CONCEPTS ANALYSIS OF ASYMMETRY FACTOR IMPLEMENTATION DURING ROLLING IN RELIEF ROLLS

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ABSTRACT

This paper presents finite element modeling of various options for implementing the asymmetry factor during rolling in relief rolls. Models of kinematic asymmetry (with different roll rotation speeds), geometric asymmetry (with different roll diameters), and contact asymmetry (with different friction coefficients of the rolls) were considered. For a comparative analysis, the shape change in the longitudinal and transverse directions, equivalent strain, Mises strain, equivalent stress, average hydrostatic pressure, and deformation force were considered. The simulation results showed that contact asymmetry is the least effective option, where the simulation results for all parameters are very close to those of the symmetrical rolling process in relief rolls. Kinematic and geometric asymmetries have shown good results in terms of the development of additional shear deformation in the longitudinal direction. The final scheme of the process must be selected based on the actual technological data of the rolling mill.

Keywords: asymmetric rolling, thick-sheet billet, modeling, FEM, stress-strain state.

INTRODUCTION

The development of metallurgical production is impossible without the development of fundamentally new technologies and equipment that make it possible to obtain high-quality products at the lowest cost of production. Obtaining high-quality 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 are mainly associated with the development of new technological processes.

A promising direction for improving the quality of finished products is the development of new deformation schemes that implement intensive shear and alternating deformation over the entire volume of the processed metal. Currently the most well-known SPD methods are equal-channel angular pressing (ECAP) [1 - 4] and high-pressure torsion (HPT) [5 - 8]. These methods and their various modifications make it possible to significantly grind the initial structure of the metal and significantly increase its mechanical properties level. However, these methods are intended for processing only small blanks in length; therefore, they still only require “laboratory” methods. In recent years, attempts have been made to circumvent this limitation, and as a result, a number of combined processes have been developed, in which the ECAP process has been combined with rolling or drawing processes that allow the deformation of long blanks [9 - 11]. Despite this technological advantage, these combined processes allow the deformation of workpieces with small cross-sectional areas. Therefore, the development of new SPD methods has been directed towards the creation of a new deformation scheme for more massive workpieces.

The most promising scheme in this aspect is the rolling of thick sheet blanks in relief rolls [12]. This scheme has been proven effective when deforming brass blanks [13]. However, a large number of deformation cycles is required to obtain a given processing level. To reduce the number of processing cycles, it is necessary to increase the single processing level, that is, to increase the level of deformation in one pass. This is possible if an asymmetry factor is added to the deformation scheme.

Asymmetric rolling is a metal forming method that can realize large shear deformations. Purposeful asymmetry is achieved by combining the following factors: difference in the roll diameters, difference in the contact friction conditions of the upper and lower rolls, difference in the roll speeds, temperature difference (temperature factor), and rigid angle of entry and exit of the strip from the deformation zone [14 - 18]. This asymmetry makes it possible to increase the compression deformation during rolling because the negative effect of contact friction is reduced and large shear deformations in the longitudinal direction are created in the deformation zone. In conjunction with the rolling scheme in relief rolls, that implements shear deformation in the transverse direction, the new deformation scheme reduces the number of deformation cycles required to achieve a given processing level.

EXPERIMENTAL

In [19], a study on relief roll rolling with the addition of kinematic asymmetry was presented. The most effective method is to use an asymmetry coefficient of 1.5. Therefore, for adequate comparative analysis, it was decided to use this value of the asymmetry coefficient. When considering possible schemes for asymmetric rolling implementation, methods that can be implemented under the laboratory conditions of Karaganda Industrial University were selected. From this position, the following types of asymmetry were selected: kinematic (difference in roll rotation speeds), geometric (difference in roll diameters), and contact (difference in the contact friction conditions of the upper and lower rolls).

To evaluate the effectiveness of the proposed deformation schemes, computer modeling was performed using the finite element method (FEM) in the Deform v.13 program, and three-dimensional geometric models were constructed in the Kompas-3D program.

Taking into account the asymmetry coefficient equal to 1.5, the following deformation conditions were determined:

- For kinematic asymmetry: the rotation speed of the upper roll was 60 rpm, and the rotation speed of the lower roll was 90 rpm;
- For geometric asymmetry: the diameter of the upper roll was 200 mm, and the diameter of the lower roll was 300 mm;
- For contact asymmetry: the friction coefficient on the upper roll was 0.3, and the friction coefficient on the upper roll was 0.5.

In all three variants, the increased values of the indicators were applied to the lower roll such that in the case of possible curvature of the workpiece in the longitudinal direction, the bend was directed upward. The diameter of the rolls in the models with the contact and kinematic asymmetries was 200 mm. The length of the rolling barrels was 500 mm. The bevels' channel angle on the protrusions and depressions was equal to 45°. The blank was a rectangular sheet with a cross-section of 10 × 400 mm and a length of 350 mm. Simultaneously it was decided to simulate rolling with a plane of symmetry in width, that is, in the model, the width of the blank was equal to 200 mm, which was mirrored. Brass L63 was used as workpiece material. The following technological parameters were used in the computer modeling of the process:

- The workpiece material was completely isotropic;
- Rolling was performed at an ambient temperature of 20°C;
- The workpiece heating temperature before rolling was 600°C;
- The heat exchange coefficient of the workpiece with the tool was 5000 W/(m^2 °C);
- Workpiece heat exchange coefficient with the environment was 0.002 W/(m^2 °C);
- In order to create the most stringent capture conditions in the models of kinematic and geometric asymmetry, the friction coefficient at the contact of metal with rolls was adopted 0.5 (which corresponds to a roughened surface with a high level of roughness);
- The roll rotation speed in the geometric and contact

asymmetry models was 60 rpm.

For the analysis, it was decided to consider the following parameters: shape change in the longitudinal and transverse directions, equivalent strain, Mises strain, equivalent stress, average hydrostatic pressure and deformation force.

RESULTS AND DISCUSSION

When analyzing the shape change, the following process features were revealed: in the transverse direction, an identical change in the workpiece shape was observed in all three models - taking the form of a gap between the rolls, the workpiece does not fill it completely (Fig. 1). Therefore, for the analytical determination of the energy-power parameters (for example, the rolling force), it is necessary to consider this factor and determine the actual contact surface area as a certain fraction of the maximum possible, the value of which can be determined by determining the roll geometric parameters. It was also noted that on the horizontal and inclined sections of the workpiece, the thickness remained almost unchanged.

The following features in the longitudinal direction were observed (Fig. 2). In all three models, due to the rolls relief profile, the workpiece during rolling takes the form of a gap between the rolls. As a result, the protrusions and depressions formed on the workpiece act as stiffeners that prevent the workpiece bending. In models with contact and geometric asymmetry, bending in the vertical plane is completely absent. In a model with kinematic asymmetry, a slight bend is observed which is

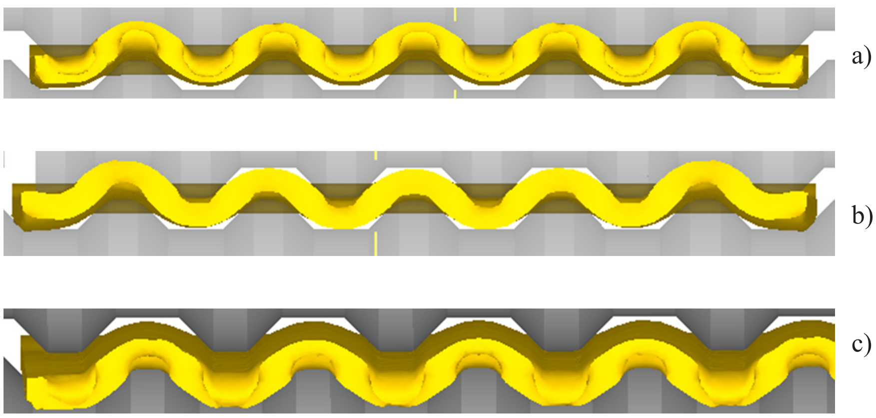

Fig. 1. Shape change in the transverse direction: a) - contact asymmetry; b) - geometric asymmetry; c) - kinematic asymmetry.

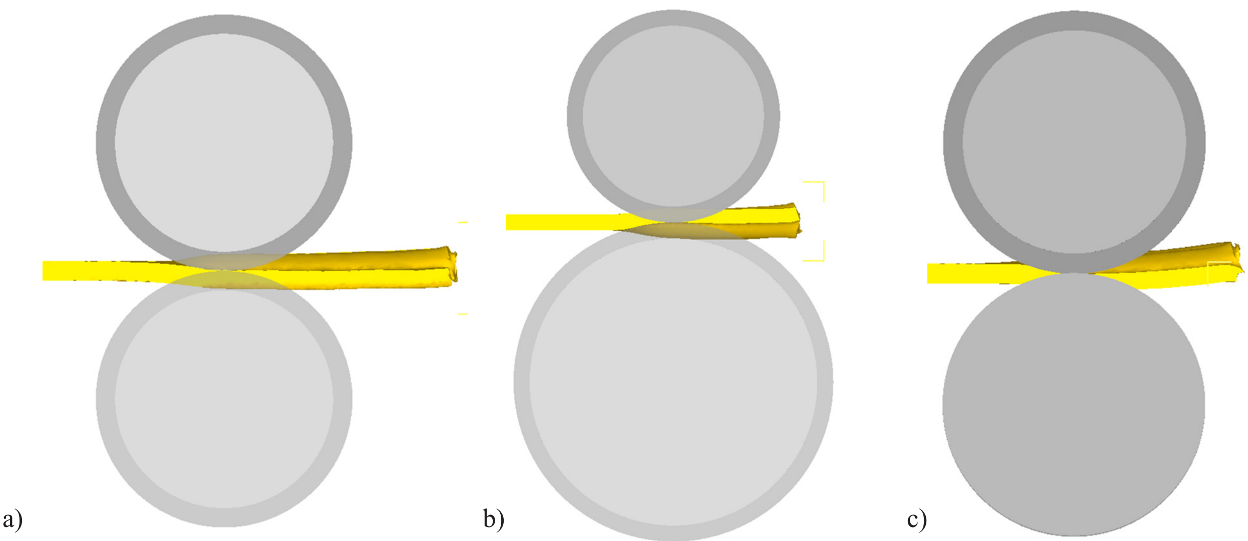

Fig. 2. Shape change in the longitudinal direction: a) - contact asymmetry; b) - geometric asymmetry; c) - kinematic asymmetry.

insignificant according to the results of work [19], since it does not prevent the workpiece from being captured by the rolls of the next stand.

When analyzing the strain state, an equivalent strain is usually considered. This parameter characterizes the level of strain accumulation from any types of deformation effects (stretching, compression, torsion, shear). When considering this parameter (Fig. 3), a fairly uniform strain distribution over the cross section was revealed in contact asymmetry model. The average strain level here is 0.45. In a model with geometric asymmetry, due to the difference in the rolls diameters, there is a mismatch of linear velocities on the rolls surface, i.e. the surface layers of metal in contact with a roll of a larger diameter receive a higher linear velocity than the opposite face. As a result, the average strain level on the upper face is 0.55, and on the lower one is 0.65. Thus, geometric asymmetry leads to uneven strain along the cross section by 18 %.

In kinematic asymmetry model an extremely uneven strain distribution is observed. There is also a mismatch of linear velocities on the rolls surface due to different circumferential velocities. This leads to the fact that the surface layers of metal in contact with a faster roll receive a higher linear velocity. As a result, the average strain level on the upper face is 0.45, and on the lower one is 1.46. Thus, geometric asymmetry leads to uneven strain along the cross section by 220 %. Such a large difference in strain levels in these two models with the same asymmetry coefficient is explained by the different asymmetry nature. With geometric asymmetry, in addition to different speed effects, the workpiece also receives different force effects from the rolls. From the side of the roll of a larger diameter, the length of the deformation zone changes with respect to the roll of a smaller diameter. As a result, there are more intense normal stresses that prevent the mismatch of velocities in the workpiece surface layers. With kinematic asymmetry, the pressure from the rolls is symmetrical, so there is nothing preventing the mismatch of velocities in the workpiece surface layers.

Since this deformation scheme is aimed at the development of shear strains in both longitudinal and transverse directions, it was decided to consider the

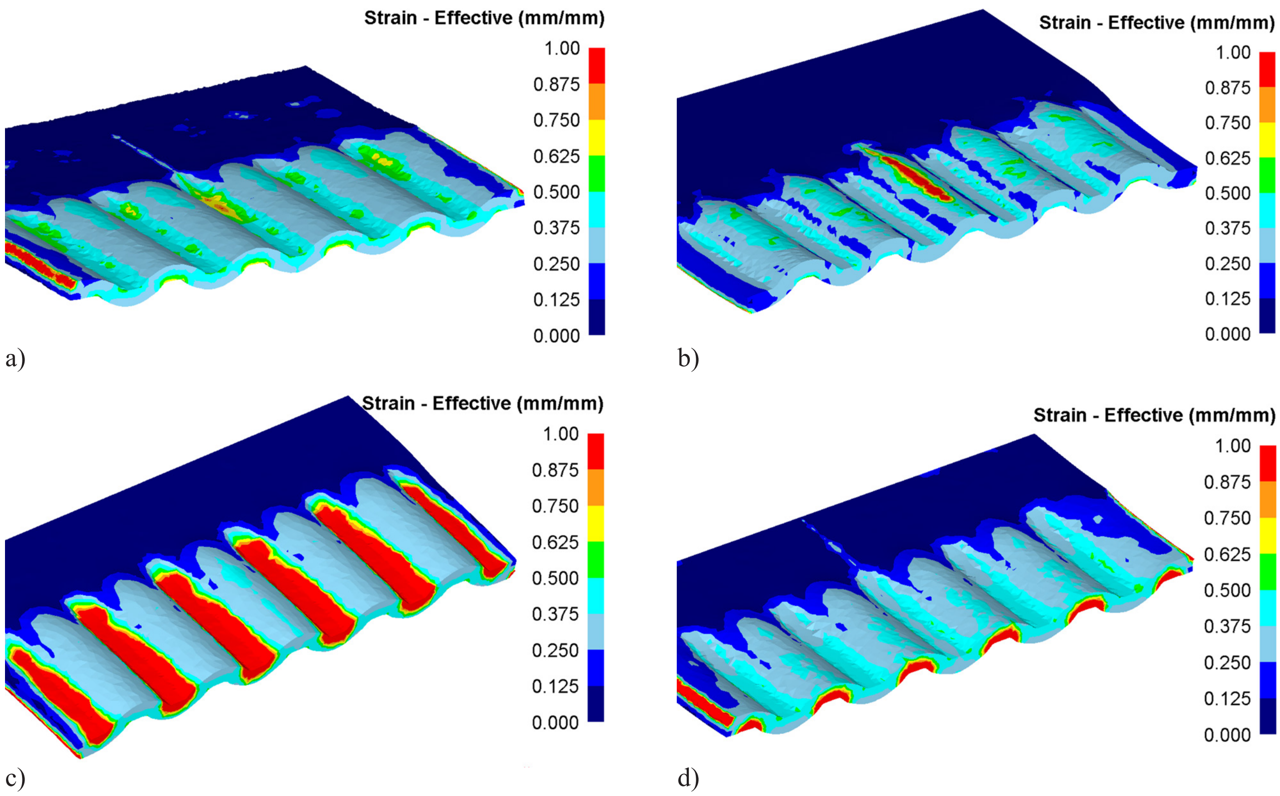

Fig. 3. Equivalent strain: a) - contact asymmetry; b) - geometric asymmetry; c) - kinematic asymmetry (lower face); d) - kinematic asymmetry (upper face).

Mises strain in addition to the equivalent strain (Fig. 4). This parameter characterizes the strain level obtained only from the shear action.

This parameter in all the models considered has a distribution completely similar to the equivalent strain distribution. In the contact asymmetry model, the Mises strain is evenly distributed over the cross-section and is in the range of 0.25 (55 % of the total strain level). In geometric asymmetry model the average Mises strain level is 0.3 on the upper face (54 % of the total strain level), and on the lower one is 0.37, (56 % of the total strain level). In kinematic asymmetry model, the average Mises strain level on the upper face is 0.25 (55 % of the total strain level), and on the lower face it is 0.76 (55 % of the total strain level). Thus, it was found that shear strains predominate in all the deformation schemes under consideration.

When studying the stress state, the equivalent stress parameter is usually considered, which the stress intensity indicator is (Fig. 5). As a result, its value is always positive.

Comparing the values of this parameter, it was noted that in the contact and kinematic asymmetry models, approximately the same level of equivalent stresses (170 - 180 MPa) is created in the deformation zone. In the geometric asymmetry model, the level of equivalent stresses is significantly lower (90 - 100 MPa). This can be explained by the action of increased diameter rolls, which causes the strain rate and the average contact pressure to change.

In addition to the equivalent stress, it is also recommended to consider the average hydrostatic pressure, which allows to estimate the tensile and compressive stresses level (Fig. 6). In the contact and geometric asymmetry models, approximately the same level of compressive stresses (-120 to -130 MPa) is created in the deformation zone. In the kinematic asymmetry model from the faster roll side, the deformation zone has two areas: at the entrance to the deformation zone, an area of compressive stresses (-140 to -150 MPa) is created, at the entrance from the deformation zone, a small area of tensile stresses (120 to 130 MPa) is formed. This is the result of the action of different linear speeds with the same roll diameters.

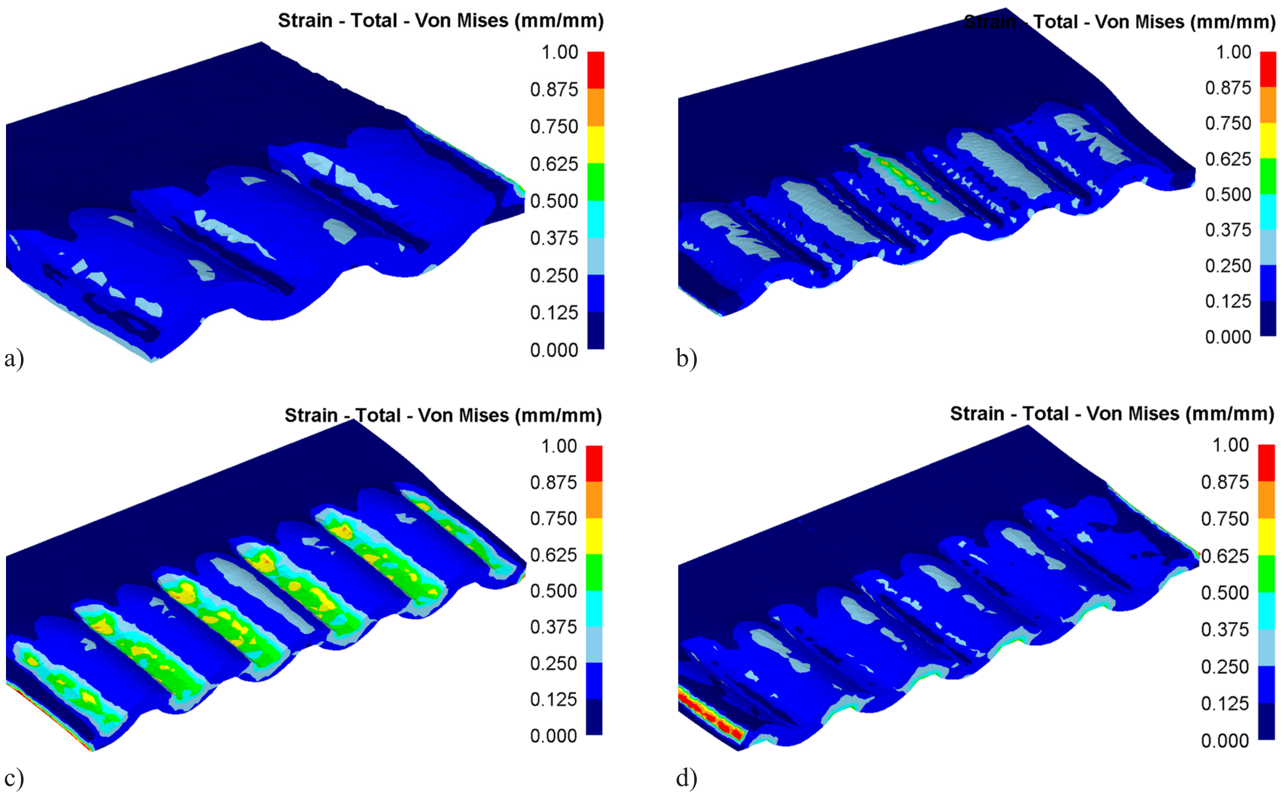

Fig. 4. Mises strain: a) - contact asymmetry; b) - geometric asymmetry; c) - kinematic asymmetry (lower face); d) - kinematic asymmetry (upper face).

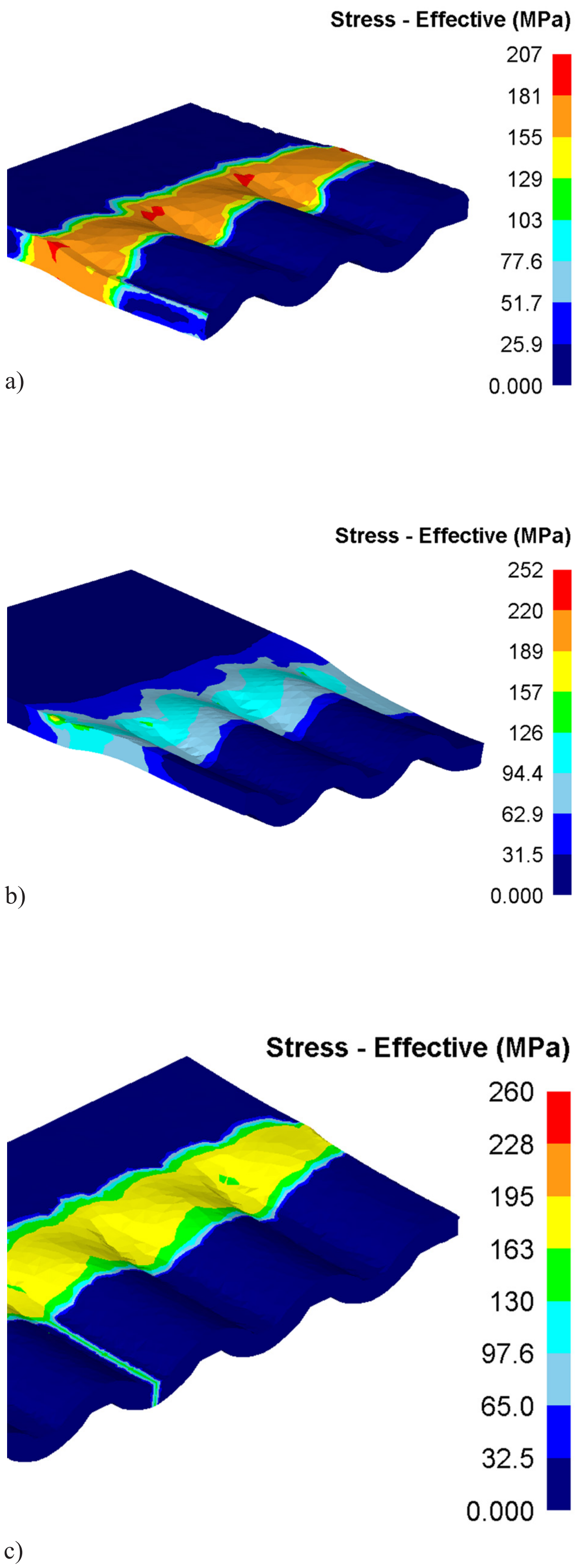

Fig. 5. Equivalent stress: a) - contact asymmetry; b) - geometric asymmetry; c) - kinematic asymmetry.

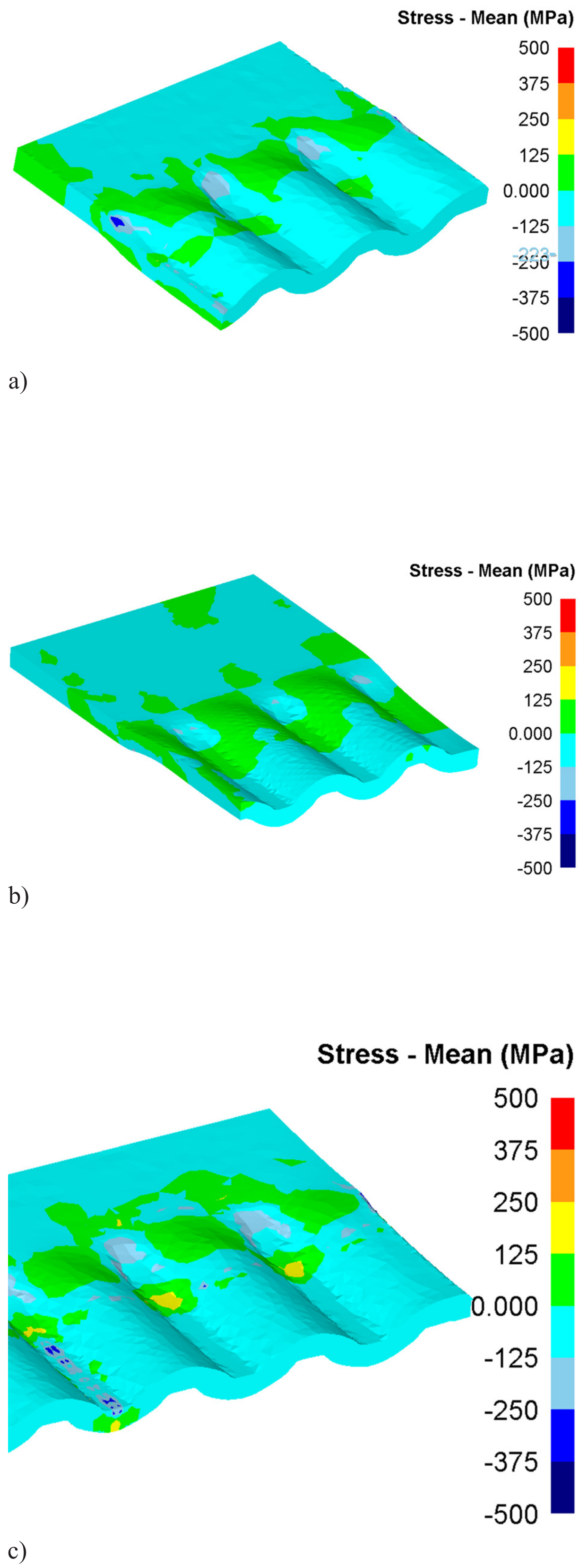

Fig. 6. Average hydrostatic pressure: a) - contact asymmetry; b) - geometric asymmetry; c) - kinematic asymmetry.

Considering the deformation force graphs (Fig. 7), the average values were determined: in the contact and kinematic asymmetry models the force on both rolls is the same and is 380 kN approximately, which is a consequence of the equality of the roll diameters in these models. In the geometric asymmetry model, the overall force level is significantly lower, which is explained by a lower level of equivalent stresses. There is also a difference in values for each roll: on a smaller roll, the force is 205 kN approximately, on a larger roll it is 225 kN approximately. This effect occurs due to the difference in the rolls diameters - with an increase in the roll diameter, the length of the deformation zone increases and, as a consequence, the area of the contact surface.

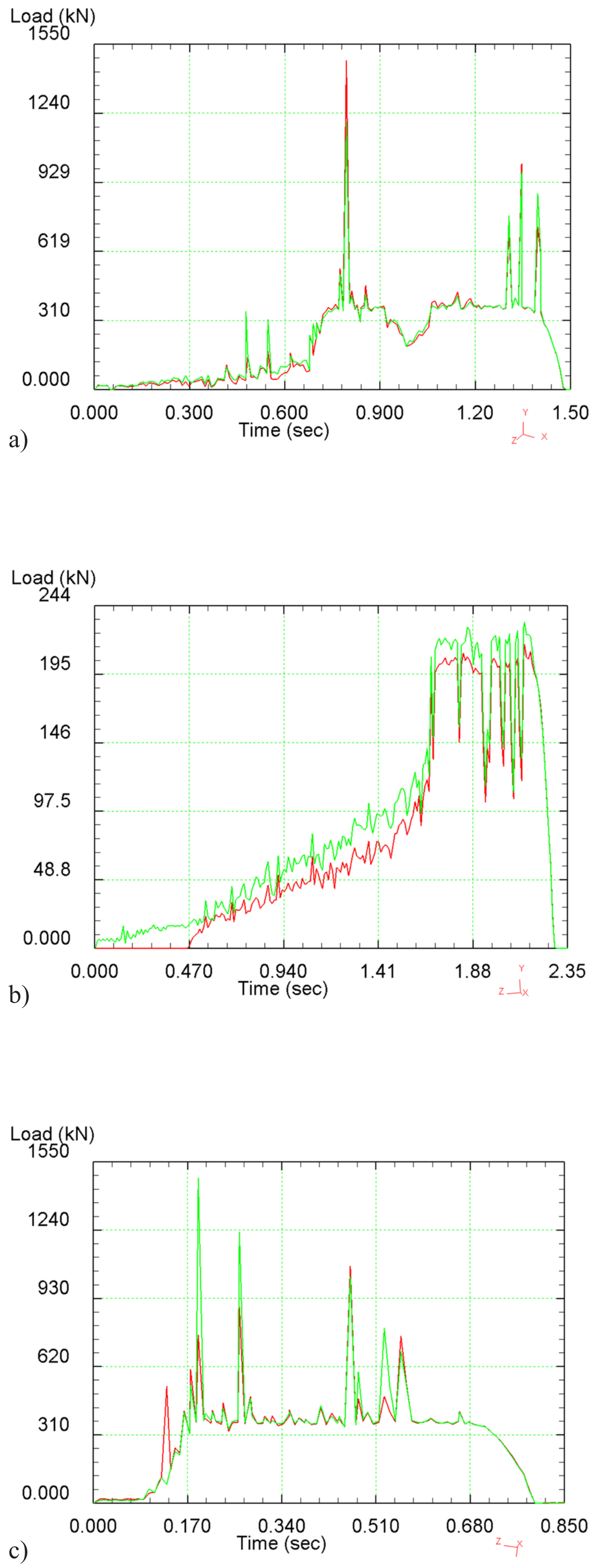

Fig. 7. Deformation force: a) - contact asymmetry; b) - geometric asymmetry; c) - kinematic asymmetry.

CONCLUSIONS

Considering the simulation results, the following conclusions were obtained:

- contact asymmetry is the least effective option, the simulation results in terms of the values of all parameters are very close to the symmetrical rolling process in relief rolls;
- kinematic and geometric asymmetries have shown good results in terms of the development of an additional level of shear deformations in the longitudinal direction. The final process scheme must be chosen based on the actual technological data of the rolling mill (the possibility of larger diameter rolls installing in the crate and the subsequent possibility of connecting them with spindles at higher angles on hinges; the possibility of regulating the rolls rotation speeds on the mill, etc.).

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