 0.75; in the surface layers of the bottom face it is 0.4 (Fig. 7a).

After two passes in smooth rolls deformation throughout the volume of the workpiece is also developing. The zones of the cavities of the upper face with a maximum value of deformation are stretched in the transverse direction. The zone of the cavities of the bottom faces are localized in small areas, characterizing the ends of the wide cavities. The average value of effective strain in the central layers is 0.4; in the surface layers of the upper face is 1; in the surface layers of the bottom face it is 0.7 (Fig. 7b).

LABORATORY EXPERIMENT

To confirm the simulation results and for a deeper study of the effect of new rolling technology on quality and energy-power parameters of the process, we had conducted a series of laboratory experiments on the mill DUO-120 (Fig. 8).

The first experiment was conducted on lead samples of rectangular shape with dimensions 25 x 100 x 200 mm. On the small side faces a grid with a step of 5 mm was applied.

The deformation of the workpieces was carried out in five passes, in both pairs of rolls, with a gap reduction in each pass 1 mm. Then on a laboratory mill set

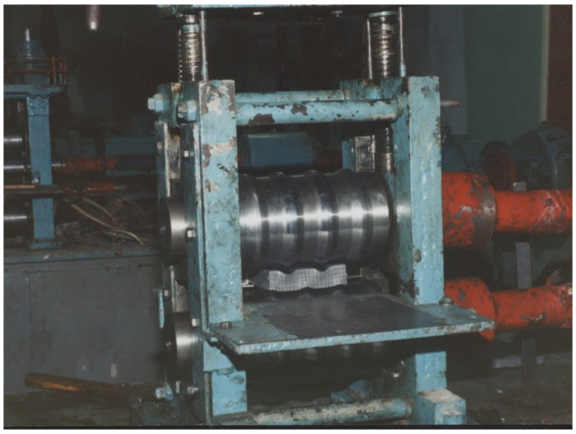
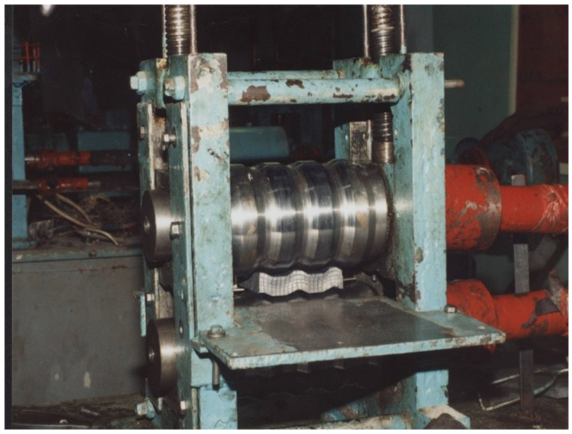
(a)  (b) 

Fig. 8. Rolling of the workpieces in relief rolls on laboratory mill DUO-120: (a) - the first scheme; (b) the second scheme.

smooth rolls deformation of the workpieces was produced in order to straighten their surface. Straightening of workpieces produced with a gap reduction of each pass of 1 mm.

While straightening of workpieces, deformed in rolls of the first scheme, it occurred after the 7th pass, whereas the workpiece, previously deformed in the relief rolls of the second scheme, it straightened fully only after the 9th pass.

Control measurements of deformed workpieces showed the following:

a) workpiece after rolling of the first scheme and straightening has dimensions 19.8 x 105,3 x 239,8 mm;

b) workpiece after rolling of the second scheme and straightening has dimensions 17.2 x 106,3 x 273,5 mm.

As can be seen from the above experimental results, resize of workpiece in rolls of the first scheme is less than in rolls of the second scheme. The results of laboratory experiments showed a good correlation with the simulation results with the software package DEFORM.

In the second phase of the experiment using the coordinate grid an analysis of the intensity of shear strain was made, defined by the formula [2]:

$$\varepsilon_{SH} = tg\alpha \quad (2)$$

where α is the angle of inclination of the coordinate grid after deformation.

In the case of using of relief rolls of the first scheme, the intensity of the shear strain is greater than when using the relief rolls of the second scheme.

So, after the first pass, using rolls of the second scheme, the intensity of shear deformation amounted ε_{sh} = 0,101, while using rolls of the first circuit, this parameter was equal to ε_{sh} = 0.146. After the fifth pass the intensity of shear strain amounted ε_{sh} = 0,384 and ε_{sh} = 0.43 respectively. Thus, the development of shear strain using rolls of the first scheme is 20 % more than using rolls of the second scheme (Fig. 9).

In addition to the main tasks of this experiment, the forces of the forming in relief and smooth rolls after each pass was calculated, and the force of deformation in the straightening of the workpiece after rolling her in relief rolls.

The calculation results were confirmed by the force measurement during the experiment on lead samples. Measuring the force in the experiment was produced us-

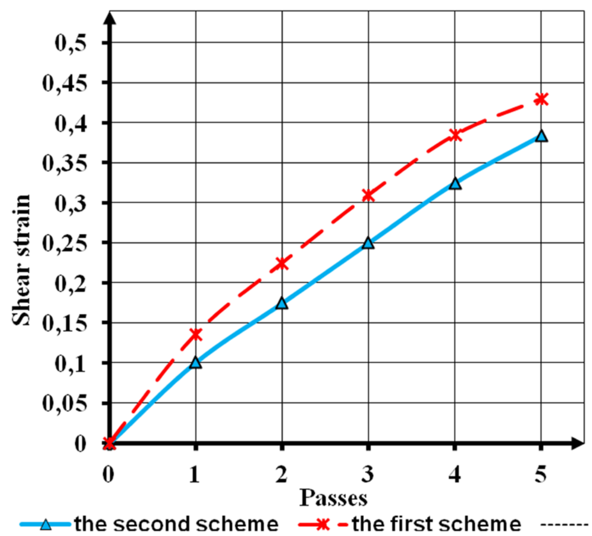


Fig. 9. The intensity of shear strain after rolling in relief rolls.

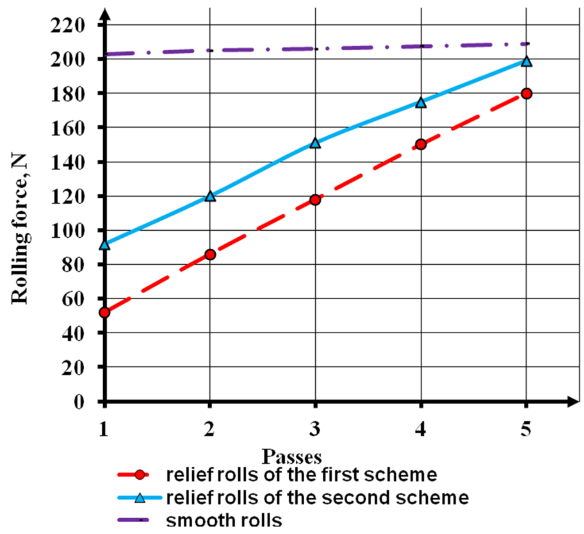


Fig. 10. Rolling force during deformation of lead workpieces in smooth and relief rolls.

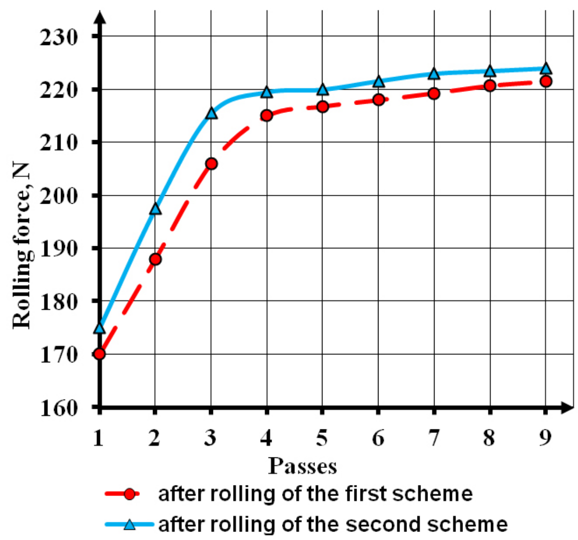


Fig. 11. Rolling force after straightening of lead workpiece in smooth rolls.

ing load cells with an annular elastic elements mounted between the roll chocks and press screws. Load cells were equipped with a wire resistance strain gauges TKFO1-2-200, collected in bridge scheme [7]. The strain gauges were glued in pairs in diametrically opposite planes and were included in the respective shoulders of the bridge. The amplification was carried out using a strain-gauge station ZET-017-T8.

Using measurement results plots of forces from the number of passes (Fig. 10) were made, which show that the rolling force in the rolls of the first scheme is with an average 30 % less effort rolling in the rolls of the second scheme and significantly less force of rolling on smooth rolls.

The same relationship is observed when aligning the workpiece after rolling them in relief rolls (Fig. 11). It is seen from the graphs that when using the relief rolls in the early stages of deformation the force is small, because the area of contact at this stage is negligible, as in the deformation of the workpiece in the relief rolls, and when it is aligned it in smooth rolls [8].

CONCLUSIONS

Studies on deformation of a plate workpiece in rolls with a surface relief in the form of annular grooves forming a trapezoidal ledges and cavities alternating each other along the entire length of the barrel (the first pair with unequal ratio of the ledge to the cavity and the second pair with equal ratio of the ledge to the cavity) have been carried out. Computer simulation of the rolling process in the rolls with unequal and equal treatment of the ledge to the depression showed the advantage of the first scheme, because in this case is implemented pure shear without compression, which is beneficial to the uniformity of distribution of accumulated plastic deformation, which, in turn, affects the forming of the workpiece. Laboratory studies have confirmed the simulation results. The analysis of the intensity of shear strain proved the superiority of the first scheme and the analysis of rolling load showed the advantage of using the relief rolls instead of smooth.

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