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NUMERICAL MODELLING OF THE PROCESS OF BIMETALLIC BAR ROLLING IN A THREE-HIGH SKEW ROLLING MILL

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Abstract

Bimetallic bars which possess higher corrosion resistance and mechanical properties, it is the new kind of bimetallic bars which are better than standard bars. The bimetallic bars are more often applied in concrete construction. There are few methods which ensure a good strength of bimetallic layer bond. Hydrostatic extrusion, rotary rolling and explosive cladding are most often used methods. The simulations of the bar rolling in a three-high skew mill were carried out using the Forge2005® commercial program. Production of bimetallic bars is very difficult. One from many problems during production bimetallic bars is assurance good strength of bimetallic layer bond. The analysis of the effect of roll rotational speed on the stability of the rolling process and the strain and stress distribution has been carried out in this work.

Key words: numerical techniques; FEM; rotary rolling; bimetallic bars; steel - steel resistant to corrosion

1. INTRODUCTION

The production of steel – steel resistant to corrosion bimetallic ribbed bars [1,3-7] is a relatively complex process and is associated with many technological problems. The most important of them include obtaining a bimetallic stock of proper joint strength in the region of core and cladding layer bonding, and assuring a uniform plastic flow of both bimetallic layers during the rolling process. Failure to meet the above conditions may results in a delamination of the bimetallic strip during rolling or the formation of other defects. One of the bimetallic bar manufacture methods is the rolling of bimetallic stock in a three-high skew rolling mill.

The process of rolling on a three-high reeling mill is complicated due to the complex strain and stress state prevailing in the roll gap. This state is influenced by a number of parameters, including: rolling speed, roll diameter, strip temperature, roll axis inclination angle, etc. [8-9].

The purpose of the theoretical studies carried out was to determine the effect of roll rotational speed on the process of rolling on the three-high reeling mill and on the strain and stress state in the roll gap.

The analysis of the effect of roll rotational speed on the stability of the rolling process and the strain and stress distribution has been carried out in this work.

2. MATHEMATICAL MODEL USED IN THE FORGE2005® PROGRAM

For the numerical analysis of the rolling process by the finite-element method, the Forge2005® software package was used. This program allows the modelling of rolling processes in a three-dimensional state of strain.

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The visco -plastic model of a deformed body, as defined by the Norton-Hoff law, was applied in computation, which can be expressed with the following equation [2]:

$$S_{ij} = 2K_0\left(\varepsilon + \varepsilon_0\right)^{n_0} \exp\left(-\beta_0 \cdot T\right)\left(\sqrt{3}\dot{\bar{\varepsilon}}\right)^{m_0 - 1} \dot{\varepsilon}_{ij} \qquad (1)$$

where: S_{ij} is the deviatoric stress tensor, $\dot{\bar{\varepsilon}}$ - equivalent strain rate, $\bar{\varepsilon}$ - equivalent plastic strain, ε_0 - base strain, T is the temperature, K_0, m_0, n_0, β_0 represent materials constants

2.1. The rolls and strip model

For performing the numerical computation of the process of rolling bimetallic bars in the three-high reeling mill, a three-dimensional model was designed in a CAD-type program. These models were surface objects, whose surfaces were then transformed into a finite-element mesh. The computer program Forge2005® utilizes models built from a finite-element mesh, whose base element is a triangle. For the tool model, a three-dimensional surface mesh was used, while for the objects being deformed a spatial mesh was generated based on the surface mesh. The finished spatial mesh in the object being deformed is built from tetrahedral elements, and its size is characterized by defining the mean edge length. The development of an appropriate mesh is an important element in the preparation of computer simulation. The mesh size is decisive to the accuracy and speed of conducted computation. It is necessary to determine the optimal element size, which will be a trade-off between the accuracy and the computation time.

The rolls were designed based on available literature describing the use of the three-high reeling mill for rolling seamless tubes and rolling bars from hard-deformable alloys [6-9].

The shape of the roll model prepared in the CAD program is shown in figure 1 and the dimensions are given in table 1.

Table 1. The constructional dimensions of the three-high reeling mill working rolls.

D1 [mm]	D2 [mm]	α [°]	β [°]	L1 [mm]	L2 [mm]	R1 [mm]	R2 [mm]
74.7	100	9	18	80	25	20	5

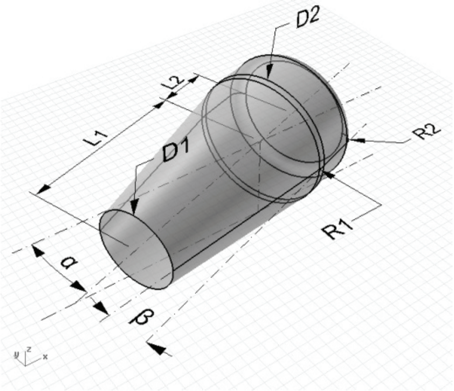

Fig. 1. *The model of a three-high reeling mill roll.*

The roll construction is defined by the following dimensions: D1 – working part diameter, D2 – sizing part diameter, α – roll face inclination angle, β – roll axis inclination angle, L1 – roll working part length, L2 – roll sizing part length, R1 – roll working part rounding radius, R2 – roll sizing part rounding radius.

Moreover, the model of bimetallic strip and the auxiliary tool holding the rolled bimetallic strip end in a stable position before the roll gap was also designed in the CAP program.

Figure 2 shows the shape of the round bimetallic stock.

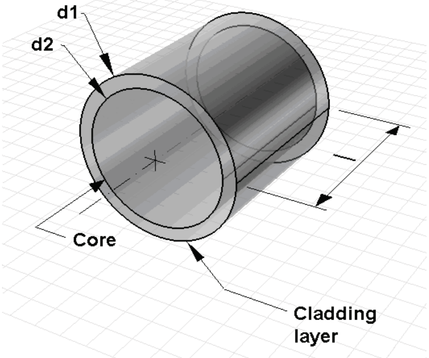

Fig. 2. *A bimetallic stock model created in the CAD program.*

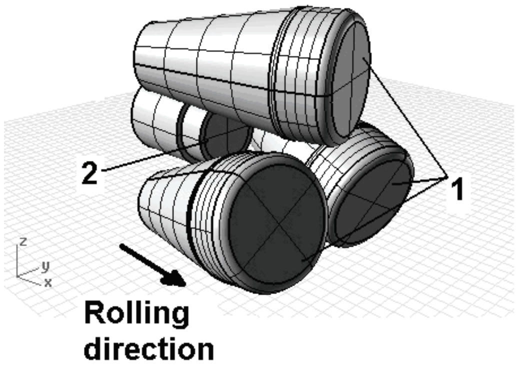

Fig. 3. *The roll and bimetallic strip models; 1 – Roll; 2 – Bimetallic stock.*

The prepared working tool and bimetallic stock models were then arranged according to the adopted rolling conditions (figure 3).

The next stage in the creation of objects for computer simulations is the operation of generating a triangular finite-element mesh on the object surfaces. The Forge2005® program enables the mesh to be condensed on quoins, rounding and places with a complicated shape and a small size by defining mesh condensing zones called *mesh boxes* [2].

Figure 4 shows the triangular surface mesh of the working roll and stock surface. As the *bilateral* friction model was adopted between the particular layers of the bar being rolled, these layers had no possibility of mutual displacement between one another. The application of this friction model caused the bar to be treated as being homogeneous.

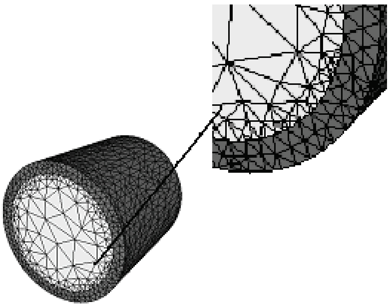

Fig. 4. *A finite-element mesh generated on the bimetallic strip surface.*

2.2. Analysis of flow curves for steels C45 and 00H18N10

The accuracy of calculations performed using a computer program is dependent on the accurate determination of the properties of materials used for tests. Undertaken experimental studies aimed at the determination of the effect of strain parameters on the magnitude of yield stress for steels C45 and 00H18N10 (according to the Polish standard). Plastometric tests were performed on Gleeble 3800 system.

Flow curves for the steels used in the tests for the strain rate equal to 10 s^{-1} are represented in fig. 5. From the flow curves shown in figure 5, a distinct effect of strain and temperature on the σ_p value can be found to occur. By comparing the diagrams shown in both figures it can be noticed that the yield stress values for steel 00H18N10 are much higher than those for steel C45. This difference has a significant influence on the process of bimetallic bar rolling. The higher yield stress values of 00H18N10 steel (the cladding layer) provide conditions favourable to the formation of bimetallic stock by the method of rolling on a three-high reeling mill [4,6-8]. The increased deformation resistance of the cladding layer compared to the bar core contributes to reducing the effect of cladding layer "flowing off" from the bar core.

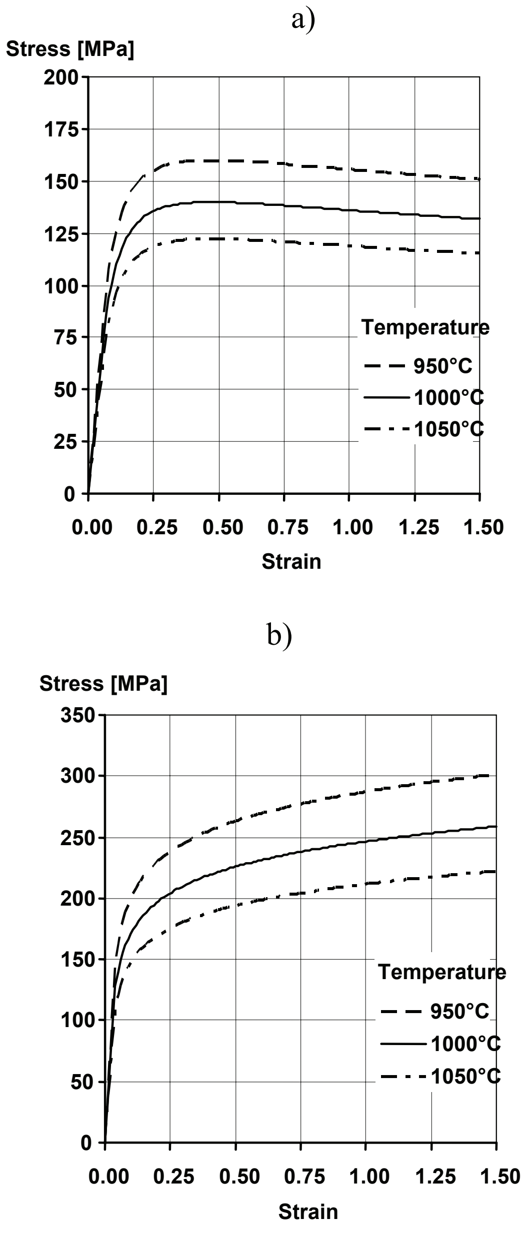

Fig. 5. *Flow curves for steels a) C45 b) 00H18N10, as deformed at a strain rate of 10* s^{-1}.

2.3. Boundary conditions for the process of rolling bimetallic bars in the three-high reeling mill

It was assumed in numerical modelling that the bar core was made of steel C45, while the cladding layer was of steel 00H18N10. The mill feedstock was composed of a tube of a diameter of 38 mm and a wall thickness of 4 mm and a 30 mm-diameter round bar. The following initial conditions were taken for numerical studies: feedstock temperature: 1000°C, tool temperature: 60°C, roll rotations: Variant I - 100 rpm, roll rotations: Variant II - 200 rpm, roll diameter: 55 mm, angle of inclination of working part roll 9°, angle of inclination of roll axis 18°, friction factor: 0.8 and thermal conductivity: 35500 W/m·K for core, 25500 W/m·K for layer. The feedstock was rolled into a bimetallic bar of a final diameter of about 17 mm.

3. RESULTS OF NUMERICAL MODELLING

From the performed computer simulations it was found that the process of rolling according to Variant I progressed stably with a minor slip between the rolls and the strip. The whole length of the bimetallic feedstock was rolled out, as a result of which a bimetallic bar of a final diameter of 17 mm was obtained. The application of Variant II caused an unstable run of the rolling process, a substantial slip occurred between the rolls and the strip, which broke the continuity of the rolling process. Figure 6 shows a distribution of the component of the velocity of bimetallic feedstock flow in the rolling direction for the variants analyzed.

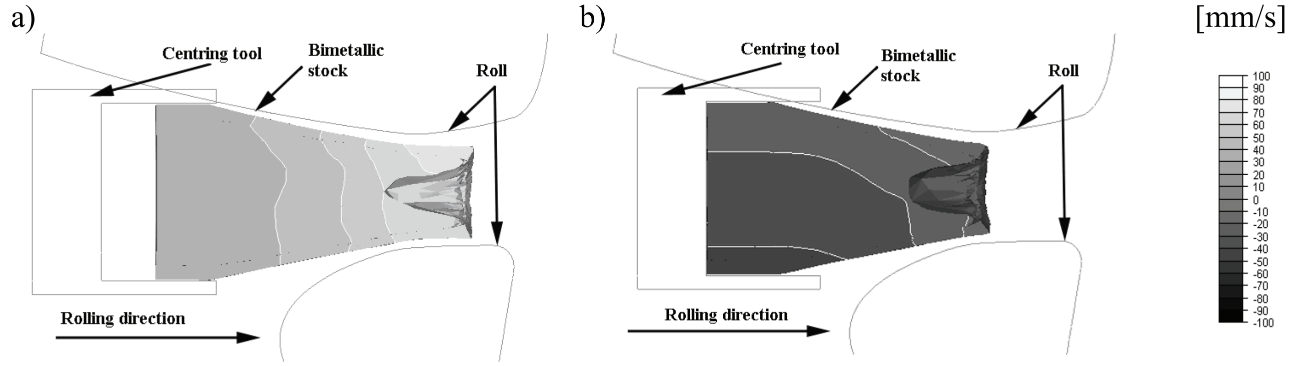

***Fig. 6.** Distribution of the velocity of metal flow in the rolling direction in the longitudinal section. a) Variant I, b) Variant II.*

When comparing both variants it can be found that the process of rolling according to Variant I ran without the involvement of the centring tool (i.e., in the steady rolling process, the centring tool did not press down on the feedstock), as shown in figure 6a. Rolling according to Variant II, in its initial stage, progressed without the involvement of the centring tool. As the strip moved along the roll gap, an increase in the deformation resistance of metal occurred, causing the strip being deformed to stop in the middle part of the roll gap. The nonstationary conditions occurring at the contact between the rolls and the strip resulted in pushing the bimetallic strip out of the roll gap. This is indicated by the obtained distribution of the velocity of metal flow in the rolling direction, as shown in figure 6b. The flow velocity values were negative, therefore the strip moved in the direction opposite to the rolling direction. In the subsequent phase of the rolling process, the centring tool started to press on the strip being rolled (figure 6b), hence the rolling process ran with the involvement of the centring tool (the computer simulation was aborted). The cause of the slip between the rolls and the strip and the cause of the breaking of process continuity was the increased rotational speed of the rolls. Increasing roll rotational speed from 100 to 200 rpm (with the remaining process parameters unchanged) caused an increase in strain rate in the strip being rolled from approx. 12 to approx. 20 s^{-1}. Such an increase in strain rate substantially influences the stress magnitude. The increment in the magnitude of stress causes an increase in deformation resistance and, as a consequence, a roll slip. Such deformation conditions favour the occurrence of the effect of round strip triangulation in the deformation zone, which adversely influences the rolling process (in extreme cases, this effect makes further rolling impossible).

At the initial stage of the rolling process, the effect of intensive "flowing off" of the surface layers of metal from the core is observed on the frontal feedstock surface. As a result, a void forms on the frontal surface inside the bimetallic strip.

To better illustrate the phenomena occurring in the simulations, for which the roll bite of the strip occurred (Variant I – figure 7), and in the simulation, in which there was no roll bite of the strip (Variant II – figure 8), the distributions of power needed for overcoming the friction resistances and of power needed for performing plastic deformation were compared for both simulations.

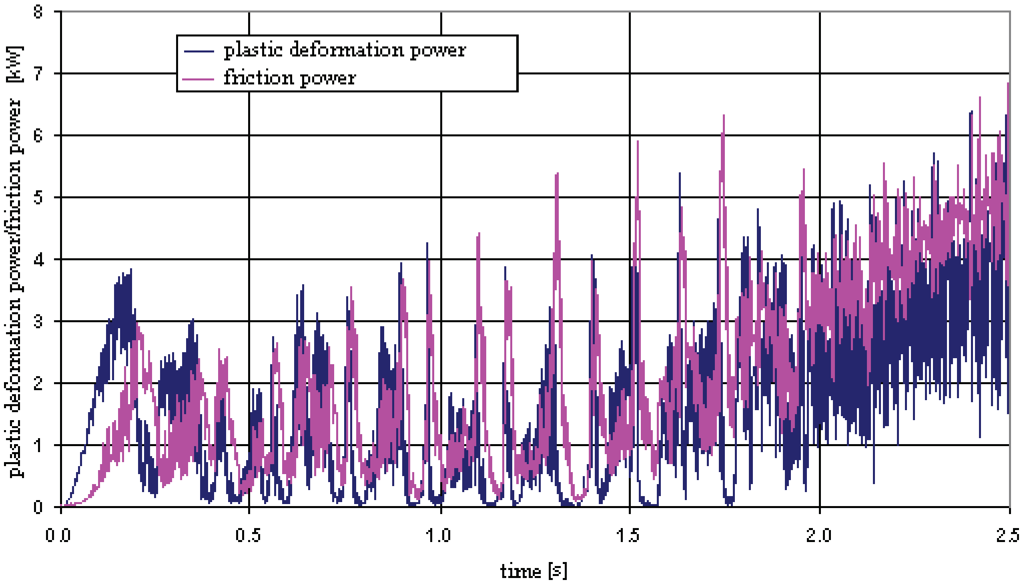

Fig. 7. *Comparison of the plastic deformation power and the friction power, as obtained for Variant I – not roll bite of the strip.*

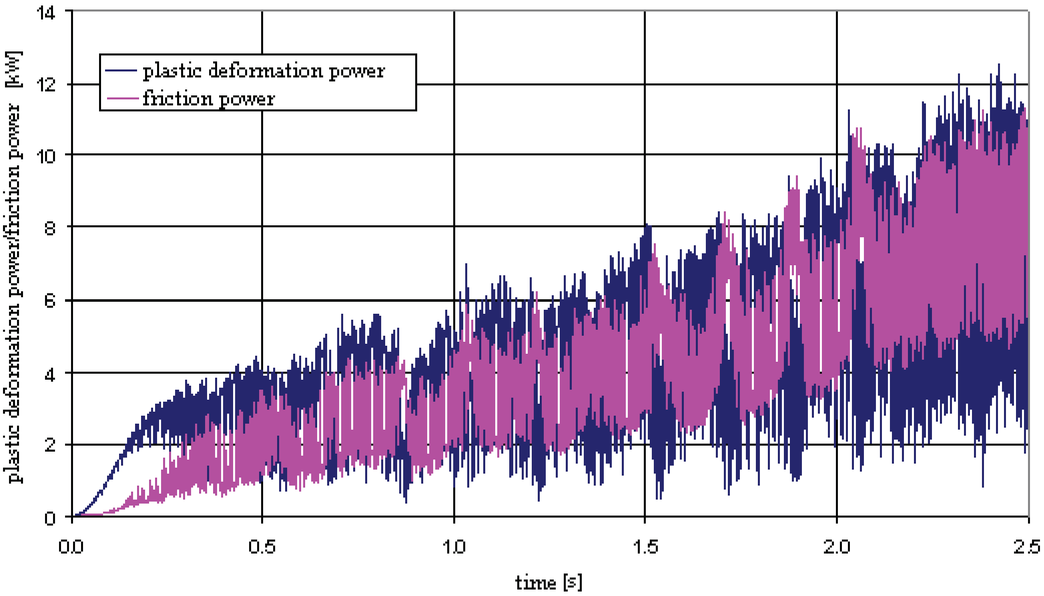

Fig. 8. *Comparison of the plastic deformation power and the friction power, as obtained for Variant II – a roll bite of the strip.*

By analyzing the obtained testing results (figures 7-8) it was found that both for Variant I, as well as for Variant II, in the initial phase of rolling, the power needed for deformation was greater than the power needed for overcoming the friction resistances. This results from the fact that the strip is being "pushed" into the deformation zone by the auxiliary tool. As the strip moves through the deformation zone, an increasingly larger strip area has contact with the rolls, which causes the strip to move faster in the rolling direction until a steady process is attained. For this stage, the distribution of deformation power and the distribution of friction power have a very uneven behaviour, and the magnitude of plastic deformation power is slightly lower than that of friction power. For a steady rolling process, on the other hand, an even distribution of particular power components was observed. The obtained magnitude of power needed for plastic deformation has a value similar to the value obtained for friction power. By contrast, when analyzing the results obtained for Variant II it was found that as the strip moved through the deformation zone, similarly as in Variant I, the distribution of deformation power and the distribution of friction power had a very uneven pattern, but the friction power took on values greater than those of the deformation power. For a steady rolling process, the deformation power is greater than the friction power. This is due to the fact that the bimetallic bar is pushed through the deformation zone by the tool, whose purpose was to initially push the strip closer to the rolls. The linear velocity of the pushing tool is much lower than the rolling speed. Therefore, in a correct simulation, this tool, after the feedstock has been pushed to the working rolls and then bitten by them, should not separate. Whereas, in rolling according to Variant II, where no roll bite of the strip has occurred, this tool pushes the strip into the deformation zone.

The analysis of the distribution of stress intensity and strain intensity has also been performed within the work. Figures 9 and 10 shows examples of the distributions of stress intensity and strain intensity on the cross-sections of rolled strip, made in the mid-length of the roll gap.

4. CONCLUSIONS

On the basis of the performed numerical studies of the process of rolling on the three-high rolling mill it can be stated that the rotational speed of rolls substantially influences the stability (continuity) of the process being run.

The deformation conditions prevailing in the roll gap are more favourable during rolling at a roll rotational speed of 100 rpm.

The use of the computer program Forge2005® has made it possible to determine the roll rotational speed that allows the process of rolling bimetallic bars on the three-high reeling mill to be correctly carried out.

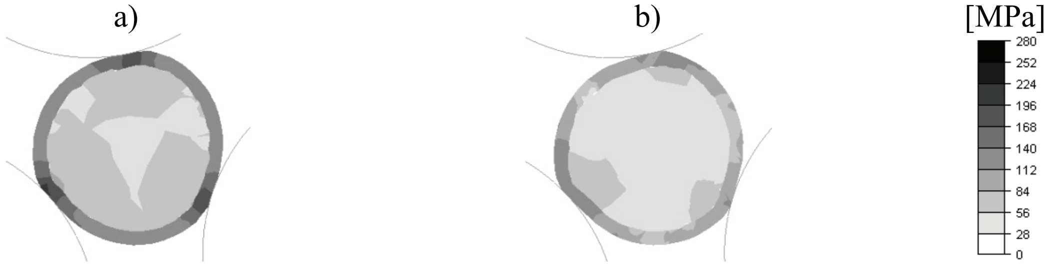

Fig. 9. Distribution of stress intensities -a); Distribution of strain intensities – b) in the cross-sections of the bimetallic strip: a) Variant I – not roll bite of the strip, b) Variant II – a roll bite of the strip.

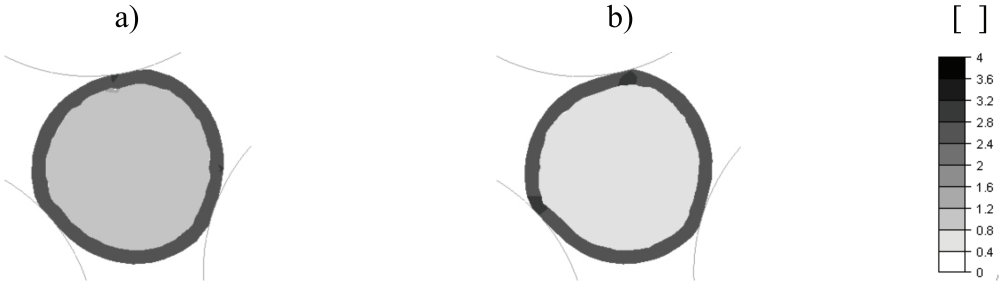

Fig. 10. Distribution of strain intensities in the cross-sections of the bimetallic strip a) Variant I – not roll bite of the strip, b) Variant II – a roll bite of the strip.

The obtained values of stress intensity during rolling acc. to Variant I were higher by approx. 25 MPa compared to the values obtained in Variant II. During rolling acc. to Variant I, higher values of strain intensity were also observed. The lower values of stress and strain intensities in rolling acc. to Variant II are also indicative of the occurrence of a slip between the rolls and the strip, which might have been caused by unfavourable deformation conditions. In the locations of contact of the rolls with the metal, local strains of higher magnitudes occurred, which caused a triangulation effect.

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MODELOWANIE PROCESU WALCOWANIA PRĘTÓW BIMETALOWYCH W TRÓJWALCOWEJ WALCARCE SKOŚNEJ

Streszczenie

Wytwarzanie prętów żebrowanych bimetalowych stal - stal odporna na korozję jest procesem stosunkowo złożonym i wiąże się z wieloma problemami technologicznymi. Do najważniejszych należy uzyskanie wsadu bimetalowego o właściwej wytrzymałości złącza w obszarze połączenia rdzenia z warstwą platerującą oraz zapewnienie równomiernego płynięcia plastycznego obydwu warstw bimetalu podczas procesu walcowania. Niespełnienie tych warunków może spowodować rozwarstwienie się bimetalowego pasma podczas walcowania lub powstanie innych wad.

Do wytwarzania bimetalowego wsadu w postaci prętów do dalszej przeróbki plastycznej stosowane są różne metody. Metoda walcowania prętów żebrowanych bimetalowych w wykroju wykańczającym z wsadu wytworzonego w trójwalcowej walcarce skośnej nie jest stosowana w przemyśle, ze względu na brak odpowiednich badań teoretycznych jak i technologicznych tego procesu. Zły dobór schematu odkształcenia bimetalowego pasma w trójwalcowej walcarce skośnej może być przyczyną "spływania" warstwy platerującej z powierzchni rdzenia i złożonego stanu naprężeń, co z kolei może spowodować powstawanie wad w warstwie platerującej (nierównomierna grubość warstwy, mikropęknięcia i rozwarstwienia, itp.). Prawidłowo zaprojektowany proces walcowania winien zapewnić otrzymanie równomiernej i odpowiedniej grubości warstwy platerującej na obwodzie i długości pręta, która nie ulegnie przerwaniu w wykroju wykańczającym.

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