INFLUENCE OF THE SHEAR STRAIN ON THE MICROSTRUCTURE EVOLUTION IN THE ASYMMETRIC ROLLING PROCESS

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Abstract

It is commonly known that shear strain occurring in asymmetric rolling process plays a very effective role to improve mechanical properties of metallic materials especially in the production of sheet metal. In the article preliminary research results of deformation in asymmetric rolling process influence on equivalent deformation distribution and austenite microstructure changes are presented. The C45 steel plate rolling process with reduction ε = 30 % in temperature 1000 °C were modeled. For experiments Forge 3D computer program based on FEM were used. The analyze of influence of different rolls speed ratio in range a_v= 1.0 ÷ 1.5 were done. Based on austenite microstructure evolution model the austenite grain size as a result of asymmetric rolling processes with different coefficient of rolls speed ratio was determined. It was found that strain distribution was inhomogeneous. The zones of increased strain were observed, which affected the uneven distribution of austenite grain size. Increasing different coefficient of roll speed ratio should caused a reduction in the uniform distribution of strains, and thus led to a more even distribution of the austenite grain size.

Keywords: Asymmetric rolling process, shear strain, austenite evolution

1. INTRODUCTION

For many years, in Institute of Plastic Working and Safety Engineering of Technical University of Czestochowa has been providing research on the application of a deliberately set asymmetry in the process of rolling flat homogeneous and multilayered products. The test results were implemented in the rolling mills and thin sheet rolling mills [1,2], and the flat products produced by this method are characterized by higher flatness and lower waviness. The use of asymmetrical deformation conditions on the upper and lower roll results in the occurrence of zones with opposite directed tangential stresses [3-5] causing deformations affecting grain size distribution in the rolled strip [6]. The presence of zones in which the friction forces on the upper and lower roll are directed against each other is beneficial for the rolling process, and their operation can be compared to the action of tension and counter-thrust forces. This has the effect of reducing the total metal pressure on the rollers, and thus it is possible to use larger individual deformation in pass, which also affects the fragmentation of the austenite structure. Using asymmetry in the rolling process also causes less elastic deflection of the roll stand elements. Thanks to this, smaller forces that bend the work rolls can be used and a ready sheet with smaller dimensional deviations on the length and width of the strand can be obtained. The **Figure 1** shows changes in the shape and dimensions of a single element of the band mesh and the entire coordination grid as a result of asymmetrical rolling. schematic illustration of changing the shape and dimensions of a single grid element before and after asymmetric strip rolling. The square ABCD after an asymmetric rolling obtains the shape of A'B'C'D'. The angle of ADC, which originally amounted to 90 degrees, has changed due to the shear stress by the angle γ, which varies depending on the asymmetry factor.

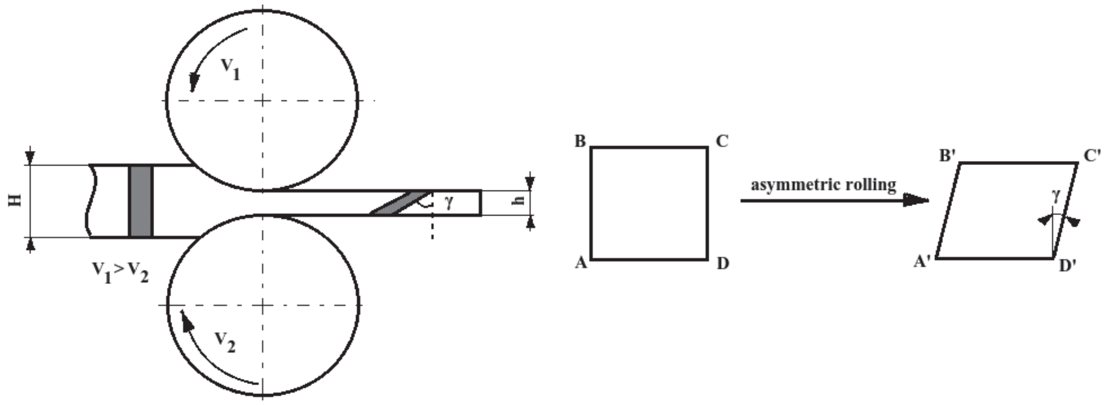

Figure 1 Change in the shape and dimensions of a single element of the band mesh and the entire coordination grid as a result of asymmetrical rolling [3]

In article [3] the result of numerical simulation of asymmetric CuZn5 alloy strip cold rolling to 70% thickness reduction with different values of speed asymmetry coefficient were done. In **Figure 2** distribution of shear strain on cross section of strip are presented.

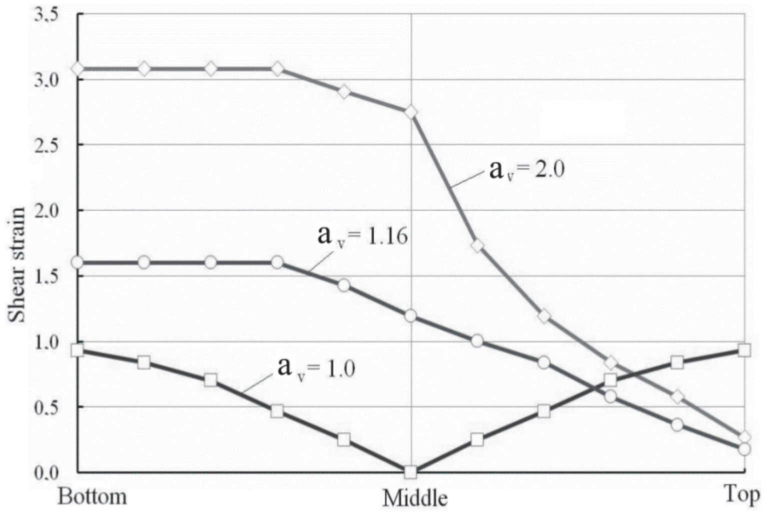

Figure 2 The distribution of shear strain on cross section of strip thickness [3]

During symmetric (a_v=1.0) of cold-rolling alloy strip CuZn5 with a total strain of 70% shear strain was about 0.9 on the top and bottom of stripe. There was no observed shear strain in the middle of cross section of strip. Increasing speed asymmetry coefficient increased shear strain too, particularly on the bottom surface of the strip where the roll has faster circumferential speed. For maximum of a_v coefficient shear strain equal about 3.1 was observed. In the processes of asymmetrical rolling, apart from the main deformations, there are still deformations caused by shear stress. Equivalent strain ε_i can be determined based on dependence [7,8] (1):

$$\varepsilon_i = \sqrt{\frac{2}{9}\left[(\varepsilon_{11}-\varepsilon_{22})^2+(\varepsilon_{22}-\varepsilon_{33})^2+(\varepsilon_{33}-\varepsilon_{11})^2+\frac{3}{2}\left(\varepsilon_{12}^2+\varepsilon_{23}^2+\varepsilon_{31}^2\right)\right]} \quad (1)$$

where:

ε_{11}; ε_{22}; ε_{33} - main strain

ε_{12}; ε_{23}; ε_{31} - shear strain which can be determined from dependence (2) for the asymmetrical rolling process:

$$\varepsilon_i = \frac{2\sqrt{3}}{3}\sqrt{\varepsilon_{22}^2 + \frac{\varepsilon_{12}^2}{4}} \qquad (2)$$

For determination of shear strain influence on the microstructure evolution in the asymmetric rolling process numerical modeling were done.

2. THEORETICAL ANALYSIS OF THE SHEAR STRAIN CHANGE DURING ASYMETRIC ROLLING PROCESS

The thermomechanical simulation of the asymetric plate rolling process was carried out using the visco-plastic body model for a three-dimensional strain state with the use of the Forge2011® program. Deformation of the body was de-scribed by the Norton-Hoff law. Simulation of the asymetric plate rolling process was conducted with the following initial parameters: feedstock temperature 1000 °C (a uniformtemperature distribution was assumed), rolls diameters 300 mm, main rolls rotation speed 63.6 rpm (linear velocity 1 m/s), deformation during rolling 30 % (initial height of the plates was 10 mm) and the friction factor 0.6. The coefficient of heat transfer between the plate and the rolls was assumed to be 3000 (W/K·m^2) and the coefficient of heat transfer between the plate and air was assumed at 100 (W/K·m^2). The numerical analysiss was performed for three rolling speeds asymetry coefficients: a_v = 1.0 (symetry, the rolls rotation speed same for both working rolls), a_v = 1.3 (asymetry, the lower roll rotation speed was 82.7 rpm) and), a_v = 1.5 (asymetry, the lower roll rotation speed was 95.4 rpm). The yield stress σ_p dependence of strain, strain rate and temperature for the C45 steel used for the theoretical analisyss has been taken from the material database of the programForge2011®. Based on the results of numerical modelling the distribution of the component of shear strain (ε_{xy}) in the deformation zone has been made (**Figure 3**).

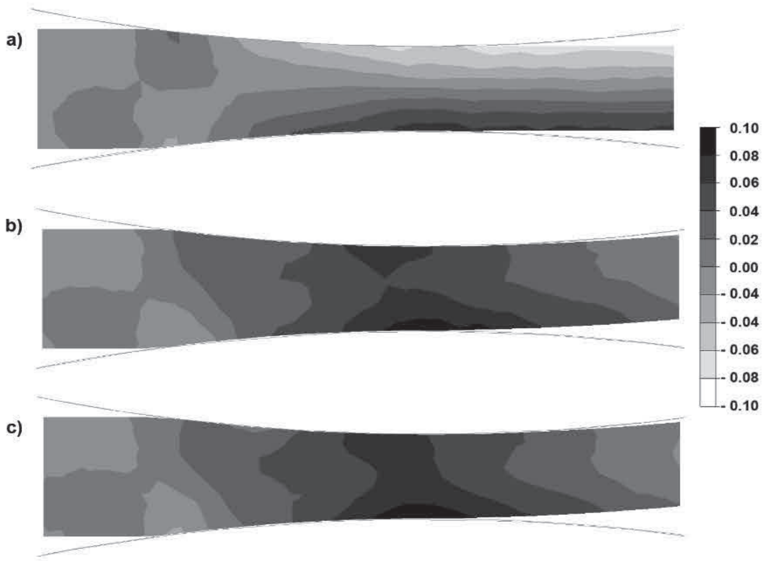

Figure 3 Distribution of the shear strain (ε_{12}) for analyzed cases of rolling: a) a_v = 1.0, b) a_v = 1.3, c) a_v = 1.5

Analyzing the data presented in the **Figure 3a**, it can be noticed that for the symmetrical process (a_v = 1.0), the tensor component in the deformation zone has opposite signs (opposite directions of interaction), arranged symmetrically to the horizontal axis of symmetry. In this case, the deformation forms a deformation with a characteristic shape (so-called herringbone) at an angle of 45 degrees to the axis of symmetry of the rolled strand. The introduction of asymmetry (**Figure 3b**) causes a disturbance of the equilibrium, which results in a change of the sign to the positive (direction of impact) of the deformations occurring in the deformation basin.

This means intensification of deformations caused by the cylinder with a higher rotational speed (bottom working roll). This also results in a change in the angle and displacement of the individual shear strain bands. Increasing the coefficient of asymmetry (**Figure 3c**) affects the change in the angle of occurrence of the deformation of the form (intensification of the impact of the roller with increased rotational velocity), slightly affecting the increase in the value of the analyzed deformations. It can be observed that the characteristic banded distribution of shear deformations in practice results in the appearance of zones with reduced particle grain size.

3. AUSTENITE MICROSTRUCTURE EVOLUTION

Based on results of numerical modeling of asymmetric rolling processes distribution of effective strain ε_i (2) was determined. Distribution of effective strain ε_i for all variants of rolling are presented in **Figure 4**. Analyzing the influence of different rolls speed ratio in range a_v= 1.0 ÷ 1.5 on equivalent deformation distribution it shown that with the increase of the asymmetry value, the effective strain increased. This is due to the greater volume of shear strains for higher values of the a_v coefficient.

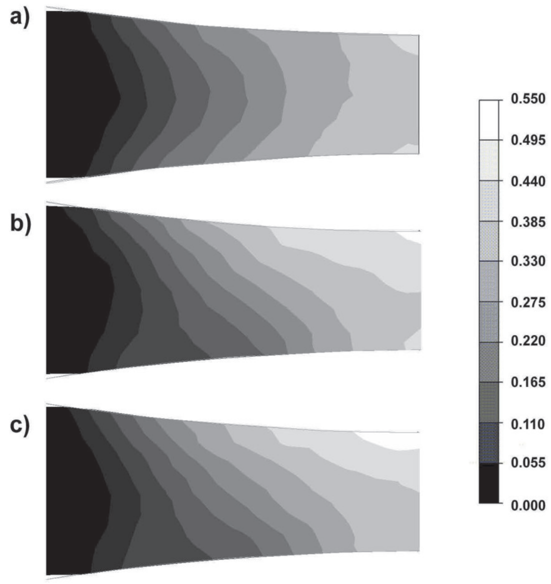

Figure 4 Distribution of effective strain ε_i for analyzed cases of rolling: a) a_v = 1.0, b) a_v = 1.3, c) a_v = 1.5

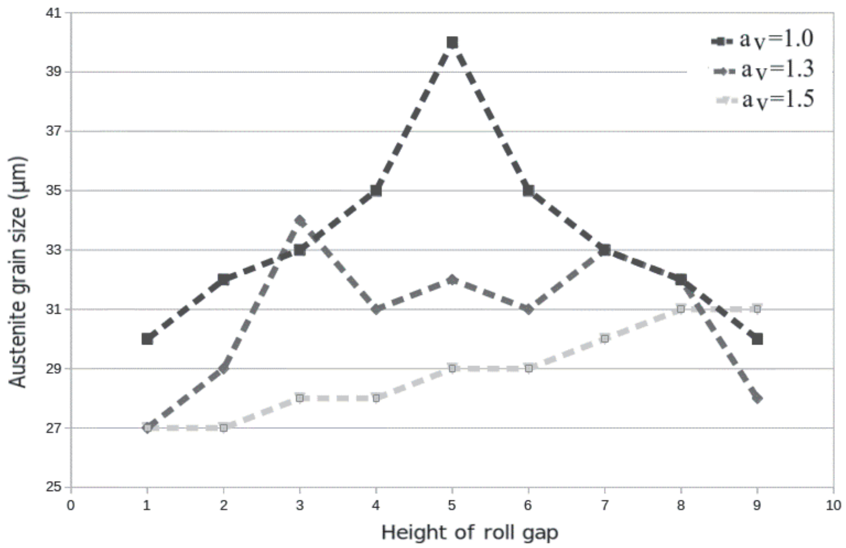

Figure 5 Distribution of austenite grain size on height of roll gap

For predicting the parameters of microstructure of austenite after rolling processes, a computer program of austenite microstructure evolution [9] were used. Based on the rolling process parameters it is possible to establish the phenomena occurring in the steel after deformation and to determine the austenite grain size and the non- recrystallized strain. The influence of the shear strain on the microstructure evolution in the sheet asymmetric rolling process is presented on **Figure 5**. It was shown that the introduction of asymmetry to the sheet rolling process provided to fined microstructure of austenite and more uniform distribution of them. During symmetric (a_v=1.0) the range of austenite grain size was 30 ÷ 40 μm. The largest austenite grain size was observed in the middle of height of strip and the smallest grain size was on the top and bottom of strip. Increasing speed asymmetry coefficient increased uniform distribution of austenite grain size on height of strip. For maximum of a_v coefficient (1.5) range of austenite grain size was 27 ÷ 32 μm.

As it can be noticed introducing of asymmetry to the rolling process should cause change in the distribution of the grain size (on the height of roll gap), a finer grain size comparing to the symmetrical rolling process are observed. When we analyze distribution of the grain size for the symmetrical process of rolling we can notice that the largest grains are observed in the central zone and then symmetrically decrease in the direction of the work rolls. Whereas for asymmetrical processes the multiplicity of grain changes in accordance with the direction of impact of shear deformations, the smallest grains occur in the zone of impact of the roller of higher velocity and increase towards the second working roll (with the smaller rolling speed). Also the distribution of austenite grain size is more uniform comparing to the distribution estimated for classical rolling process.

CONCLUSION

Based on the analysis of the obtained results it can be found that asymmetry introduced to the rolling process has considerably increased the intensity of occurrence of shear bands, which cause a change of the shear strain directions in the deforamtion zone. It also can be found that for the rolling processes with greater asymetry coefficient increase of the values of shear strain in comparsion to symetrical process can be noticed. Based on stres - strain conditions in the deformation zone estimated distribution of austenite grain size (on the height of roll gap) show that for asymetrical rolling processes a finer grain size has been obtained within the entire rolled plate. Also the distribution of austenite grain size is more uniform comparing to the distribution estimated for classical rolling process. In the next stage of experiments the verification of the theoretical results is been planed.

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