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DEVELOPMENT AND THEORETICAL STUDY OF NEW SCHEME OF REALIZATION OF COMBINED PROCESS "ROLLING - PRESSING" USING EQUAL CHANNEL STEP MATRIX

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ABSTRACT

Using a computer simulation it was conducted a study of new modification of the combined process "rolling-pressing", the distinctive feature of which is the use at the exit of equal-channel step matrix vertical rolls instead of horizontal rolls. It was performed the investigation on the stress-strain state, the deformation of the workpiece and the microstructure evolution. The values obtained were compared with those of the model with two pairs of horizontal rolls. As a result, it was found that the use of vertical rolls at the exit of the equal-channel step matrix has the following advantages: the treatment of the workpiece is more uniformly throughout the section; in general, by changing the direction of compression during rolling in the vertical rolls the deformation occurs at much lower values of the extrusion, which entails a slight change in the original dimensions of the workpiece; the initial grain size is reduced more intensively both on the surface and in the central zone.

Keywords: rolling - pressing, combined process, vertical rolls, FEM.

INTRODUCTION

Currently, there is considerable interest in the development of industrial technologies of obtaining of metals and alloys with subultrafine-grained structure. This is because the refinement of the structure to ultrafine-grained state in combination with heat treatment allows to achieve in these metals and alloys high level of mechanical and operational properties [1]. To achieve refinement of the microstructure of metals and alloys in the processing of their pressure is possible through the implementation in the process of deformation severe plastic deformation (SPD) of a deformable volume. These methods include equal channel angular pressing (ECAP) [2] and ECAP in parallel channels [3], which in conditions of multi-cycle treatment ensure the formation ultrafine-grained structure in the workpieces with high metal utilization factor, which is important for industrial use. However, these schemes have drawbacks associated with a large number of processing cycles and, accordingly, have higher energy and labor costs while getting products. Also not all SPD methods allow to deform lengthy workpieces, because there are restrictions on the working space of the tool, for example, when pressing the original length of the workpiece is limited to the working stroke of the punch.

To eliminate the above drawbacks was developed a new combined technology of deformation "rolling-pressing" using equal channel step matrix (Fig. 1a) [4]. During the implementation of the deformation process according to this technology the blank is rolled successively in the first pair of horizontal rollers which push it through the channels of equal-channel step matrix. At the exit from the die the billet enters the second pair of horizontal rolls, which pulls the workpiece from the die. As a result of implementation of this process in practice fully removed restrictions on the initial sizes of blanks, and ensured the continuity of the process. The works [5 - 7] have studied the stress-strain state (SSS) in this scheme of deformation and metallography of aluminum and copper alloys, deformed by this technology. In the course of these researches the advantage of the proposed technology has been proved compared to the simple equal channel angular pressing.

It is known from work [8] that to produce ultrafine-grained structure in the workpiece in deformation process it is necessary to develop equivalent strain, in excess of $e = 3$. In this regard, to obtain this level of deformation during realization of combined process "rolling - pressing" using equal channel step matrix it is needed to exercise at least three cycles of deformation. In this case the deformation under this scheme will be harvesting several times to get the compression height when rolling in horizontal pairs of rolls that will result in a significant change in the size and shape of the original cross-section, which is often undesirable, and sometimes a negative factor.

Therefore, this scheme was improved by replacing the second pair of horizontal rolls in vertical rolls (Fig. 1b). Thus, after leaving the matrix, the workpiece will not get the compression height, but in width. As a result, the change of the shape and size of the cross section will not be as intense.

Computer simulation

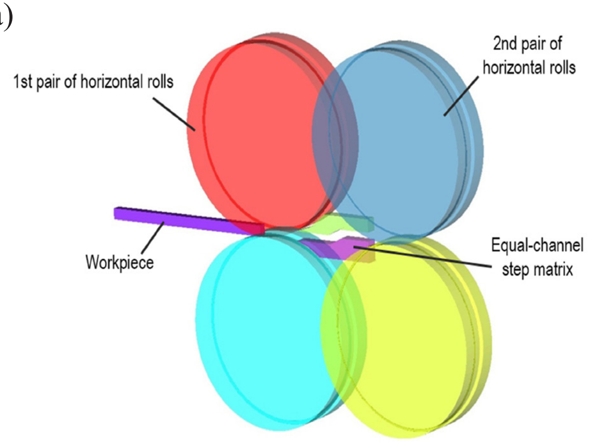
Since the proposed design of the combined process is a new scheme of deformation, this requires a thorough study of the features of the new modification, including a study of the stress-strain state, the deformation of the workpiece, as well as the evolution of the microstructure.

The analysis was carried out with the use of virtual simulation by the finite element method in the software package Simufact.Forming. The dimensions of the original workpiece were 20x15x300 mm. Conditions and assumptions in modelling in the software package Simufact.Forming are:

- workpiece material in the initial state (before deformation) was isotropic and there was no initial stress and strain;
- workpiece was meshed from 180 000 finite elements with an average edge length of an element was equal to 0.5 mm;
- initial temperature of the billet was assumed to 1150 °C, also was attended deformation heating and heat transfer between the workpiece, tool and environment;
- tool was made absolutely rigid; the tool geometry (3D model) was created using the program KOMPAS 3D V15 and saved with the extension STL;
- model of the billet material was assumed to elastic-plastic;
- material adopted in the simulation is AISI 1015 steel corresponding to steel 15, the hardening curves were taken from the library of Simufact. Forming;
- coefficients of friction between the tool and the workpiece were selected based on recommendations from [4] equal to 0.5 at the contact of the workpiece with the rolls, and 0.1 on the contact of the workpiece with the matrix;
- roll rotation speed was equal to 60 rpm.

In work [9] it was found that the most effective way of implementing this combined process is the use

a)



b)

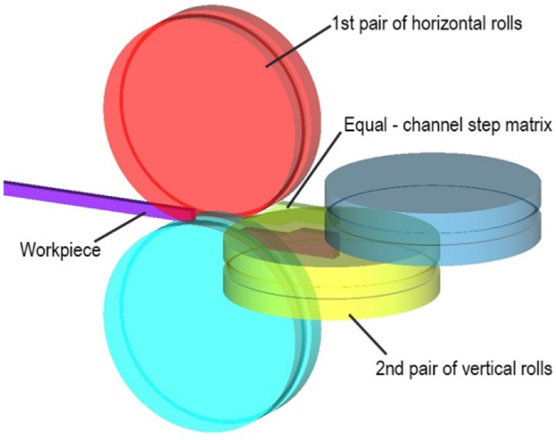


Fig. 1. New design of combined process "rolling-pressing".

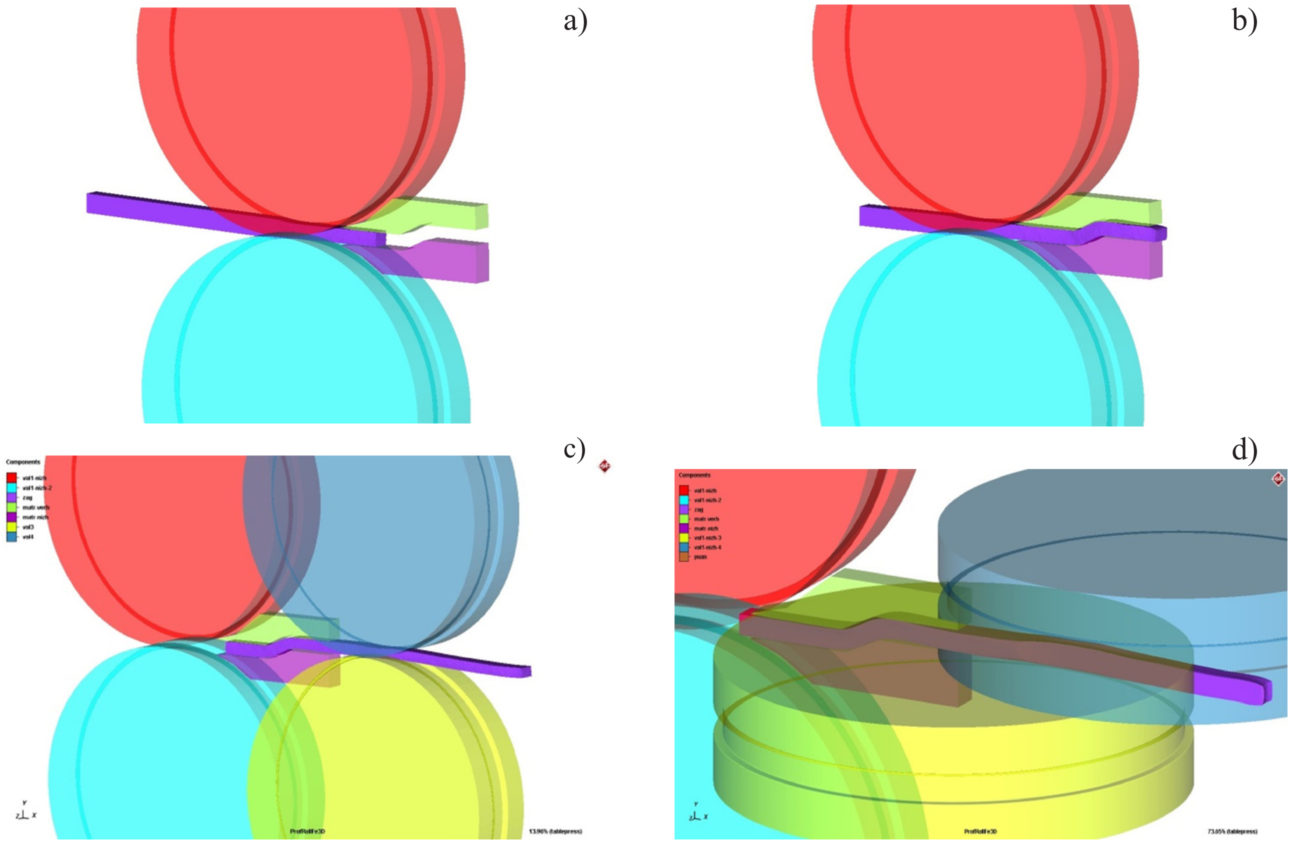


Fig. 2. Stage of combined process: a - rolling in the 1st pair of rolls, b - pressing in the matrix, c - rolling in the 2nd pair of horizontal rolls and the exit from the matrix, d - rolling in the 2nd pair of vertical rolls and the exit from the matrix.

of grooved rolls, since in this case the intensification of active friction forces around the perimeter of the gauge, and provides the ability to control the broadening of the workpiece. Using rolls with smooth barrel can only be justified by the fact, it needs to carry out deformation of billets with different width at one stand. In this case, it is necessary to consider the broadening of the workpiece, the value of which will be affected by the back pressure from the matrix [10]. In this case, the decision was made to use grooved rolls.

The result was a successful model of combined process "rolling-pressing". In it the workpiece is sequentially captured by the first pair of horizontal rolls (Fig. 2a), which pushes it through the channels of equal-channel step matrix (Fig. 2b). At the exit from the mattrix the billet enters to the second pair of rolls, which pulls the workpiece from the matrix (Fig. 2c, 2d).

After receiving the finished model was examined for the following parameters:

- stress-strain state (equivalent stress and equivalent strain);
- forming of the workpiece (dimensions of the cross section of the sample at the output of the second pair of rollers);
- evolution of the microstructure (average grain size).

The values obtained were compared with similar data from the model with two pairs of horizontal rolls.

RESULTS AND DISCUSSION

Stress state

As shown by the comparison of the equivalent stress, in both cases there is a similar picture of the distribution of this parameter. On the workpiece are clearly visible three characteristic zones, which define key stages of deformation - two small deformation zone during rolling in the rolls, and one sufficiently long deformation during compaction in the matrix that occurs in the zone of junction of the channels (Fig. 3 a, 3b).

The average stress in the deformation zones of rolls is equal to 110 - 120 MPa, in the zone of junction of the channels of the matrix it reaches 135 - 145 MPa. A distinctive feature of this process in both cases is the effect of back pressure from the matrix. It is evident in the area between the butt zone of the channels and deformation of the 1st pair of rolls throughout the length of the area the stress acts, up to 80 - 90 MPa. In the area between the butt zone of the channels and the deformation zone 2nd pair of rolls, the influence of the backpressure is significantly lower, as after overcoming the zone of junction of the channels, the workpiece is moving at a certain speed and hits the 2nd pair of rolls, the diameter of which provides not backwater, but a small tension. Here the stress is in the range of 40 - 50 MPa.

Strain state

In the analysis of the strain state it was found that the use of vertical rolls leads to a more uniform distribution of equivalent strain throughout the volume of a deformable workpiece. This is evident from the simulation results in Fig. 4.

In both cases, the level of equivalent strain reaches the value e = 1 or more in a single pass. However, when using horizontal rolls at the output of the accumulation of deformation it is only at the height of the workpiece. As a result the central layers of the billet are worked less intensely than the surface (Fig. 4a). The use of vertical rollers allows a compression of the workpiece across the width, which, in fact, is equivalent to a tilting of the workpiece by 90 degrees. As a result, the distribution of equivalent strain after rolling in the vertical rolls is more uniform throughout the volume of the workpiece (Fig. 4b).

Forming of the workpiece

Key parameters in the study of the forming of the workpiece during of this combined process are dimensions of the cross section of the sample at the output of the second pair of rolls. The initial preform had dimensions of the cross section h_0 x b_0 = 20 x 15 mm; cross-sectional area was 300 mm^2. After compression in the first pair of rolls dimensions of the cross section amounted to h_1 x b_1 = 15 x 18,2 mm; cross-sectional area was equal to 273 mm^2; elongation factor amounted to λ_1 = 1,098.

After compression in the second pair of rolls horizontal dimensions of the cross section h_{2H} x b_{2H} = 12 x

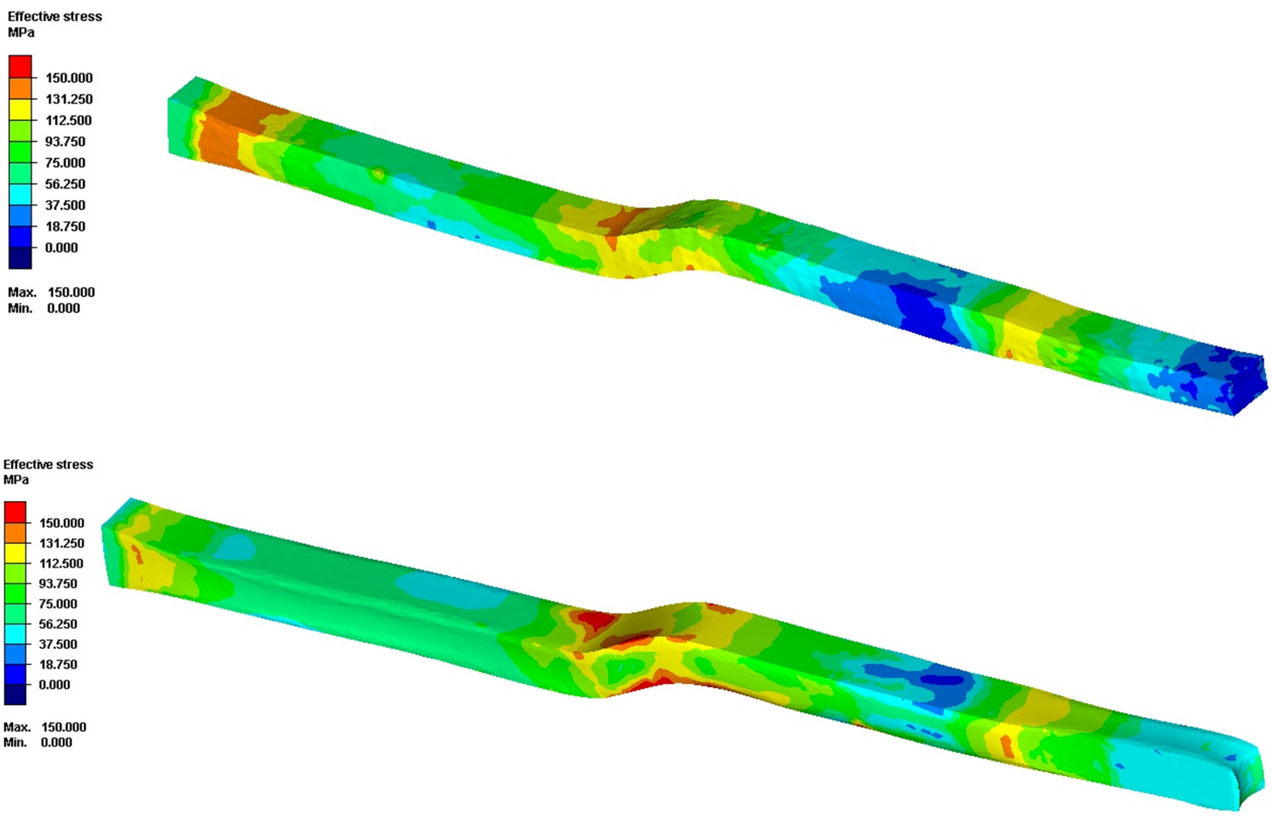


Fig. 3. Equivalent stress: a - model with horizontal rolls at the exit from the matrix, b - model with vertical rolls at the exit from the matrix.

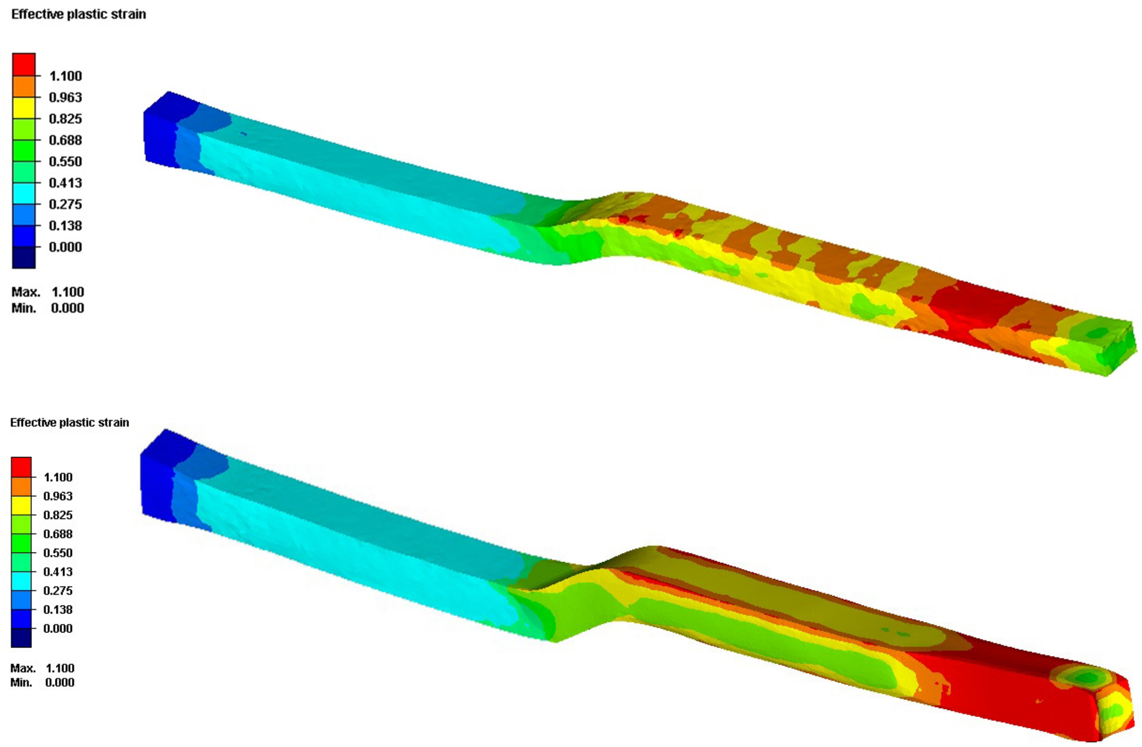


Fig. 4. Equivalent strain: a - model with horizontal rolls at the exit from the matrix, b - model with vertical rolls at the exit from the matrix.

19,8 mm; cross-sectional area was equal 237,6 mm^2; elongation factor amounted λ_{2H} = 1,149.

After compression in the second pair of vertical rolls, the cross-sectional dimensions h_{2V} x b_{2V} = 15 x 16,9 mm; cross-sectional area was equal 253,5 mm^2; elongation factor amounted λ_{2V} = 1,076.

Thus, it is established that the use of vertical rolls at the exit from the matrix allows to produce the combined process "rolling-pressing" with significantly lower values of elongation, which entails a slight amendment to the original size of the workpiece.

Evolution of the microstructure

To study the evolution of microstructure was used the specialized database of the microstructure of the MATILDA program. This program is a tool for modeling physico-chemical processes in deformable billet and is a modular add-on to the program SIMUFACT. MATILDA uses the data of stress-strain state, strain rate and temperature of ready designed models to SIMUFACT.forming complements them with the data of physico-chemical properties and their behavior for a given material and its structure from the database, the algorithm YADA [11], calculates the process parameters of static and dynamic recrystallization that may cause changes in grain size. Grain size is also calculated for each node of the finite element model and displayed at the end of the simulation at any convenient time for rendering the form.

The simulation of the microstructure in the program uses the assumption that the workpiece before the deformation has a uniform structure with the same grain size at any point. As the initial size was adopted the average grain diameter of 40 μm. The results of simulation are presented in Figs. 5 and 6.

During rolling in the first pair of rolls the surface layers of the workpiece are subjected to intense deformation, leading to considerable grain refinement from 40 μm to 30 μm. After passing through the channels of the matrix through the implementation of shear strain there is a further grain refinement to 22 μm. After the second pair of horizontal rolls, the grain size on the workpiece surface is 18 μm.

The central layers of the billet during rolling in the first pair of rolls are worked less intensely - here the grain size is changed from 40 μm to 32 μm. After passing through the channels of the matrix grain size in the central zone varies from 32 μm to 28 μm. After the second pair of horizontal rolls, the grain size in the

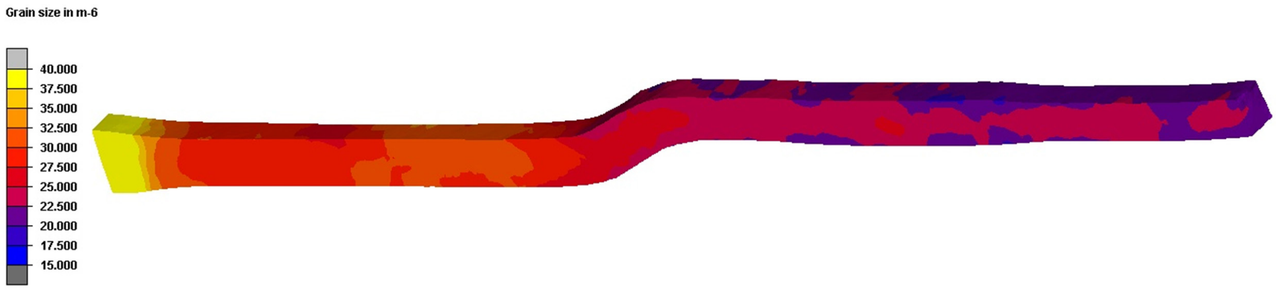


Fig. 5. Change of grain size in the longitudinal section of the billet during horizontal roll at the exit of the matrix.

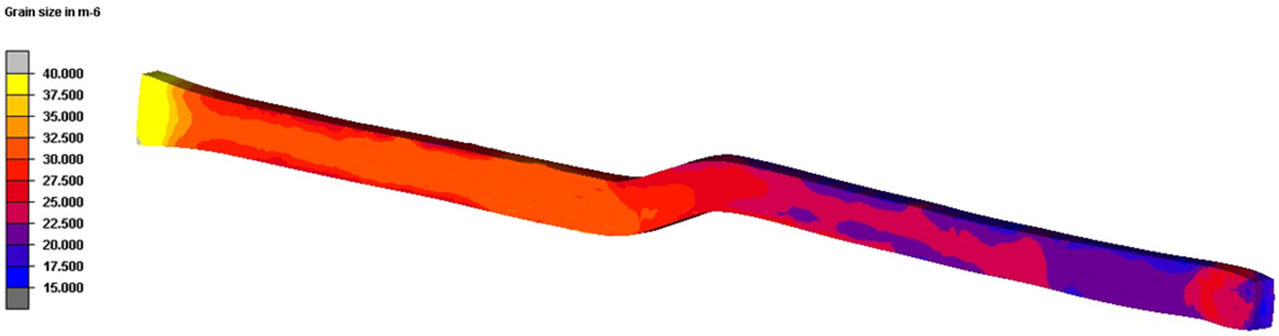


Fig. 6. Change of grain size in the longitudinal section of the billet during vertical roll at the exit of the matrix.

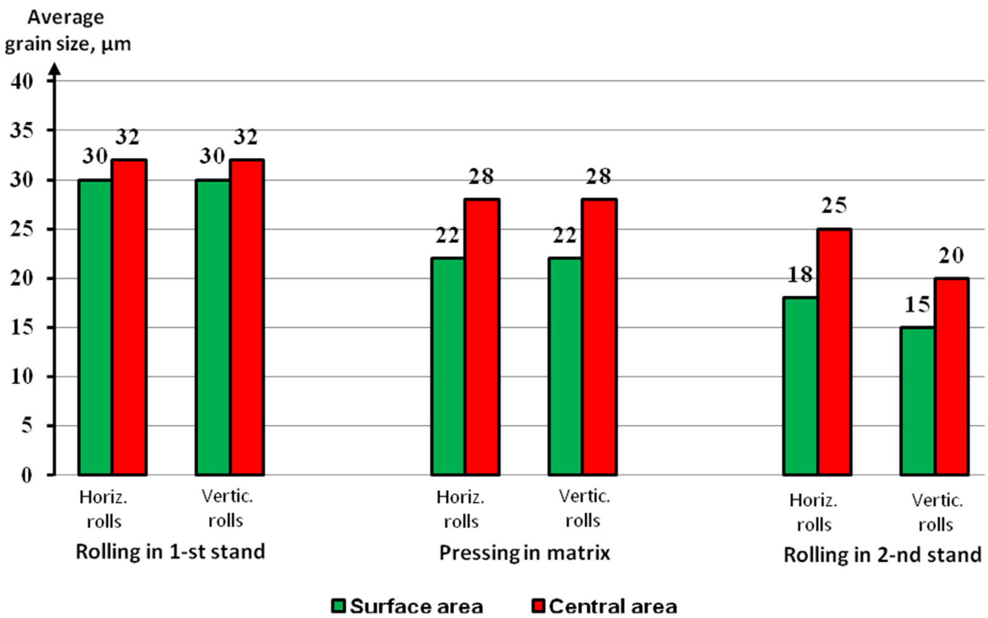


Fig. 7. Summary chart of the calculation of grain size.

central part of the billet is 25 mm.

When using vertical rolls at the exit from the matrix study and surface, and the central zone is more intensive. The average grain size at the surface is 15 µm; in the central zone of 20 µm. The summary of the results of the calculation of the microstructure is presented in Fig. 7.

Thus, during study of the microstructure evolution, it was found that using vertical rolls at the exit from the matrix has double effect. First, the grain is reduced more intensively both on the surface and in the central zone, which is directly related to the direction of compression of the workpiece. Second, the treatment of the structure of metal is more evenly, as evidenced by the difference of grain size between the central and surface areas in both considered variants.

CONCLUSIONS

During the simulation it was conducted a study of a new modification of the combined process "rolling-pressing", the distinctive feature of which is the use of vertical rolls at the exit from the matrix. It was performed investigation of the stress-strain state, forming of the workpiece and microstructure evolution. The values obtained were compared with similar data of the model with two pairs of horizontal rolls. As a result, it was found that the use of vertical rolls at the exit of the equal-channel step matrix has the following advantages: the treatment of the workpiece is more uniformly throughout the section; in general, by changing the direction of compression during rolling in the vertical rolls the deformation occurs at much lower values of the extrusion, which entails a slight change in the original dimensions of the workpiece; the initial grain size is reduced more intensively both on the surface and in the central zone and more evenly. Minor weakness of this method is the complexity of the mechanical design of equipment during fabricating a laboratory-industrial stand by installing a vertical stand.

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