INVESTIGATION OF THE METAL STRESS-STRAIN STATE PECULIARITIES ASSOCIATED WITH THE PLATE TEMPERATURE FIELD IRREGULARITY DURING ROUGH ROLLING

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Abstract

The problem of plate hot rolling on mill 5000 JSC "Severstal" was solved by finite element modeling in Deform-3D. It was shown by Deform-3D calculations that the presence of cold surface layers greatly increases the strain rate in the central layers of the plate thickness, which can greatly improve the quality of metal. The quantitative relations between the basic parameters of rolling and intensity of deformation in the plate central layers of roll considering the plate temperature field irregularity were obtained.

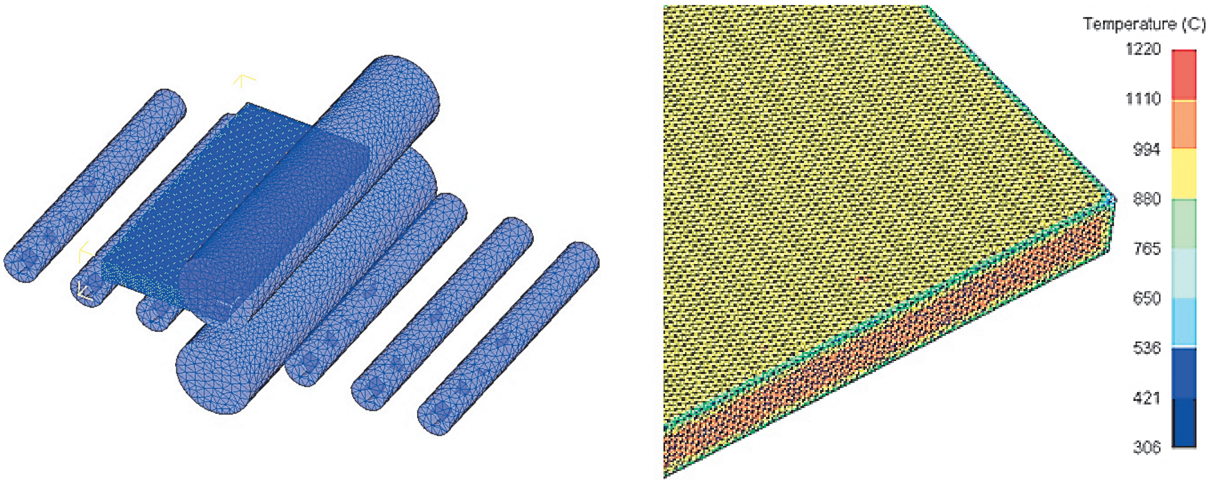
Keywords: Plates Rolling, High deformation zone, Stress-strain state, Temperature field irregularity, Mathematical modeling

1. INTRODUCTION

It's well-known [1] that the final structure and mechanical properties homogeneity of rolled plate is largely determined by the metal stress-strain state behavior in the deformation zone during rolling. The low, medium and high deformation zones distinguish depending on the strain distribution nature of plate's height [2]. Criterion value l / h_{av} (where l - length of the contact arc, h_{av} - the average height of the plate before and after rolling pass) is the formal characteristic that determines the height of deformation zone. Because of possibility to proceed the rolling force rough rolling often passes so that the relation $l / h_{av} < 1$ is usually holded. This deformation zone is called the high [2]. High deformation zone characterized by an extremely strain and stress distribution irregularity at plate's height, since the deformation does not penetrate in central layers of metal. This makes the existence of active and passive deformation zones. In the active deformation zones metal deforms directly under the rolls action. In the passive deformation zones metal is forced to stretch under active zones action. Strain-stress state tonality is largely determined by the active and passive zones interaction. Passive zones dimensions are greater than the deformation zone high. It's well-known [3] that in the passive deformation zones, which are the central layers and edges of plate, tensile stresses occur. At certain conditions, these stresses can damage the metal continuity. Because the central metal layers are passive deformation zones, they deform weak, which may affect the final structure and mechanical properties of the plate [4,5]. It is noted that the plate rolling theory was created without taking into account temperature field irregularity in the deformation zone. Meanwhile rough rolling is always accompanied by considerable plate temperature field irregularity, which obviously can significantly affect on the metal stress-strain state tonality in the deformation zone [1]. The stress state definition without temperature problem solving can lead to significant errors. Today's existing computer programs are used to calculate strain-stress state at various metal forming processes are able to solve both the temperature and the deformation problem. In that way work problems were formulated: investigate the metal stress-strain state peculiarities associated with the plate temperature field irregularity during rough rolling. Finite element modeling program Deform-3D was used to solve this problem.

2. EXPERIMENTAL PROCEDURE

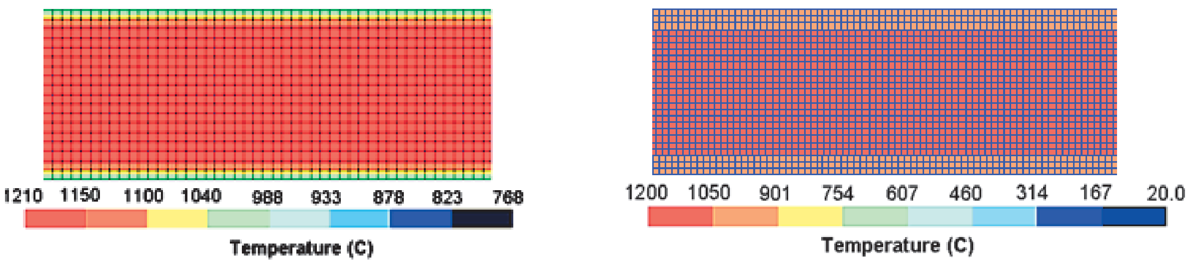
Calculations were performed using the finite element model of rolling process (**Fig. 1a**) which was adapted for the conditions on the rolling mill 5000. Model contains next parameters: geometric (size of rolls, plates, etc.), time (times of passes, pauses for reversal, etc.), temperature (thermal characteristics of rolled steel and rolls materials, heat transfer coefficients between plates and rolls, etc.), technological (number of passes, reductions, strain rates in passes, etc.).



a) b)

Fig.1 Rough rolling simulation in Deform- 3D: *a* - model of rough rolling process; *b* - initial plate's temperature field irregularity before rolling

For the model's temperature calibration the plate's surface temperature values obtained by stationary pyrometers was used. Initial plate's temperature field (**Fig. 1b**, **Fig. 2a**) was calculated in the Deform-3D by method [7]. It appears in presence of heated central metal layers (called the nucleus) and cold surface layers (called incrustations). Simplified scheme adopted to analyze the metal stress-strain state peculiarities associated with the plate's temperature field irregularity during rough rolling is shown in **Fig. 2b**. As a simplification takes the incrustations temperature constancy within their predetermined thickness, which was varied in the calculations of 30 to 50 mm when the initial thickness of the cast billets of 250 mm or 315 mm. Incrustations temperatures were taken between 700-1000 °C in the numerical experiment, the temperature of the heated central part was constant and equal to 1200 °C.



a) b)

Fig. 2 The temperature distribution across the plate thickness calculated using Deform-3D (*a*) and simplified scheme adopted to analyze the effect of temperature field irregularity on the metal stress-strain state (b)

First pass of rough rolling with a relative reduction of 1.6 to 19% was modeled. Plate was considered as plastic body. Plastic properties (stress-strain curves) for microalloyed pipe steel were determined by experiments on Gleeble-3800 system.

3. RESULTS

The modeling results are the fields of metal stress-strain state and over parameters in the deformation zone depending on the selected reduction, temperatures and thickness of the nucleus and incrustations. One of these fields is presented in **Fig. 3**. Irregularity of stress-strain state could be clearly seen on **Fig. 3**. There are significant areas of the longitudinal tensile stresses in the rolled plate central and near-contact layers. To assess changes in the stress-strain nature in the central part of the deformation zone in the case of a temperature gradient ratio h_{tens} / h_{avg} was used, where h_{tens}. - height of the area under tensile longitudinal stresses in the central layers, $h_{av.}$ - average height of the deformation zone. Graphics of h_{tens}/h_{avg} depending from the relative reduction ε and value of l / h_{av} parameter with different incrustations thicknesses and temperatures are shown on **Fig. 4**.

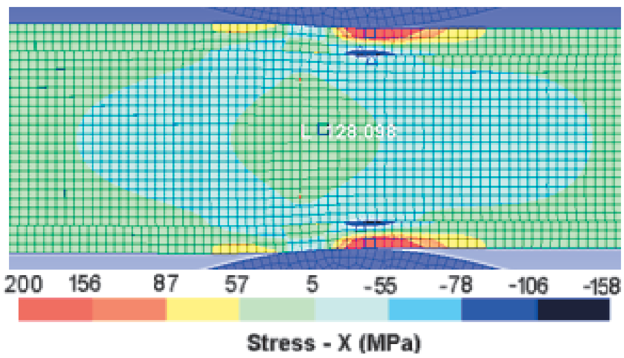
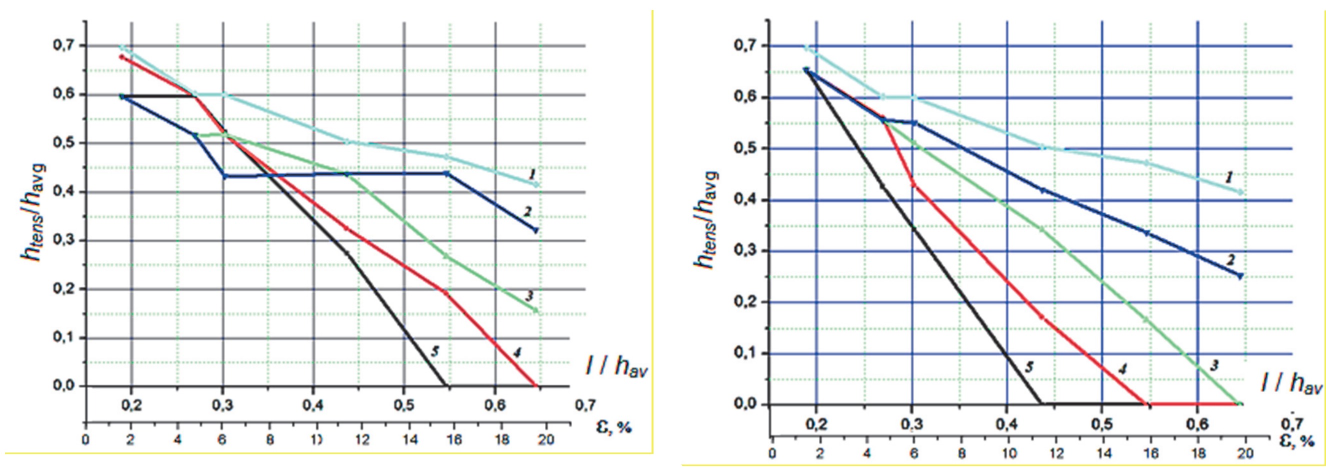


Fig. 3 Longitudinal stresses distribution in the deformation zone during rolling (incrustations thickness 30 mm, incrustation temperature 700 °C, relative reduction 3.3%)

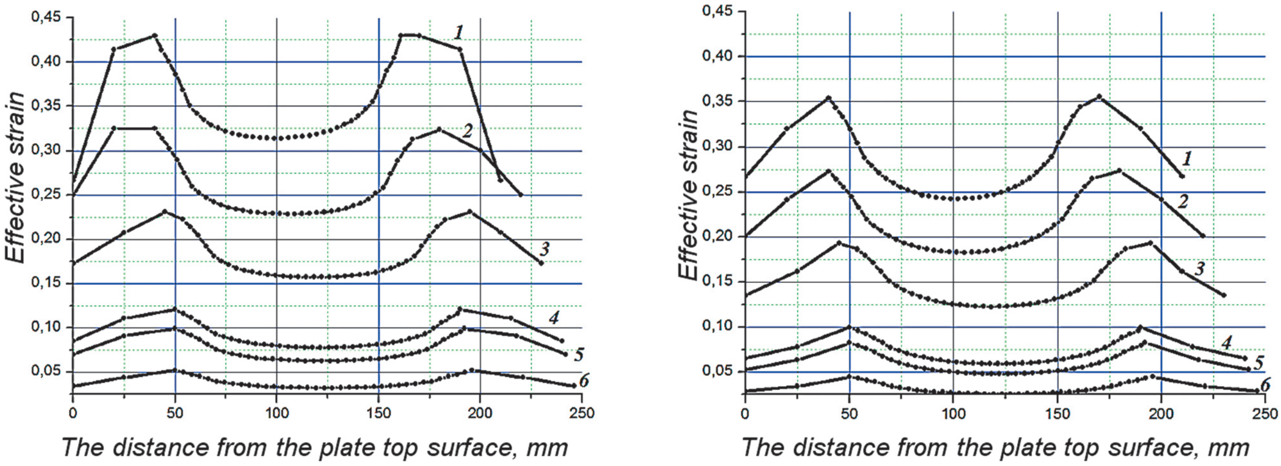
It's clearly seen that tensile stresses in the deformation zone present in the central and near-contact layers, occupying 70% of the deformation zone height.

Fig. 5-6 shows the effective strain distribution at plate height depending on the incrustations thicknesses and temperatures.



a) b)

Fig. 4 h_{tens}/h_{avg} dependence from the relative reduction ε and value of l / h_{av} parameter at incrustation temperatures 1200 °C (1), 1000 °C. (2) 900 °C (3) 800 °C (4) 700 °C. (5). Incrustation thicknesses are 30 mm (*a*) and 50 mm (*b*)



a) b)

Fig. 5 The effective strain distribution across the plate thickness during rough rolling of the slab with initial thickness 250 mm with relative reduction 19% (1), 16% (2) 12% (3) 6% (4) 3.3% (5) 1.6% (6) with incrustations thickness 50 mm and incrustations temperature 700 °C (a) and 1000 °C (b)

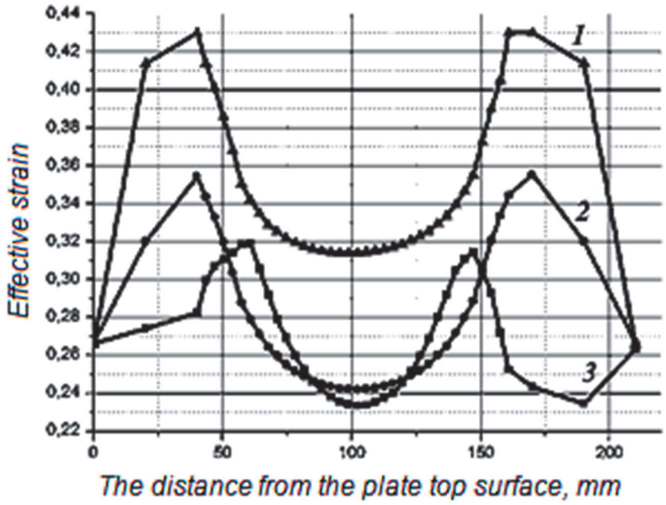


Fig. 6 The effective strain distribution across the plate thickness during rough rolling of the slab with initial thickness 250 mm with relative reduction 19% and incrustations thickness 50 mm and temperature 700 °C (1), 1000 °C (2) and uniform plate temperature 1200°C (3)

4. DISCUSSION

According to the numerical experiments results which are shown on **Fig. 4** it can be concluded that the metal stress-strain state in the deformation zone significantly affects not only on the plate's temperature gradient presence, but on the plate's temperature distribution behavior, which is determined by incrustations thicknesses and temperatures. According to **Fig. 4** the higher incrustations thickness and lower the incrustations temperature, the higher tensile stress drops in metal central layers with increasing reduction. Thus, when the incrustation thickness is 50 mm and incrustation temperature is 700 °C stresses in plate's central layers become compressive already at 11.5 % relative reduction and l / h_{av} parameter value at 0.44.

Tensile stresses at central layers of uniformly heated plate do not disappear even when the relative reduction is 20% and parameter l / h_a is 0.65. This significantly (1.35 one) increases the effective strain in the plate central layers (**Fig. 6**). Thus, the stress-strain state behavior at irregular temperature distribution of the plate compared with a uniform distribution becomes more favorable. Tensile stress do not increase in the metal central layers in deformation zone. Furthermore, the presence of cold surface layers greatly increases the strain rate in the central layers of the plate thickness, which can greatly improve the quality of metal. It provides additional control over the quality of rolled products, in particular, the uniformity of structure and mechanical properties across the thickness.

Also it should be noted that the temperature field irregularity shifts the boundaries of high deformation zone toward the lower values of the criteria l / h_{av}, in some cases (**Fig. 4**) there are no tensile stresses at values of the form factor l / h_{av} = 0.44. Small reductions undesirable at rough rolling, because they lead to low effective strain in central layers and appearance of tensile stresses there.

CONCLUSIONS

The nature of the metal stress-strain state in the deformation zone during rolling plate at high deformation zone significantly affects not only on the presence of a temperature gradient over the plate thickness, but on the behavior of the temperature distribution, which is determined by the incrustation thicknesses and temperatures.

Creating the temperature gradient in the plate before rough rolling could reduces the tensile stress in the plate central layers as well as significantly improves effective strain in these layers. It provides additional control over the quality of rolled products, in particular, the uniformity of structure and mechanical properties across the thickness.

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