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Influence of Different Asymmetric Rolling Processes on Shear Strain

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Abstract**—**Materials with ultrafine-grained structure and unique physical and mechanical properties can be obtained by methods of severe plastic deformation, which include processes of asymmetric rolling (AR). Asymmetric rolling is a very effective way to create ultrafine-grained structures of metals and alloys. Since the asymmetric rolling is a continuous process, it has great potential for industrial production of ultrafine-grained structure sheets. Basic principles of asymmetric rolling are described in detail in scientific literature. In this work finite element modeling of asymmetric rolling and metal forming processes in multiroll gauge was performed. Parameters of the processes which allow achieving significant values of shear strain were defined. The results of the study will be useful for the research of the evolution of ultra-fine metal structure in asymmetric rolling.

Keywords**—**Asymmetric rolling, equivalent strain, FEM, multiroll gauge, profile, severe plastic deformation, shear strain, sheet.

I. Introduction

RECENTLY much attention has been paid to reducing weight of metal ware with simultaneous increase of its strength. This explains the use of high strength aluminum and its alloys as substitute for steel. To provide such high strength the ultrafine-grained structures of metal is necessary. Such structure can be formed by severe plastic deformation methods. However, most of these methods do not give possibility to produce long products with such structure. From our point of view, asymmetric rolling can be considered as one of the perspective method for that goal. Basic principles of asymmetric rolling are described in detail in scientific literature. Asymmetry during rolling can be created due to the difference in angle speeds, roll diameters, different friction conditions in the points of metal-roll contacts [1]-[13]. Asymmetry allows creating great shear strain exceeding 3.

In this article the results of numerical studies for two cases of asymmetric rolling with two working rolls and three working rolls gauges are presented. In both cases asymmetry originated from the difference of the working roll speeds.

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II. Finite Elements Modeling of Asymmetric Sheet Rolling

A. Review Stage

During asymmetric rolling the lower roll circumferential speed V_1 was greater than the circumferential speed of the upper roll. Equivalent strain ε_i can be calculated by the following equation:

$$\varepsilon_i = \frac{1}{\sqrt{3}}\sqrt{4\varepsilon_y^2 + \gamma_{xy}^2} \qquad (1)$$

Equation (1) represents the equivalent strain during asymmetric rolling.

A commercial software DEFORM-2D, based on finite element method (FEM), was used to analyze asymmetric rolling process. Pure aluminum DIN-Al-99.7 from database DEFORM-2D was chosen as the material for modeling.

Input data varied within the following limits: 1) friction coefficient at the contact points with upper and lower rolls $\mu = 0.08...0.32$; 2) working roll radii R = 50…200 mm; 3) roll speed difference coefficient K_v= 1.00…3.33 (2); 4) one-pass reduction $\varepsilon = 30...70\%$. Circumferential speed of the lower roll in all the variants of calculation was constant and equal to V_1 = 1000 mm/sek, while the circumferential speed of the upper roll was reduced K_v times.

$$K_v = \frac{V_1}{V_2}, \text{ where } V_1 > V_2 \qquad (2)$$

During modeling of the asymmetric rolling processes the influence of the process parameters on the distribution of shear strain γ_{xy} through the sheet thickness was studied.

During asymmetric rolling (K_v = 1.00) maximum shear strain values are observed in the upper and lower contact surfaces of the sheet, while in the central part they are equal to zero. Increase in roll speed difference contributes to the alignment of shear strain distribution through the cross-section of the sheet (Fig. 1). While K_v= 2.00 the value of shear strain varies through the cross-section within the narrow limits from 2.20 to 2.22. Extremely high values of shear strain are achieved due to combining considerable reduction ($\varepsilon \geq 50\%$) and speed difference ($K_v \geq 2.0$). So, while $\varepsilon = 70\%$ and $K_v = 3.33$, shear strain reaches 10 (Fig. 2). At that value the accumulated deformation is 5.94 according to (1).

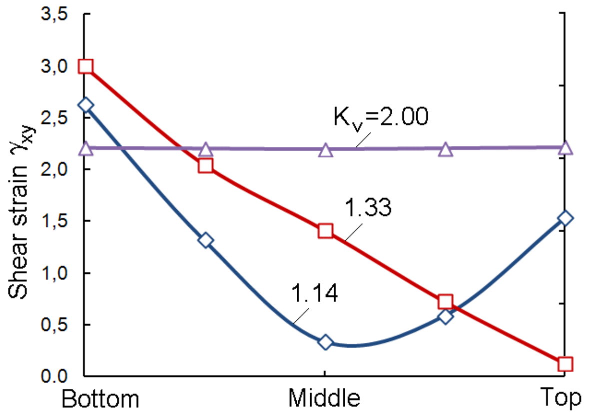


Fig. 1 Roll speed coefficient influence on distribution of shear strain across sheet thickness ($R = 200\,mm,\ h_0 = 2\,mm,\ \varepsilon = 50\%,\ \mu = 0.32$)

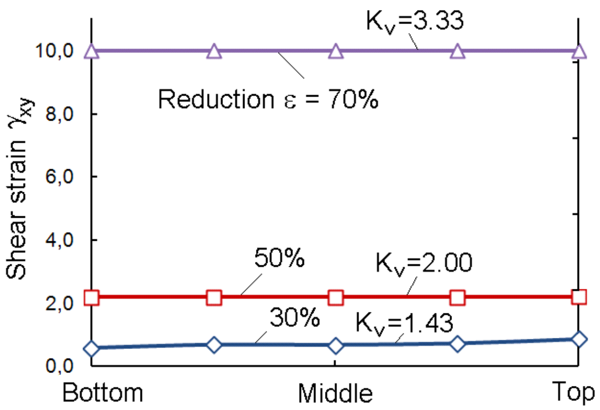


Fig. 2 The influence of the reduction-pass ratio on shear strain distribution across sheet thickness ($R = 200\,mm,\ h_0 = 2\,mm,\ \mu = 0.32$)

III. Finite Element Modeling of Asymmetric Rolling in Multiroll Gauge

To obtain high-strength metal materials with ultrafine-grained structure a unique method of asymmetric severe plastic deformation of metal in the stand with two converged three roll gauges was developed. In this stand additional shear strain influence is created due to the speed difference of the working rolls (Fig. 3).

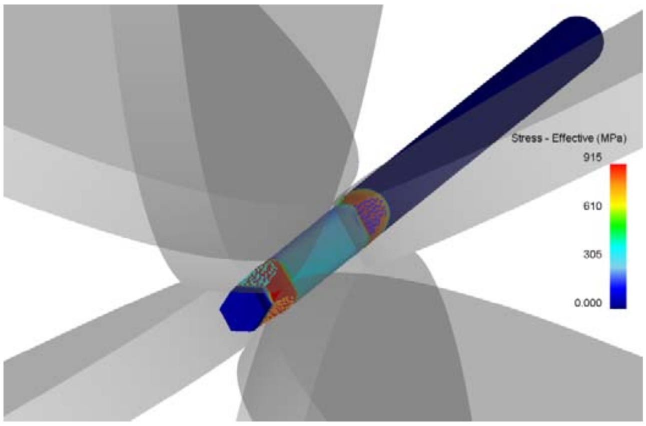
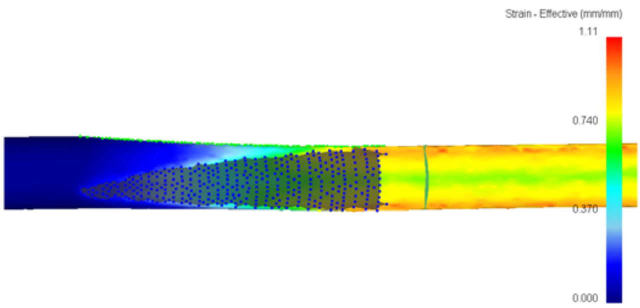


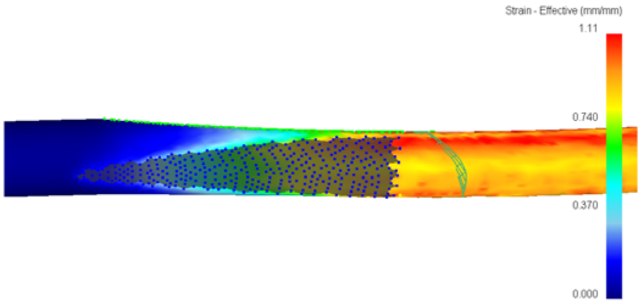
Fig. 3 Severe plastic metal deformation during asymmetric rolling in dual three roll-gauges

A round copper CDA-110 profile with diameter of d=4 mm was used as an incoming billet. Rolling was carried out on flat rolls with the roll body radii R=180 мм. Circumferential speed of the first roll rotation was considered to be equal to $V_1 = 1.0\,m/\sec$. Circumferential speed of other rolls were set in accordance with the equation: $V_2 = V_3 = 1.0...1.7\,m/\sec$. Hybrid friction law was used. Friction coefficient at the point of contact between the metal and working rolls varied in the range of 0.06 to 0.36. Front tension varied in the range of 10...60 MPa, back tension variation constituted 10...30 MPa correspondingly. For the approximation of incoming billet geometric parameters the elements of a triangular pyramid form were used.

With the increase of the roll speed difference the initial Lagrange's net starts rotating (Fig. 4). The research shows that during round profile rolling in the first three-roll gauge the angle of the net rotation reaches 40-50o. Shear strain is characterized by this angle tangent and might reach the value 1-2. The second gauge application may result in shear strain values high enough for ultrafine-grained structure acquisition.



(a)



(b)

Fig. 4 Strain effective at symmetric (a) and asymmetric (b) rolling

Roll speed difference growth makes it possible to increase stretch ratio in the three-roll gauge, all other conditions being equal (Fig. 5). Thus, the increase of roll speed difference coefficient by 1.7 allows increasing stretch ratio from 1.61 to 1.68.

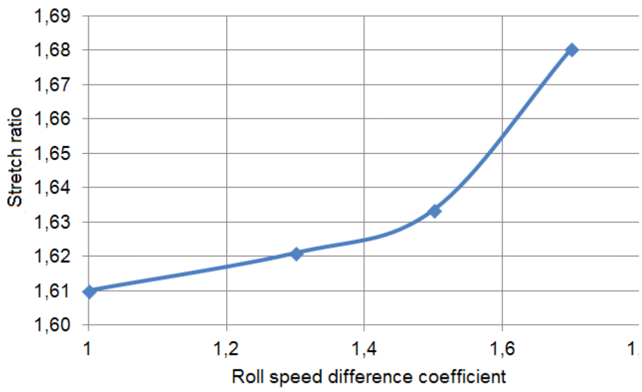


Fig. 5 Roll speed difference coefficient influence on the metal stretch ratio during severe plastic deformation in the asymmetric rolling process

IV. Conclusion

It was demonstrated that during asymmetric sheet rolling with asymmetry coefficient of $K_v = 3.33$ and reduction of $\varepsilon = 70\%$ shear strain reaches 10, while accumulated strain reaches 5.94.

During asymmetric rolling in multiroll gauges with the working roll speed difference coefficient increase, the stretch ratio and strain effective increase.

The results of the study will be useful for the research of the evolution of ultra-fine metal structure in asymmetric rolling.

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