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Numerical Research of Shear Strain in an Extreme Case of Asymmetric Rolling

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Abstract. Considerable shear strain is necessary for manufacture of metallic materials with ultramicrograin structure. For flat rolling shear strain intensity is determined by two components: compression strain ε_{yy} and shear strain ε_{xy}. The vertical asymmetric sheet rolling process in rolling-drawing mode was investigated with the purpose of shear strain implementation. Calculation results show that during asymmetric rolling mode a vertical cross-section inclination takes place being especially pronounced with the total amount of deformation of 50% and more.

Introduction

Active development of intensive plastic deformation methods has been noted recently which allow getting ultramicrograin materials with unique complex of physical and mechanical properties. Nevertheless, given the versatility of well known methods of intensive plastic deformation, there remains a vital problem of their wide industrial application. This problem is connected with low adaptability of the existing processes to manufacture and small sizes of rolling billets [1]. Besides, at present methods of continuous intensive plastic deformation for getting ultramicrograin structures in flat long metallic semi-products have not been practically developed yet.

In the view of a number of researches [2-5] one of the promising methods of intensive plastic deformation for mass production of ultramicrograin structures in strip and band are processes of vertical asymmetric sheet rolling based on asymmetry purposefully created by means of different speeds of working rolls, divergence of diameters and contact friction conditions, etc. Processes of asymmetric rolling possess three substantial characteristics necessary for getting ultramicrograin structures in long semi-products: 1) possibility of carrying out high shear deformations; 2) possibility of creating high pressing strain in deformation zone; 3) possibility of rolling thin sheet and band.

Asymmetry in a vertical plane causes changes of deformation zone kinematics [6-9], that is changes in the extension of lead zone and delay zone in the upper and low working rolls. Correspondingly, we can distinguish the following cases of asymmetric rolling [6]: 1) a common case, when in a deformation zone there are two kinematic zones both of lead and delay but the extension of these zones in an upper and low working rolls is different; 2) an intermediate case, when there are two zones on one roll - a zone of lead and zone of delay, while on the other roll there exists only one zone - either a delay zone or lead zone; 3) an extreme case, when on one roll we have only a zone of delay and on the other roll we have only a lead zone.

Considerable shear strain appearance is a determining factor in the asymmetric rolling development as a method of intensive plastic deformation. During symmetric rolling shear strain is extremely small and vertical cross-section inclination does not take place. As to the asymmetric rolling (Fig. 1), particularly in the so-called extreme case, when there exists only a delay zone on the one roll and only a lead zone on the other roll, shear strain intensity in deformation zone may increase 2 or 3 times and more.

The purpose of this paper is numerical research and possibility evaluation of attaining considerable shear strain in an extreme case of asymmetric sheet rolling.

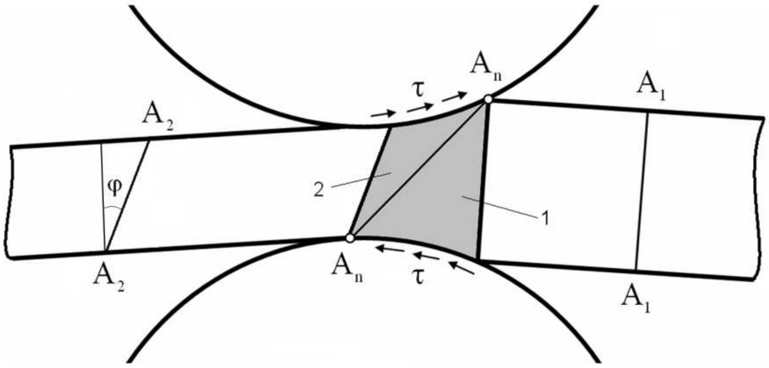

Fig. 1. A simplified scheme of asymmetric deformation zone in an extreme case (1 – delay zone, 2 – lead zone, A_nA_n – neutral cross-section, τ – contact friction forces, A_1A_1 – cross-section before deformation, A_2A_2 – cross-section after deformation, φ – cross-section inclination angle)

One of the variants of an asymmetric sheet rolling extreme case implementation is rolling-drawing process developed by Vyudrin V.N. and Ageev L.M. in 1971. This process is characterized by keeping the precise speed of front and back strip ends while deformation is being carried out at a high level of front tension.

Asymmetric sheet rolling numerical modeling in rolling-drawing mode was carried out with the use of finite elements method in the program complex DEFORM. According to the scheme (Fig. 2) the strip is deformed between two rolls one of which being a lead roll rotating at an angular velocity ω_2 while the other is a driven roll rotating at an angular velocity ω_1. Herewith the following condition should be fulfilled:

$$\omega_2 R_2 > \omega_1 R_1 \text{ and } \frac{\omega_2 R_2}{\omega_1 R_1} = \frac{h_1}{h_2}, \qquad (1)$$

where h_1, h_2 – a strip thickness before and after deformation; R_1, R_2 – radius of upper and lower working rolls correspondingly.

The strip back end is moving at speed $V_1 = \omega_1 R_1$ while the front end – at speed $V_2 = \omega_2 R_2$. Herewith tension of a definite value σ_1 and σ_2 is applied to the strip front and back end. Under the afore mentioned conditions on the contact surface of a lead roll only a delay zone will be present while on the contact surface of a driven roll only a lead zone will exist.

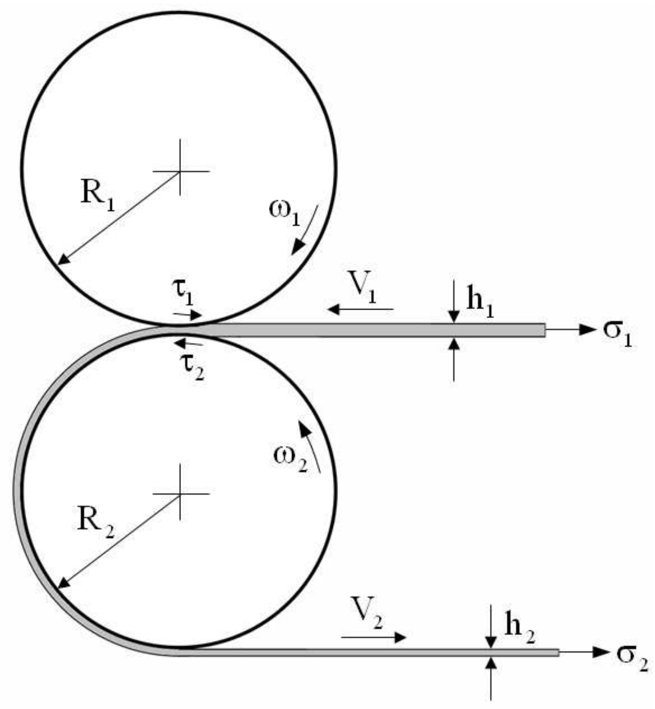

Fig. 2. Scheme of asymmetric sheet rolling modeled process
(τ_1, τ_2 – contact friction forces)

Assumptions used in modeling: 1) plane-strain state; 2) the deformed media is self-hardening rigid-ductile media; 3) working rolls are rigidly fixed; 4) Culon's law of friction; 5) the process is isothermal.

Shear strain intensity for three-dimensional deformation:

$$\Gamma = \sqrt{\frac{2}{3}}\sqrt{(\varepsilon_{xx} - \varepsilon_{yy})^2 + (\varepsilon_{yy} - \varepsilon_{zz})^2 + (\varepsilon_{zz} - \varepsilon_{xx})^2 + 6(\varepsilon_{xy}^2 + \varepsilon_{yz}^2 + \varepsilon_{zx}^2)}, \tag{2}$$

where $\varepsilon_{xx}, \varepsilon_{yy}, \varepsilon_{zz}, \varepsilon_{xy}, \varepsilon_{yz}, \varepsilon_{zx}$ – deformation tensor components.

For conditions of plane-strain state may be presented by the following equation:

$$\varepsilon_{xx} = \varepsilon_{yy}, \varepsilon_{zz} = 0, \varepsilon_{yz} = 0, \varepsilon_{zx} = 0. \tag{3}$$

With consideration (3) shear strain intensity (2) for plane-strain state can be transformed into:

$$\Gamma = \sqrt{\frac{2}{3}}\sqrt{2\varepsilon_{yy}^2 + 6\varepsilon_{xy}^2}, \tag{4}$$

Thus, for flat rolling shear strain intensity is determined by two components: compression strain ε_{yy} and shear strain ε_{xy}.

Initial data for modeling: 1) initial strip thickness $h_1 = 3\ mm$; 2) working rolls radius $R_1 = R_2 = 200\,mm$; 3) deformed material is AISI-1045 out of DEFORM material base; 4) deformed material temperature is 20 0C; 5) friction coefficient on the contact with the upper roll is $\mu_1 = 0{,}05$, on the contact with the low roll is $\mu_2 = 0{,}15$; 6) low roll angular velocity of rotation is $\omega_2 = 5\ rad/s$.

During modeling the following parameters were viewed: 1) vertical lines distortion (vertical cross-section inclination); 2) strip cross-section shear strain intensity (4) variation. The influence of the total amount of deformation by the thickness was analyzed: 10%, 30%, 50%, 70%, 80%. Obtained results were compare to those of symmetric rolling (under $\mu_1 = \mu_2 = 0{,}05$, $\omega_1 = \omega_2 = 5\ rad/s$ and other parameters being equal).

Calculation results show that during asymmetric rolling mode vertical cross-section inclination takes place (Fig. 3, 4) being especially pronounced with the total amount of deformation of 50% and more. Particularly, angle of inclination φ under total amount of deformation of 50% was approximately 45o while under 80% it was about 75o.

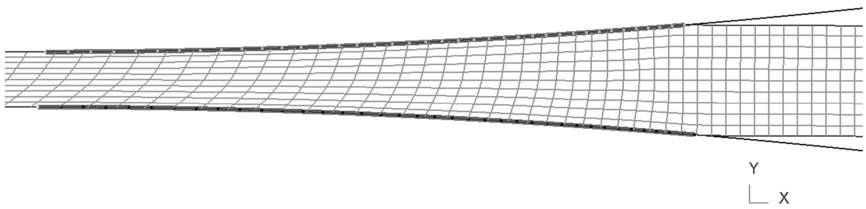

Fig. 3. Grid distortion during asymmetric rolling

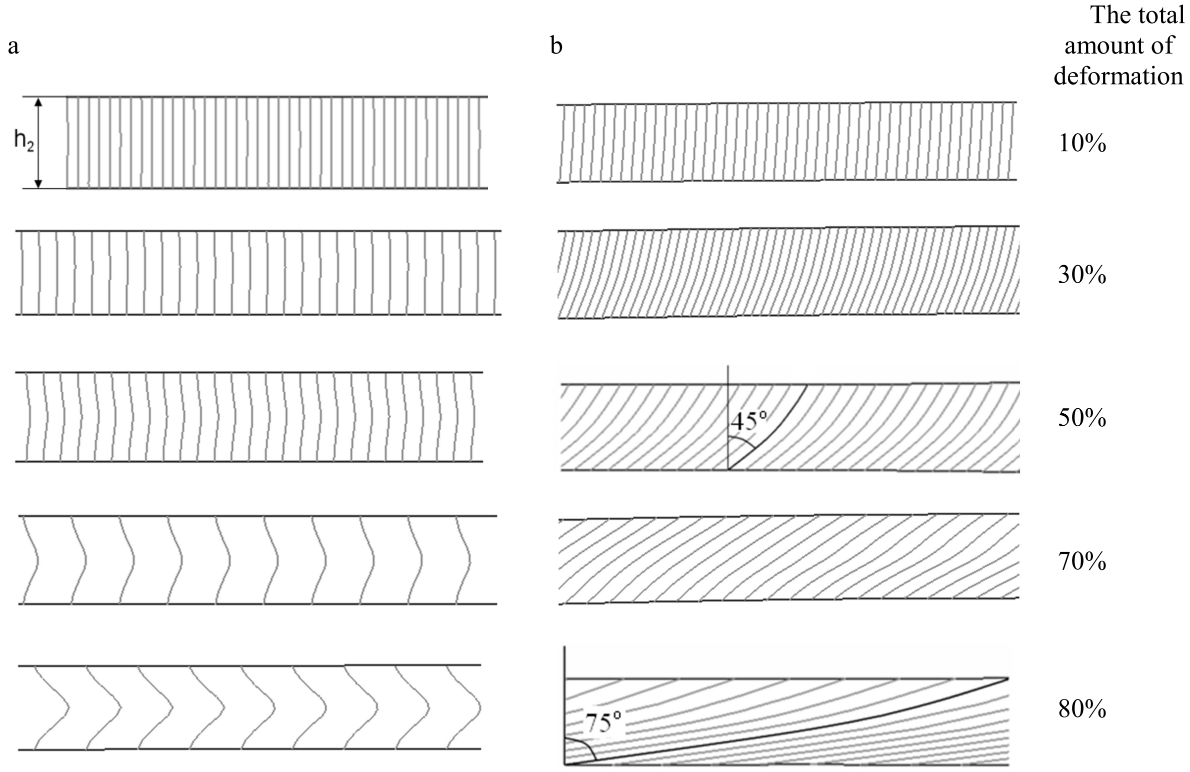

Fig. 4. Vertical lines distortion under symmetric (a) and asymmetric (b) rolling

During asymmetric rolling mode compression deformation ε_{yy} is distributed over the strip cross-section irregularly unlike symmetric rolling where compression deformation ε_{yy} does not change by the thickness.

Asymmetric sheet rolling peculiarity is a considerable increase in shear strain ε_{xy} over the whole strip cross-section (Fig. 5). For the upper strip surface this value ε_{xy} increased by 2,6 (from 0,183 to 0,477), for the lower surface shear strain increased by 9 (from 0,183 to 1,65) in comparison with symmetric rolling mode. Besides, during symmetric rolling shear strain in the strip center equals zero while during asymmetric rolling mode they constituted 0,917.

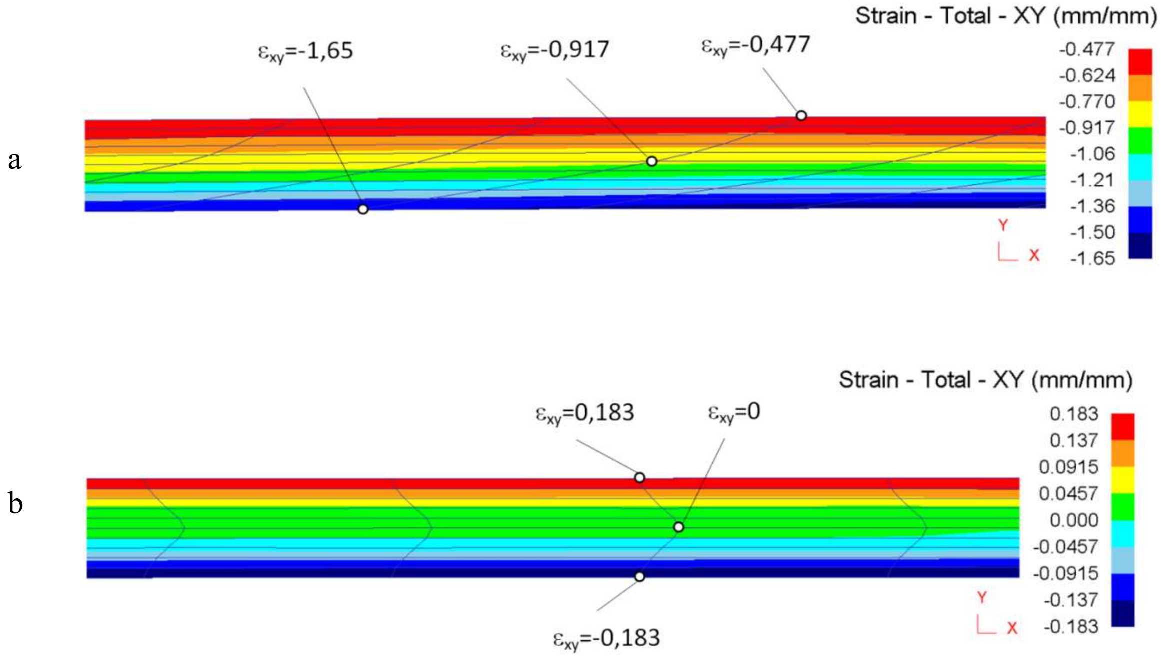

Fig. 5. Compression deformation distribution εyy and shear strain εxy by the thickness during asymmetric (a) and symmetric (b) rolling (the total amount of deformation is 80%)

Considerable shear strain intensity increase during asymmetric sheet rolling in comparison with symmetric rolling mode exists under total amount of deformation of more than 50%(Fig. 6) which may be connected with cross-section inclined angle rise of more than 45o. Distribution of shear strain intensity over strip cross-section is irregular: its maximum value Г=3,5 corresponds to the strip lower surface, while its minimum Г=2,1 – to the strip upper surface.

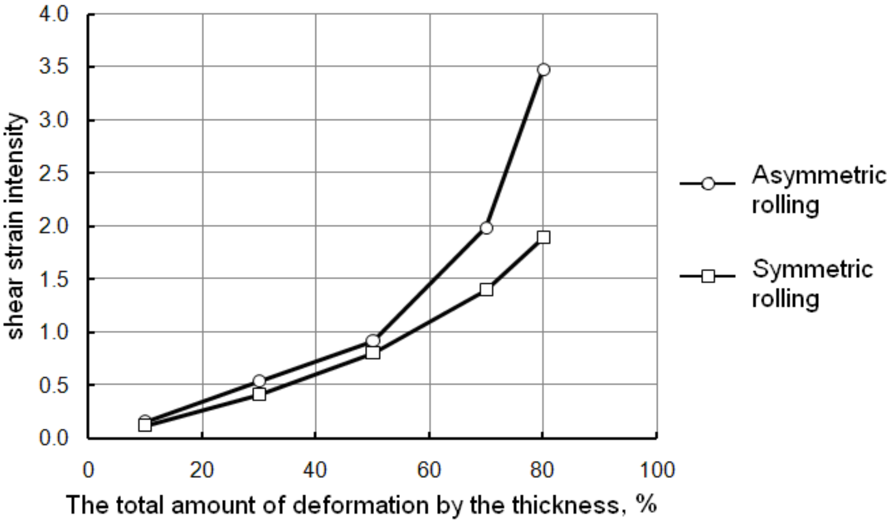

Fig. 6. The influence of total amount of deformation by the thickness and rolling mode on shear strain intensity: a – for strip lower surface; b – for strip center; c – for strip upper surface

Thus, processes of asymmetric sheet rolling possess considerable possibilities for shear strain intensity increase over strip cross-section and can be used for ultramicrograin structures in long rolling products.

Conclusion

Criteria for getting ultramicrograin structures in asymmetric rolling of thin metallic sheet and band have been offered: a) the scalar $\Gamma = \sqrt{\frac{2}{3}}\sqrt{2\varepsilon_{yy}^2 + 6\varepsilon_{xy}^2}$ for flat deformed state characterizing accumulated shear deformations intensity and defined by two components: compression strain ε_{yy} and shear strain ε_{xy} (target level $\Gamma \geq 2$); б) angle φ of vertical cross-section inclination of the billet material (target level $\varphi \geq 45^{\circ}$).

Evaluation of possibility of getting high shear deformation during thin sheet and band asymmetric rolling has been carried out. On the basis of mathematic modeling with finite elements method it has been established that during asymmetric rolling shear deformations s along the strip cross-section increase more than 9 times in comparison with symmetric rolling.

It has been theoretically proved that asymmetric sheet rolling processes possess considerable potential for shear deformation intensity increase along strip cross-section (up to the level of 3,5) and can be used for getting ultramicrograin structures in thin metallic sheet and band manufacture. However, processes of asymmetric rolling belong to the very intensive plastic deformation methods when initial and final billet sizes do not match which limits to some extend the possibility of their application.

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