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The numerical analysis of roll deflection during plate rolling

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During the plate rolling process, considerable values of the forces of material pressure on the tool occur. These pressures cause the elastic deformation of the roll, thus changing the shape of the deformation region. Plate obtained from the rolling process always exhibits a variable thickness along the width. This state enables the rolling process to be carried out correctly, as thanks to the elastic deflection of rolls mounted on the rolling stand housing it is possible to guide the rolled strip precisely in the centre of the rolling stand. Roll deformation should be, however, controlled, because its too large value causes the permissible deviations in the thickness of the strip along its width to be exceeded. A numerical simulation of roll deflection during hot rolling is presented in the paper. The real conditions of the Plate Rolling Mill of the Czestochowa 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.

1. 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.

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 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.

2. 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 50mm, and the strip was rolled with a relative rolling

reduction of $\epsilon = 20\%$; the roll gap height was 40mm. Five strips of widths of 1800mm, 2000mm, 2400mm, 2800mm and 3200mm, respectively, 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 thermo-mechanical properties of this material were accounted for by using the visco-plastic model of deformation.

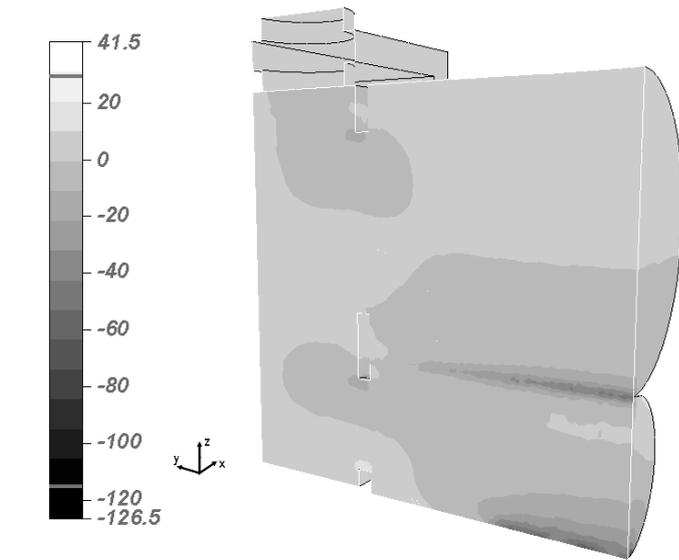


Figure 1. Distribution of the stresses in the direction of roll face length; negative values – compression; width of the rolled plate equal 1800mm

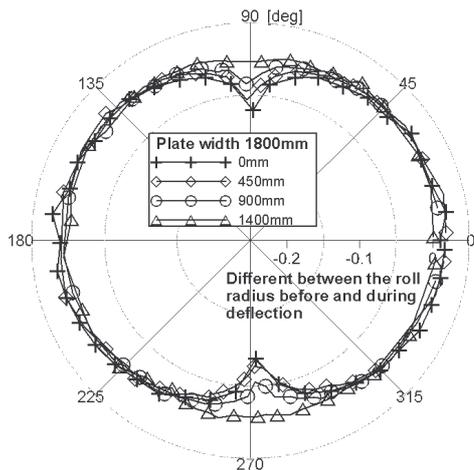


Figure 2. Working roll profiles in different part of the rolling face.

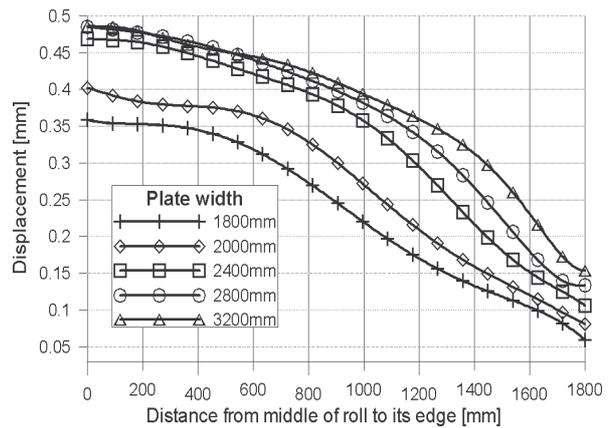


Figure 3. The longitudinal profile of the working roll in the plane of material exit from the deformation region

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. In the second step, the distribution of normal stresses on the roll surface, as obtained from the first simulation, 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 and Poisson's ratio. The working roll diameter was assumed to be 950mm, the backing-up diameter 1800mm, whereas the roll face lengths were identical and equal to 3600mm.

In this abstract, only selected examples of testing results are presented. Figure 1 shows the distribution of stresses in the direction of roll face length, caused by roll face deflection during rolling the 1800mm-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.

In Figure 2, 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. Figure 3 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.

3. 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.

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