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FEM 3D ANALYSIS OF ROLL DEFLECTION DURING PLATE ROLLING

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A numerical simulation of roll deflection during hot rolling is presented in the paper. The real conditions of the Plate Rolling Mill of the Częstochowa Steelworks were taken for the simulation. The effect of rolled strip width on the deformation of the working and backing-up rolls was analysed. The investigation carried out has enabled the determination of roll shape during the rolling process.

Key words: *FEM 3D, plate rolling, elastic deflection of the rolls*

FEM 3D analiza otklona valjaka pri valjanju lima. U radu je prikazana numerička simulacija otklona valjaka tijekom toplog valjanja. Za simulaciju je uzeto stvarno stanje u valjaonici lima železare u Częstochowa. Analizirao se utjecaj širine valjane trake na deformaciju radnih i potpornih valjaka. Provedena istraživanja su omogućila određivanje oblika valjaka tijekom procesa valjanja.

Ključne riječi: *FEM 3D, valjanje lima, elastični otklon valjaka*

INTRODUCTION

Rolled products should be characterized by a good quality and tight dimensional tolerances. Because of automation that is commonly implemented in flat product rolling mills, these products should meet the requirements of tightened tolerances, particularly those of strip thickness and width, and feature the greatest possible flatness. In order to obtain the correct shape of the strip upon exit from the deformation region, all factors influencing deformation region shape should be considered when determining roll gap height.

The spatial shape and dimensions of the roll gap are influenced by the elastic deformation of all parts of the rolling stand equipment affected by the pressure force. The magnitude of elastic deformations depends on the type of roll assembly, materials used, and the dimensions of particular nodes [1].

The rolling of flat products is done on two-high mill, three-high mill (Lautha), four-high mill, six-high mill, and multi-roll, such as planetary, twelve-roll and twenty-roll assemblies. If we assume that total flexibility of four-high working stand is equal to 100 %, then 60 % is made up by roll deformations and 40 % by the deformations of the remaining parts of the rolling stand.

The deformation process occurs in a two-roll roll gap. Forces acting within the roll gap, caused by the resistance of metal deformation, result in the elastic deformation of the roll, which changes the roll dimensions. As a result of this deformation, a strip with an incorrect cross-sectional contour and diverse dimensional deviations is obtained.

If the pressure force does not vary during the pass, then a strip of a thickness variable along both length and width will be obtained. Depending on the type of roll assembly and the design of the rolling stand, different roll gap deformations are observed with the same widths and rolling reductions. They depend on both the construction and material of the rolls (and additionally on the design of the working rolling stands), as well as the accuracy of rolling gap positioning between the unloaded rolls. The total pressure force, understood as a continuous load acting on the roll faces, causes the following phenomena [2]:

- the elastic deflection of the rolls (the deflection of the roll face) resulting in the lenticularity of the strip, and
- the elastic flattening of the rolls, contributing to an increase in roll gap length and a change in the shape of contact surface under load.

In four-high and multi-roll assemblies, elastic deformations at the contact of the working rolls and the backing-up rolls additionally occur. These factors should be allowed for in the adjustment of the roll gap by respectively reducing the roll gap height. The overall effect of

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all the factors mentioned above ultimately imparts a specific shape to the roll gap during loading. In addition, the roll gap may change its shape depending on changes in roll temperature along the roll face length, since the thermal expansion of the roll material increases the diameter of the roll face when it is heated.

In modern four-high rolling mills, adjusting the shape of the roll face by changing the temperature along its length is avoided; on the other hand, in two-high hot rolling mills, the rolls are heated up with torches, which compensates for the contour convexity caused by the temperature increase, and the elastic deformation of the rolls caused by loading. In order to compensate for the elastic deflection of rolls, the systems of roll bending are commonly used at present. These systems enable the rolls to be elastically deflected in a controllable manner to counteract their deflection caused by the pressure of the material being rolled.

TESTS AND TESTING RESULTS

The purpose of tests carried out within this study was: the determination of the effect of strip width on the character of deflection of the working roll and backing-up roll assembly of the two-high rolling stand; the analysis of the distributions of volumetric displacements and internal stresses within the rolls; the comparison of changes in the geometry of the working roll depending on the strip width; and the observation of the course of deflection in characteristic sets of points on the longitudinal section along the roll axis. As the characteristic sets of points on the longitudinal section of the roll assembly, the following were chosen: the line of contact of the working roll with the deformed material in the plane of exit from the roll gap; the line of contact of the working roll and the backing-up roll; and the line located on the upper surface of the backing-up roll in the plane of material exit from the roll gap.

When selecting basic input parameters for analysis, real averaged data deriving from the Plate Rolling Mill of the Częstochowa Steelworks were taken as a basis. The tests were carried out for the first pass in the finishing stand, for which the following parameters were adopted. The initial strip height was 50 mm, and the strip was rolled with a relative rolling reduction of ε = 20 %; the roll gap height was 40 mm. Five strips 1800 mm, 2000 mm, 2400 mm, 2800 mm and 3200 mm in width were analyzed. The strip temperature was assumed to be constant within the entire volume and equal to 1020 °C, whereas the ambient temperature was assumed at 30 °C. No thermal profile of the roll was analyzed in the study; the temperatures were needed in order that the simulation of the rolling process was conducted correctly. The rolled material was carbon steel of a carbon content of approx. 0,7 %. The thermomechanical properties of this material were accounted for by using the visco-plastic model of deformation.

The analysis of the elastic deflection of rolls was carried out for each strip width in two steps, using the commercial software FORGE3® [3]. The first step was the simulation of rolling on the flat roll face, with the use of a rigid tool in the form of a single working roll. The mechanical properties of the rolled material were modeled by Hensel-Spittel rheology law, given by the following formula:

$$\sigma_f = A e^{m_1 T} T^{m_9} \varepsilon^{m_2} e^{\frac{m_4}{\varepsilon}} \left(1+\varepsilon\right)^{m_5 T} e^{m_7 \varepsilon} \dot{\varepsilon}^{m_3} \dot{\varepsilon}^{m_8 T} \tag{1}$$

where:

σ_f - yield stress,
ε - equivalent strain,
$\dot{\varepsilon}$ - equivalent strain rate,
T - temperature,
$A, m_1, \dots, m_9$ - constant coefficients.

Author used the following values of coefficients: A = 1881,002, m_1 = – 0,00291, m_2 = – 0,16201, m_3 = 0,14923, m_4 = – 0,06842 and m_5 to m_9 = 0.

These values corresponding to steel grade C70 in the following conditions: temperature 628,3 to 1250 °C, equivalent strain 0,04 to 1,5 and equivalent strain rate 0,01 to 500. The friction conditions between the plate and the rolls were modeled by the Coulomb friction law, given by the following formula:

$$\tau = \mu\sigma_n \quad \text{if} \quad \mu\sigma_n < \bar{m}\frac{\sigma_0}{\sqrt{3}}$$

and

$$\tau = \frac{\sigma_0}{\sqrt{3}} \quad \text{if} \quad \mu\sigma_0 \geq \bar{m}\frac{\sigma_0}{\sqrt{3}} \tag{2}$$

where:

τ - the shear stress,
m - Coulomb friction coefficient,
$\bar{m}$ - a friction factor,
σ_n - the normal stress and
σ_0 - the flow stress.

The Coulomb friction coefficient was equal to 0,3 and Tresca friction factor was equal to 0,6. These values correspond to real conditions of the friction during the hot rolling. Figure 1. shows the distribution of the equivalent strain on the surface of the plate obtained form numerical simulation.

In the second step, the distribution of normal stresses on the roll surface, as obtained from the first simulation,

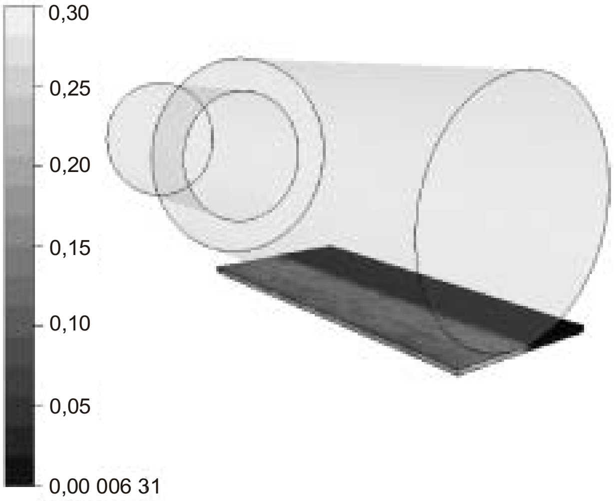

Figure 1. **Distribution of the equivalent strain on the surface of the rolling plate**

Slika 1. **Raspored ekvivalentne deformacije na površini valjanog lima**

was transferred to the second simulation, where the deformed material was the system of the working and backing-up rolls. The mechanical properties of the rolls were accounted for with the elastic model by specifying Young's modulus equal to 200 000 MPa and Poisson's ratio equal to 0,3. The working roll diameter was assumed to be 950 mm, the backing-up diameter 1800 mm, whereas the roll face lengths were identical and equal to 3600 mm.

The part of the results of this work was published in proceeding [4]. There was presented the elastic deflection of the rolls calculated for the plate width equal to 1800 mm. In this paper, selected examples of testing results for plate width 3200 mm are presented. Figure 2. shows the scaled view of the cross-section through the exit plane of the rolls with the distribution of stresses in the direction of roll face length, caused by roll face deflection during rolling the 3200 mm-wide strip. A compressive stress accumulation region can be clearly distinguished, which occurs within the roll and material contact zone. In addition, tensile stresses are visible, that occur on the upper surface of the backing-up roll in its central part, and in the lower part of the working roll journal. These last tensile stresses are particularly unsafe because their too large value can lead to the break of the roll.

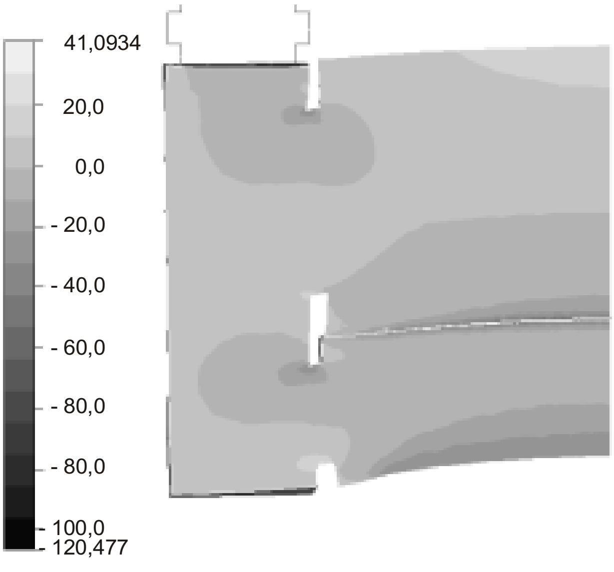

Figure 2. **Scaled view of the deformed rolls with the distribution of the stresses in the direction of roll face length; negative values compression; values in MPa; width of the rolled plate equal 3200 mm**

Slika 2. **Pogled s mjerilom na deformirane valjke s rasporedom naprezanja u smjeru dužine valjaka; negativne vrijednosti - sabijanje; vrijednosti u MPa; širina valjanog lima iznosi 320 mm**

In Figure 3., working roll profiles in different part of the rolling face are presented in the polar system. The angular position of 270° corresponds to the plane of material exit from the roll gap. A distinct flattening of the roll in the part that contacted the strip is visible. The profile of the roll is a little lengthened in rolling direction and flattened in direction of the plate height.

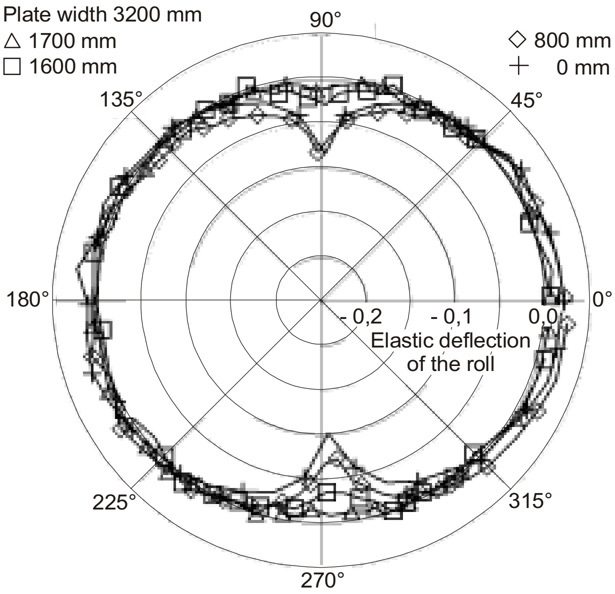

Figure 3. **Deformed profiles of the working roll at different cross-sections along the length of the roll; 0 mm symmetry plane of the roll, 1700 mm nearest to the edge of the roll; values of deflection in mm**

Slika 3. **Deformirani profili radnog valjka na različitim presjecima po dužini valjka; 0 mm - po ravnini simetrije valjka; 1700 mm neposredno uz rub valjka; vrijednosti savijanja izražene u mm**

Figure 4. and 5. show the movement of the rolls material in direction of the plate height. In Figure 4. the distribution on the surface of the rolls is shown. It's a view from the exit side of the rolling stand. It can be observed that the part of the backing-up roll from the exit side is more deformed as the part from the entry side. Figure 5. shows

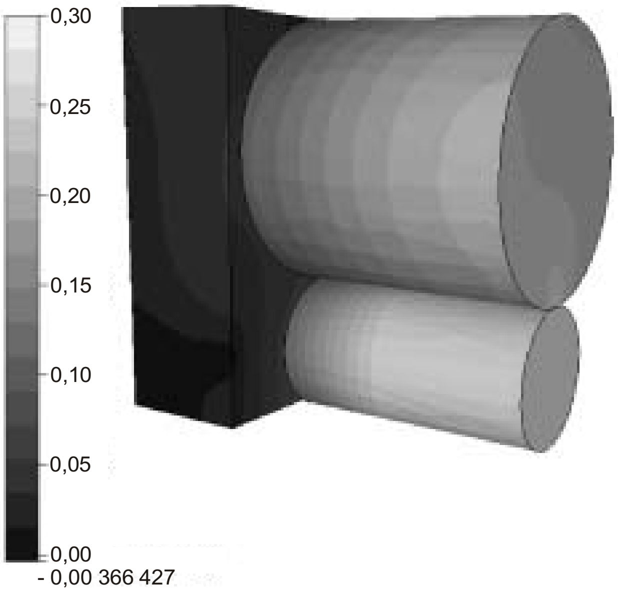

Figure 4. **Distribution of the movement of the rolls materials in direction of the plate height; the view from the exit side of the rolling stand; values in mm.**

Slika 4. **Raspored gibanja materijala valjaka u smjeru visine lima; pogled s izlazne strane valjačkog stana; vrijednosti izražene u mm**

the distribution on the cross-section through the exit plane of the rolls. The maximal deflection of the rolls is higher than 0,3 mm and these maximal values are located in region of the contact of the working roll with the plate.

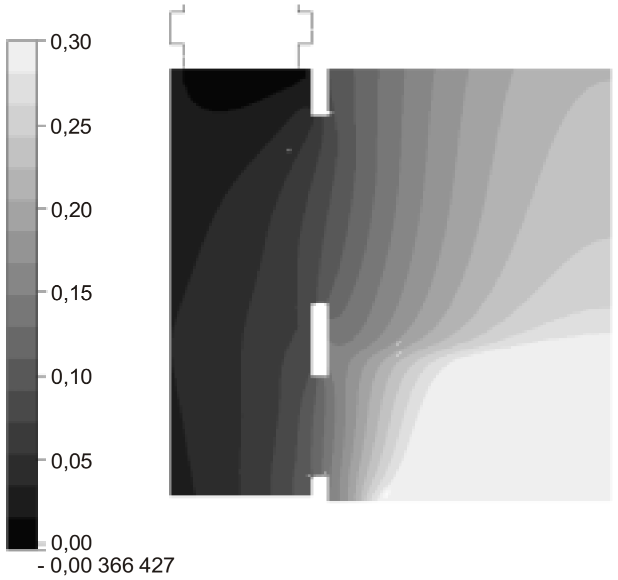

Figure 5. **Distribution of the movement of the rolls materials in direction of the plate height; the cross-section through the exit plane; values in mm.**

Slika 5. **Raspored gibanja materijala valjaka u smjeru visine lima; presjek kroz ravninu izlaza; vrijednosti u mm**

Figure 6. shows the longitudinal profile of the working roll in the plane of material exit from the deformation region, for different widths of the rolled plate. This profile is at the same time the profile of the upper surface of the rolled strip, and on its basis the maximum differences in plate thickness over the plate width can be determined.

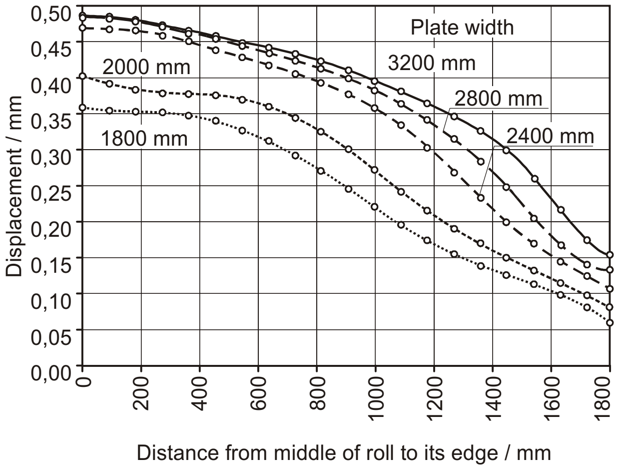

Figure 6. **The longitudinal profile of the working roll in the plane of material exit from the deformation region**

Slika 6. **Uzdužni profil radnog valjka u ravnini izlaza materijala iz zone deformacije**

SUMMARY

The performed analysis of the elastic deflection of rolls during the rolling of flat products of different widths allows the following conclusions to be drawn. The values of tensile stresses acting along the height of the rolling stand have a very adverse effect on roll mounting journals. They cause material fatigue and, as a consequence, a possible damage to the roll journals. Compressive stresses acting in the directions of rolling stand height and width have a negative effect on product quality by causing the flattening of the working roll. The geometry of the roll undergoes considerable distortions during rolling over the whole roll length. This results in obtaining incorrect dimensions of the finished product. The largest deflection of rolls occurs in the central part of the roll face, causing a lenticular shape of the cross-section of the rolled product.

REFERENCES

[1] Z. Jeglarz, W. Letkiewicz, M. Morawiecki: Technologia i urzadzenia walcowni wyrobow plaskich (The technology and equipment of a flat product rolling mill), Katowice 1979.

[2] H. Dyja, K. Wilk: Asymetryczne walcowanie blach i tasm (The asymmetric rolling of sheets and strips). Częstochowa University of Technology, Metallurgy Series No. 2, Częstochowa, 1998.

[3] Forge3. Users guide, Transvalor SA, Sophia Antipolis, France, 2001.

[4] M. Knapiński, Proceedings, 12th International Scientific Conference Achievements in Mechanical & Materials Engineering, 2003, L. A. Dobrzanski (ed.) Gliwice 2003, 475 - 478.