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Computer Modeling and Investigation of the Rolling Process of Thick Strips in Relief Rolls Under Conditions of Kinematic Asymmetric Interaction

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Abstract: This work, carried out within the framework of grant project № AP19678682, funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, presents the results of finite element modeling in the Simufact Forming program of the rolling process of thick strips in relief rolls under conditions of kinematic asymmetry. A 10 mm thick blank made of CuZn39Pb2 brass alloy was used for the simulation. For kinematic asymmetric rolling, the speed of the first roll was 90 RPM, and for the second roll it was 60 RPM (asymmetric coefficient was 1.5). For comparison, the results of symmetric rolling were also considered. When analyzing the strain state, it was revealed that the maximum value of equivalent strain in asymmetric rolling is 13.7% higher than in symmetrical rolling. Also, with asymmetric rolling, a deeper processing of the workpiece is observed. When analyzing the stress state, it was found that during asymmetric rolling, the stresses at the point of contact between the fast roll and the workpiece exceed the stresses at the same point of contact with the slow roll by 12%. There is also a more uniform stress distribution over the thickness of the workpiece compared to symmetrical rolling. An analysis of the force values on the rolls showed that when using asymmetric rolling, the force is 5.4% lower compared to the same symmetrical rolling (456 kN versus 432 kN). With asymmetric rolling, the material flow rate is higher in the deformation zone caused by the higher rotation speed of one of the rolls. The direction of material flow, compared with symmetrical rolling, is deviated towards a fast roll. At the points of contact of the workpiece with the rolls, the flow rate is 15.5% higher near the fast roll, compared with the slow roll.

Keywords: FEM, Modeling, Relief rolls, Rolling, Kinematic asymmetry

Introduction

One of the promising high-tech methods for producing high-quality metal products in the form of hot-rolled sheets and thick plates has been asymmetric rolling for more than a decade, during which additional shear deformation flows are realized in the deformable material (Pustovoytov et al., 2021). The most common types of asymmetric rolling are kinematic (different roll rotation speeds) (Ji et al., 2007), geometric (different roll diameters) (Ji et al., 2009) and the use of a roll without a drive (idling). During asymmetric thin-sheet rolling, additional shear deformations occur, which in combination with compression deformations can provide effective structural refinement of grains. Currently, various technological schemes for the implementation of asymmetric rolling in practice have been developed for each of these options, including the availability of auxiliary devices and mechanisms for the possibility of inclusion in a continuous rolling line (Salganik & Pesin, 1997; Pesin, 2003; Belsky, 2009; Yu et al., 2016). A strip rolling method is also known (Fedorov et al., 1990), in which plastic deformation of the metal is carried out in profiled conical rolls with longitudinal bending of the strip produced from the rolls. In this rolling method, the SPD is realized due to the mismatch of the circumferential speeds of the roll between the edge and central areas along the strip width.

Due to the formation of a complex stress state in the deformation zone during asymmetric rolling, it is possible to achieve a significant increase in the strength properties of various ferrous and non-ferrous metals and alloys due to the intensification of the refinement process of their structure. Asymmetric rolling was successfully used to produce ultrafine-grained aluminum alloys with improved mechanical properties (Yu et al., 2013; Bobor et al., 2012; Yu et al., 2012). Blanks of copper, titanium, and zirconium were rolled using asymmetric rolling, in which an ultrafine-grained structure was obtained (Wang et al., 2018; Li et al., 2012; Afifeh et al., 2019). Besides pure metals, this method is also used for deformation of complex alloys (Aksenov et al., 2024). A number of studies are devoted to the asymmetric rolling of bimetallic billets consisting of both completely non-ferrous metals and a combination of non-ferrous metals with steels (Chang et al., 2020; Li et al., 2011; Zhang et al., 2012). As a result of the asymmetric impact, an ultrafine-grained structure was formed in these blanks with an increase in the level of mechanical properties. It is also clear from the review that the key feature of asymmetric rolling is the uneven working of the workpiece height, i.e. creating a gradient of properties across a section (Cui et al., 2024).

The rolling technology of thick-sheet metal was investigated (Naizabekov et al., 2016; Naizabekov et al., 2017), which solved the problem of obtaining high-quality thick-sheet metal without significantly changing the initial workpiece dimensions. For this purpose, two versions of rolls with a raised profile in the form of annular ducts have been developed. It was found that the most optimal design is relief rolls with an uneven ratio of the protrusion to the recess. In (Naizabekov et al., 2021) the results of research on improving the deformation technology of thick-sheet blanks in relief rolls were presented. Considering that asymmetric rolling makes it possible to increase the level of shear deformation during rolling, the asymmetry coefficient was introduced into this technology. Also, to achieve a high level of asymmetry, a geometric asymmetry method was implemented using relief rolls of different diameters (Figure 1).


Figure 1. Rolling in relief rolls with geometric asymmetry

This method proved to be very effective in terms of working through the metal section, as well as improving the mechanical properties of aluminum and copper thick-sheet blanks (Panin et al., 2024; Lezhnev et al., 2025). It should be noted that this method of implementing asymmetric rolling has technological disadvantages. The realization of geometric asymmetry when rolling a wide range of thick-rolled products requires the manufacture of a whole fleet of rolls of various diameters. Also, with geometric asymmetry, it is impossible to achieve a high value of the asymmetry coefficient due to the limitation of the range of roller diameters by the structural dimensions of the bed. The realization of kinematic asymmetry during rolling in relief rolls has no obvious limitations of the asymmetry coefficient and depends on the possibility of regulating the speeds of electric motors. Therefore, the purpose of this work was finite element modeling of this deformation process for the theoretical study of stress-strain state.

Method

The main characteristics used for the construction of the rolls were the dimensions of the groove on the barrel of the rolls, which are shown in Figure 2. The chamfer angle was assumed to be 45°. The distance between the protrusion of one roll and the opposite hollow of the other roll is 10 mm. The minimum distance between the chamfers of the two rolls is 10 mm. The width of the collars is 10 mm. The roll radius is 100 mm. The width of the rolls is 190 mm.

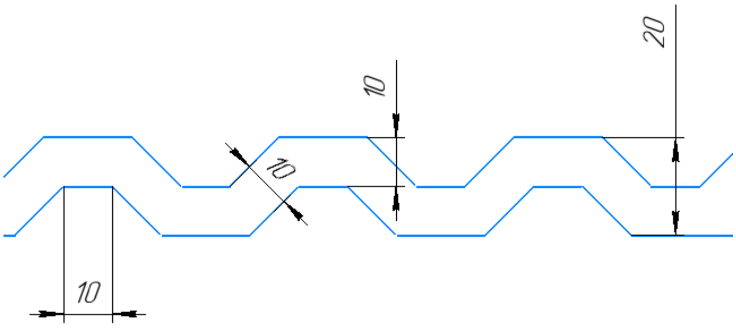

Figure 2. Roll relief dimensions

The construction of the workpiece and pusher models was performed in the Simufact.forming program, where it is possible to build simple three-dimensional models. The length of the workpiece is 200 mm, the width is 140 mm and the height is 10 mm. Brass was chosen as the studied material. In the Simufact Forming program, there is a database of materials from which CuZn39Pb2 alloy was selected, as it most closely corresponds to L63 alloy.

The simulated rolling process is cold, so the temperature for the workpiece and the dies is set to 20°C. The heat transfer coefficient was set to 50 W/((m^2×K). The calculation of the coefficient of heat transfer by radiation to the environment was carried out automatically, taking into account the average properties of surface roughness. The coefficient of friction for the rolls is set to 0.45. In the case of asymmetric rolling, the speed of one roll was set to be 50% higher than the speed of the other, so the rotation speed was set to 90 RPM for the first roll and 60 RPM for the second roll. With symmetrical rolling, the rotation speed of the two rolls was 60 RPM.

Results and Discussion

The following indicators were considered:
- Equivalent plastic deformation is a parameter that shows the intensity of metal processing along the workpiece section;
- Equivalent stress is a parameter that determines the overall load level, calculated from the values of the main stresses;
- Rolling force;
- Material flow is a parameter that shows the linear velocity of the material particles.

The values of equivalent plastic deformation for symmetrical rolling are shown in Figure 3.

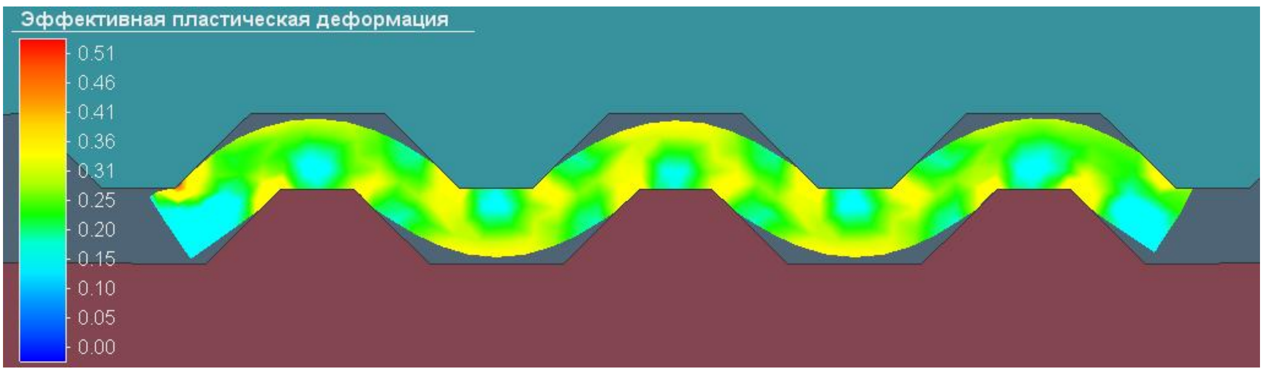

Figure 3. Equivalent plastic deformation of symmetrical rolling

At the moment of capture, the main deformation occurs at the point of contact of the rolls with the workpiece. When the shape of the workpiece changes, the greatest accumulated deformation occurs in the places where the edges of the rolls rest, and in the area of the groove of the rolls, where the workpiece is stretched. The least amount of work is done in the areas opposite the roller projections. In these places, the accumulated deformation is two times lower than in the stretch zone. The values of equivalent plastic deformation for asymmetric rolling are shown in Figure 4.

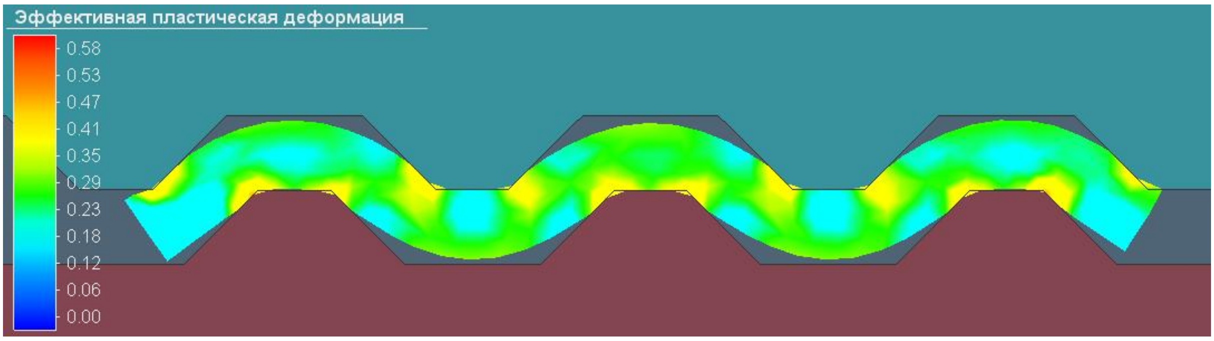

Figure 4. Equivalent plastic deformation of asymmetrical rolling

At the moment of capture, for asymmetric rolling, the values of accumulated deformation are one and a half times higher on the fast roll side. At the points of contact with the fast roller, the workpiece is being worked deeper in depth. The maximum equivalent plastic deformation is 13.7% higher for asymmetric rolling than for symmetrical rolling. Also, asymmetric rolling has a deeper study of the workpiece. The equivalent stress values for symmetrical rolling are shown in Figure 5. The results of the equivalent stress distribution show that the greatest stress is located in the places where there was the greatest accumulated deformation.

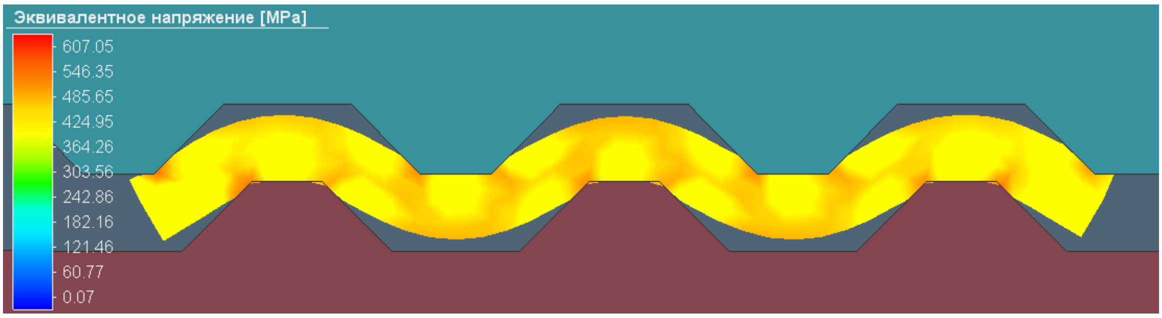

Figure 5. Equivalent stress of symmetrical rolling

The equivalent stress values for asymmetric rolling are shown in Figure 6. During asymmetric rolling, the stresses at the point of contact between the fast roll and the workpiece exceed the stresses at the same point of contact with the slow roll by 12%. There is also a more uniform stress distribution in depth compared to symmetrical rolling.

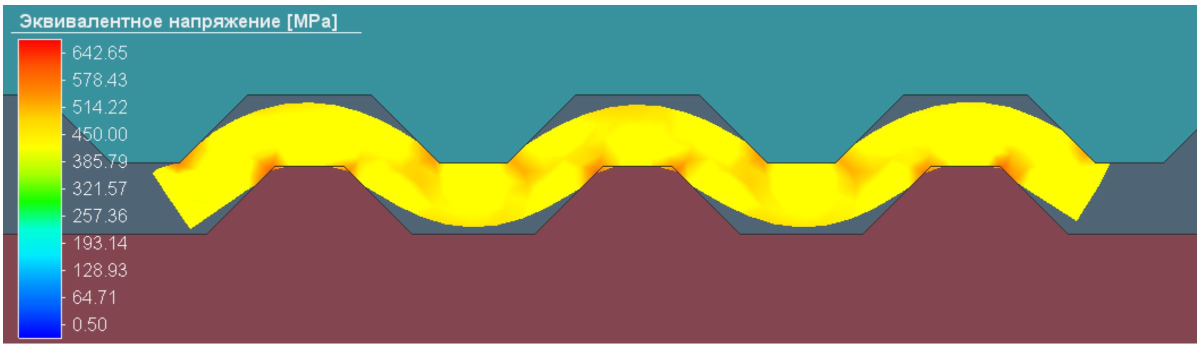

Figure 6. Equivalent stress of asymmetrical rolling

Figure 7 shows graphs of the action of forces on rolls depending on time. The left graph corresponds to symmetric rolling, and the right graph corresponds to asymmetric rolling. By adding the modules of the averaged forces during rolling, the values of 456 kN for symmetrical rolling and 432 kN for asymmetric rolling were obtained. Based on the data obtained, it can be concluded that the rolling forces are 5.4% lower when using asymmetric rolling compared to similar symmetrical rolling.

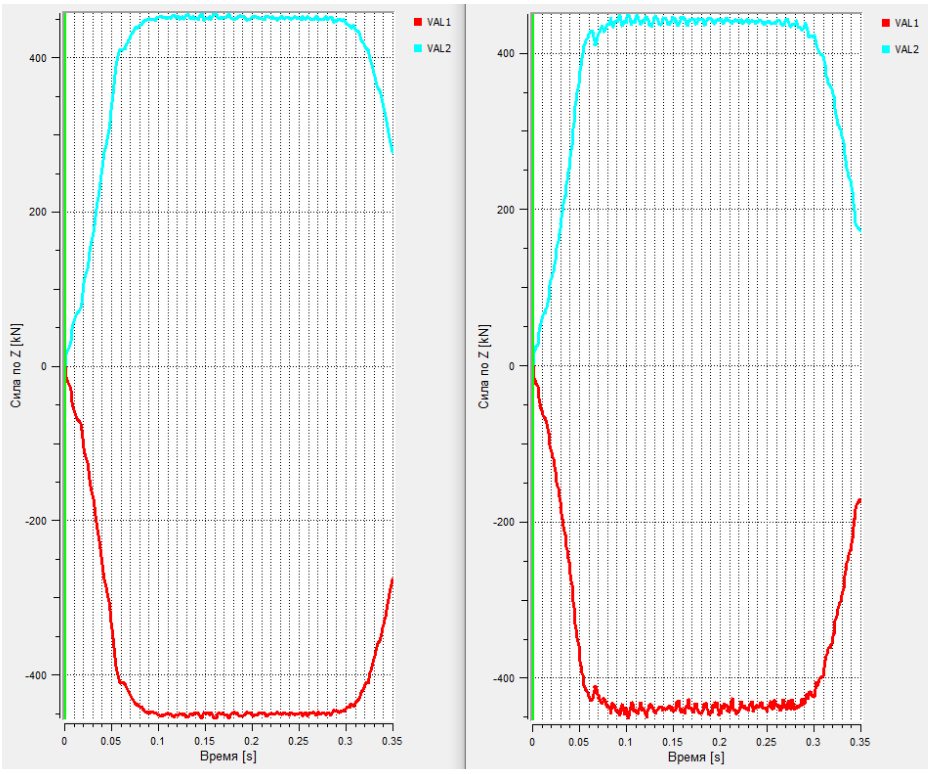

Figure 7. Graphs of the forces on rolls

The flow of material during symmetrical rolling is shown in Figure 8. During symmetrical rolling, the highest flow rate of material is observed in the area of the recesses of the rolls, where the material is stretched. In the area between the projections of the opposite rolls, the smallest displacement of the material in the section occurs.

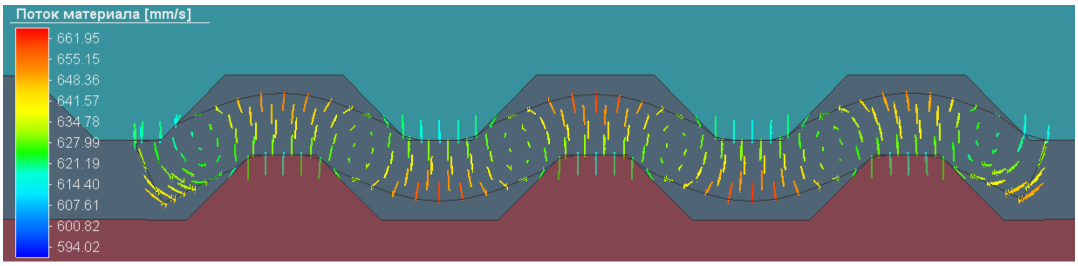

Figure 8. Material flow during symmetrical rolling

The flow of material during asymmetric rolling is shown in Figure 9. With asymmetric rolling, the material flow rate is higher in the deformation zone caused by the fast roll. The flow direction of the material, compared with symmetrical rolling, is deflected towards a fast roll. At the points of contact of the workpiece with the rolls, the flow rate is 15.5% higher near the fast roll, compared with the slow roll.

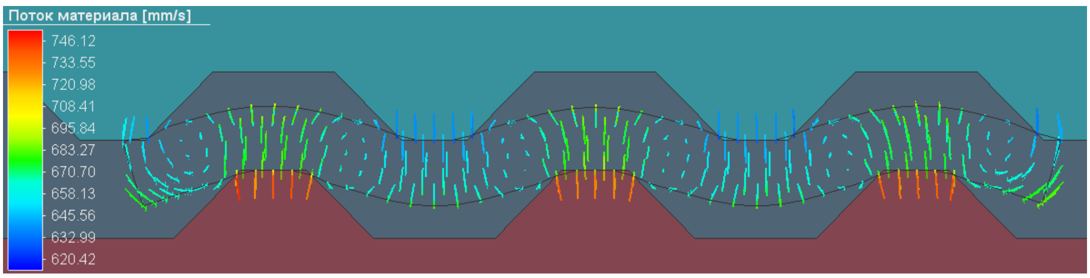

Figure 9. Material flow during asymmetrical rolling

Conclusion

This paper describes computer modeling in the Simufact Forming program of the rolling process of thick strips in relief rolls with an unequal ratio of protrusions to depressions and a comparison of the results of symmetrical and asymmetric rolling. Comparative analysis has shown that when using asymmetric rolling, the accumulated deformation increases and conditions are created for deeper metal processing. Also, when analyzing the force parameters, it was found that the forces of asymmetric rolling are 5% lower than those of symmetrical rolling. Based on the results obtained, it can be concluded that the use of asymmetric rolling makes it possible to achieve improved quality and lower energy costs.

Scientific Ethics Declaration

* The authors declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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