ANALYSIS OF STRESS AND STRAIN IN ASYMMETRIC ROLL GAP

DYJA Henryk[1], SZYIŃSKI Paweł[2], KAWAŁEK Anna[3],LABER Konrad[4]

[1,2,3,4]Czestochowa University of Technology, Faculty of Production Engineering and Materials Technology, Czestochowa, Poland, EU,

[1]dyja@wip.pcz.pl, [2]pawelszyinski@wip.pcz.pl, [3]kawalek@wip.pcz.pl, [4]laber@wip.pcz.pl

Abstract

The paper presents results of numerical simulation of the asymmetric rolling process for band with shape ratio h_0/D = 0.072 - steel grade S355J2G3. The study was conducted to determine the differences in the impact factor of different kinds of asymmetry on the band bending after leaving the deformation zone and the power parameters of rolling process. Introduction of single asymmetry, by varying the peripheral speed of the work rolls, does not have an effect on reduction of force parameters values. Based on the survey it was found that simultaneous introduction of second asymmetry, by varying the diameter of the work rolls, allows to lower rolling force and it also allows to obtain flat band after rolling process.

Keywords: Dual asymmetry, speed asymmetry, geometric asymmetry, plate rolling

1. INTRODUCTION

1.1. Basic problem

Rolling of flat products is one of the most common kinds of metallic materials forming process. In recent years, in addition to the increase in the production of plates and thin sheets, there has been an increase in the production of panels, with thickness more than 40 mm [1, 2]. This products must fulfill still growing customer requirements as to the shape, plastic parameters and the chemical composition. Increasing requirements for strength of machines and equipment construction, creates a demand for construction steel with high mechanical properties [3]. During the production of such products there is a greater load on rolling stands. The increase in pressure force during the rolling process causes a large elastic deformation of the roll stand. To prevents this the bending rollers systems is introduced for work and back-up rolls, this causes additional load on roll stand and increases energy consumption. In industrial reality rolling process is not a symmetric one, which in effect leads to occurrence of numerous defects. One of them is the band bending on the output of the deformation zone caused by uncontrolled asymmetry of deformation conditions. The alternative is asymmetric rolling, which is based on intended change of state of stress and strain in the deformation zone, which does not increase the load on the roll stand and the drive and even reduces the total strength of the metal pressure on the rolls. Introduction of controlled asymmetry to the rolling process allows to eliminate shape defects while reducing value of metal pressure on work rolls [2].

1.2. Solution idea

Introduction of single asymmetry by varying the peripheral speed of the work rolls does not have an effect on reduction of force parameters values and have a negative effect on torque distribution between work rolls. Band could band on the direction of lower or upper roll, depending on other rolling parameters [4, 5, 6]. The study was conducted to determine the differences in the impact factor of asymmetry in the band bending after leaving the deformation zone and the power parameters of rolling process during introduction of second asymmetry in the same time for band with initial thickness h_0 = 70 mm. In conclusion asymmetry was introduced in two different ways by varying peripheral speed and the diameter of the work rolls at the same time (dual asymmetry).

2. THE RESEARCH

2.1. Border conditions

To determine the effect of asymmetry factor on the band bending after leaving the deformation zone and strength parameters of rolling process numerical studies were performed using the program FORGE 2011®. FORGE 2011® program was used numerous time to simulate the industrial environment and it was confirmed that results given by it are correct [4]. The paper presents results of numerical simulation of the asymmetric rolling process for band shape ratio h_0/D = 0.072. To the study work rolls with a diameter of 970 mm was used. Speed of the lower work roll was constant and it was *n* = 80 rev/min. Asymmetry was introduced by reducing the peripheral speed of the upper work roll. The asymmetry coefficient of the work rolls speed ($a_v = v_l/v_u$)wasa_v = 1.10. For research purposes the following data were adopted: rolling temperature *T* = 880 °C, relative reduction *ε* = 0.10÷0.25. The material used for research was a low-alloy steel with increased strength S355J2G3, which chemical composition is shown in **Table 1**.

Table 1 Chemical composition of steel S355J2G3, [%]

C	Mn	Si	P	S	Cr	Ni	Mo	Cu
0.15	1.36	0.33	0.017	0.03	0.05	0.089	0.03	0.23
Al	**N_2**	**V**	**Nb**	**B**	**Ti**	**Sn**	**Ca**	**Zn**
0.03	0.0092	0.001	0.002	0.0003	0.002	0.018	0.0007	0.003

During use of FORGE 2011®it is crucial to determine yield stress properly. To do it a series of plastometer studies with use of Gleeble 3800 simulator were conducted. Obtained data were approximated to find parameters of Hansel-Spittel equation (1) and determine flow curves used by a FORGE 2011®.

$$\sigma_p = Ae^{m_1 T}\varepsilon^{m_2}\dot{\varepsilon}^{m_3}\varepsilon^{\frac{m_4}{\varepsilon}}(1+\varepsilon)^{m_5 T}\varepsilon^{m_7 \varepsilon}\dot{\varepsilon}^{m_8 T}T^{m_9} \quad (1)$$

Data from plastometer studies and after approximation are shown in **Fig. 1**.

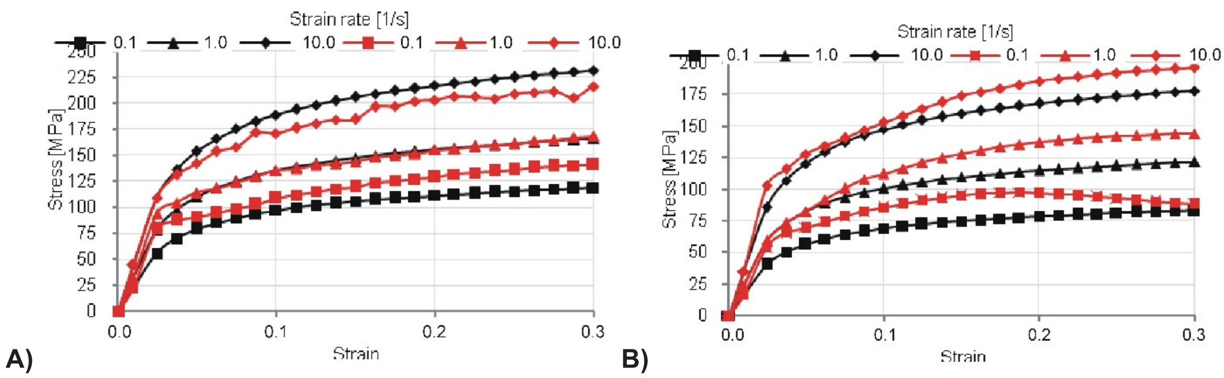


Fig. 1 Plastic flow curves of steel grade S355J2G3: A) 800 °C; B) 900 °C; red lines - plastometer data; black lines - data after approximation

2.2. Stress in asymmetric rolling

Fig. 2 shows exemplary distribution of the equivalent strain in band during: A - symmetric rolling; B - rolling with single asymmetry; C - rolling with double asymmetry. Based on the results obtained after simulations it was found that for the band shape ratio h_0/D = 0.072 introduction of single asymmetry caused unequal distribution of equivalent stress between upper and lower side of rolled bandfor all values of the relative reduction ε. Example of unequal equivalent stress distribution, during introduction of single asymmetry, between upper and lower side of band is shown for the relative reduction ε = 0.25 in **Fig. 2B**.

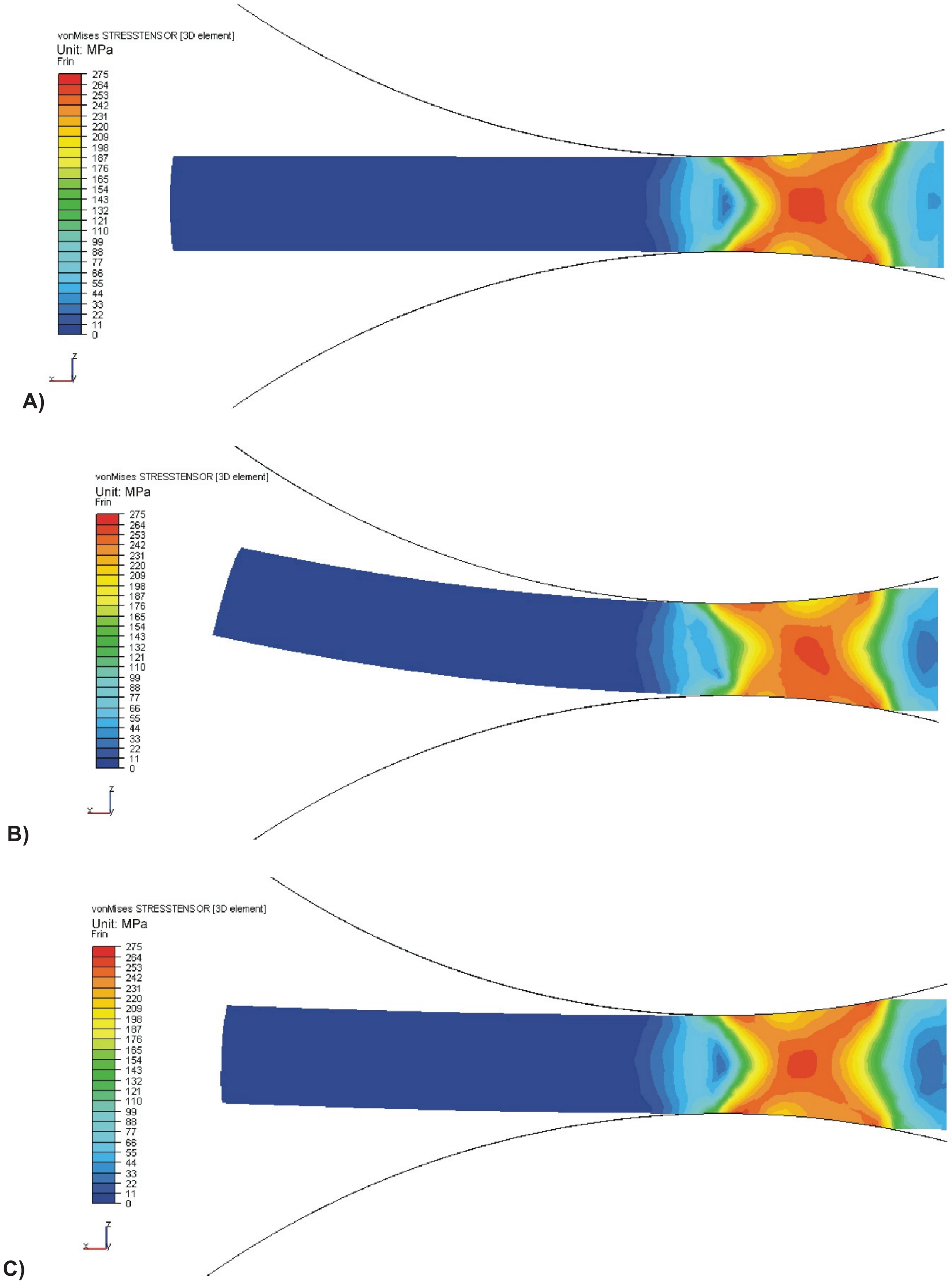
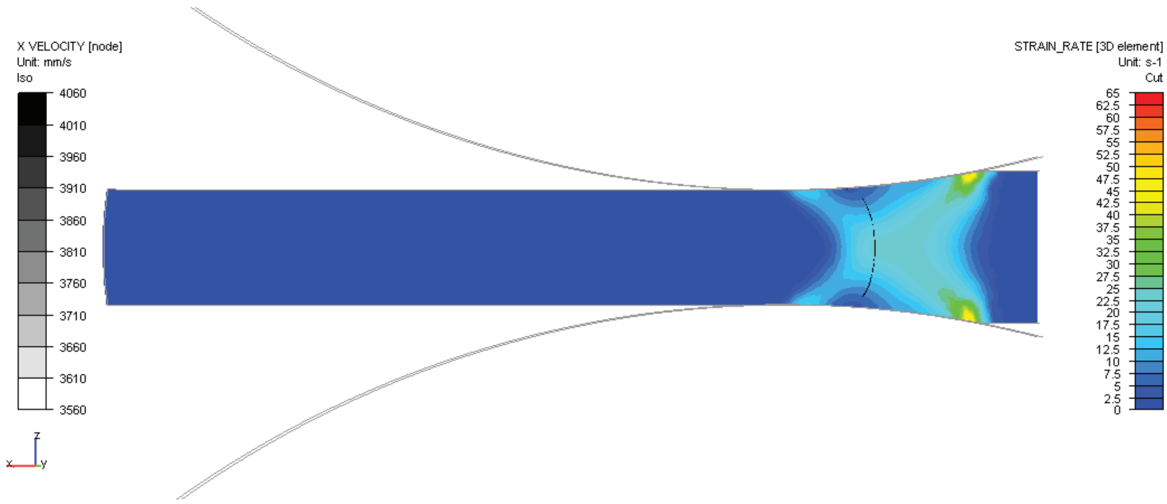


Fig. 2 Distribution of the equivalent stress σ_i for rolling of billet with initial thickness h_0 = 70 mm; ε = 0.25; A) symmetry; B) single asymmetry a_v = 1.10; C) dual asymmetry; a_v = 1.10; a_d = 1.10

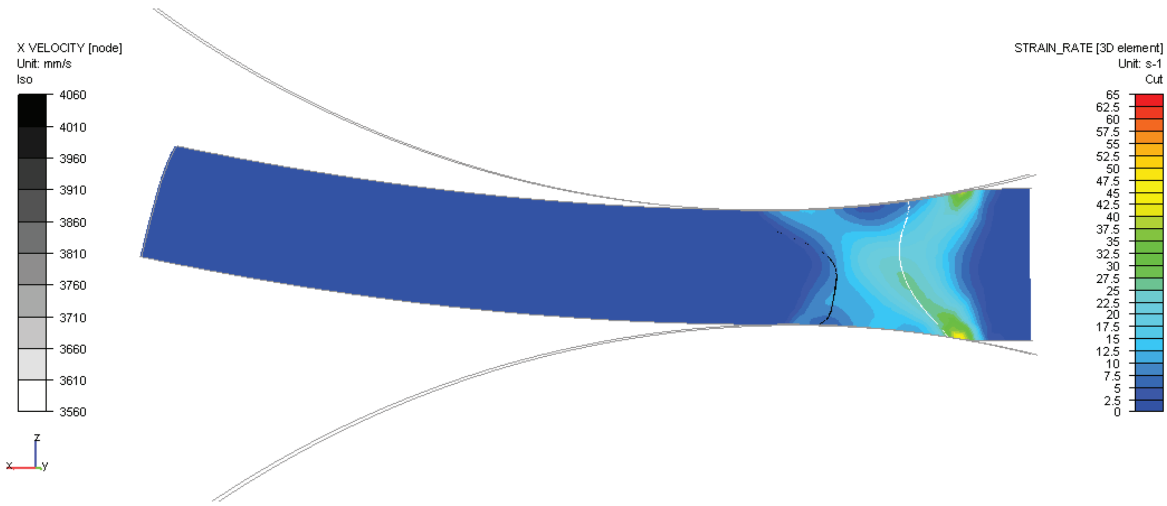
Simultaneous introduction of two kinds of asymmetry reduce value of equivalent stress and allows to restore almost equal distribution of equivalent stress in rolled band as it is shown in **Fig. 2C**.

2.3. Strain in asymmetric rolling

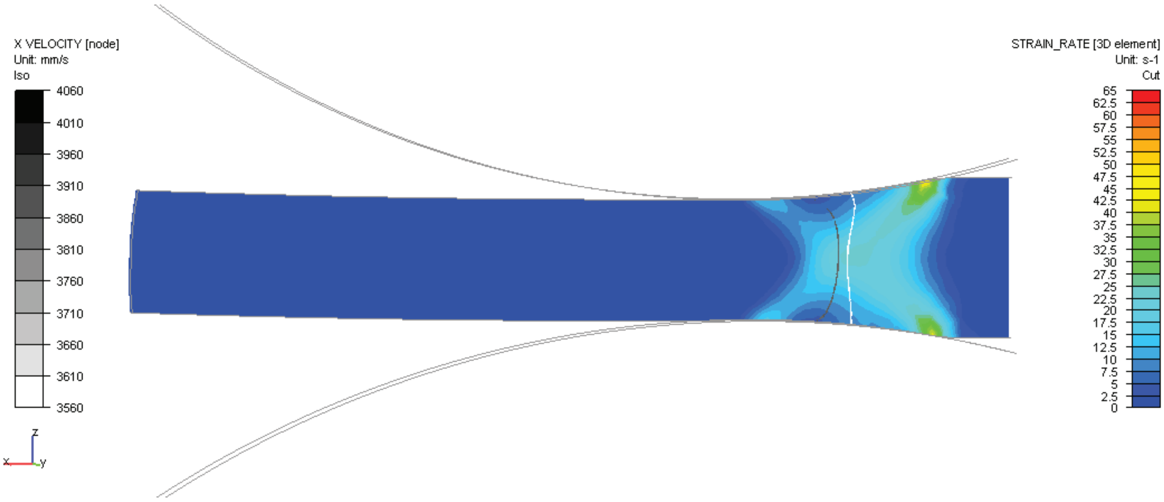
Fig. 3 shows exemplary distribution of the equivalent strain in band during: A - symmetric rolling; B - rolling with single asymmetry; C - rolling with double asymmetry. Based on the obtained results it was found that for the band shape ratio h_0/D = 0.072 introduction of single asymmetry caused unequal distribution of equivalent strain between upper and lower side of rolled band for all values of the relative reduction ε. Simultaneous introduction of two kinds of asymmetry allows to restore equal distribution of equivalent stress in rolled band as it is shown in **Fig. 2C**. For all cases a position of neutral plane is shown (black line for upper roll, white line for lower roll). Presentation of two neutral planes, for each roll, is a simplification (resulting from the program capabilities in result presentation) in reality there is only one neutral plane which is the result of presented surfaces. Introduction of single asymmetry causes that length of thelead zone from the side oflowerwork rollis reducedas a result ofshiftingthe neutral surfacein the direction ofthe outputcross section. While thelength of the lagzoneis reducedbythe impact ofthe upperrollon metal, resulting in a shift ofthe neutral surfacetowardthe inputcross sectionof the roll gap.The actualneutralsurfaceisthenat an angle. The differencein the length oflead and lagzonescauses bending of rolled band. Simultaneous introduction of two kinds of asymmetry causes only slight difference in length of lead and lag zones and allows to obtain flat band.



A)



B)

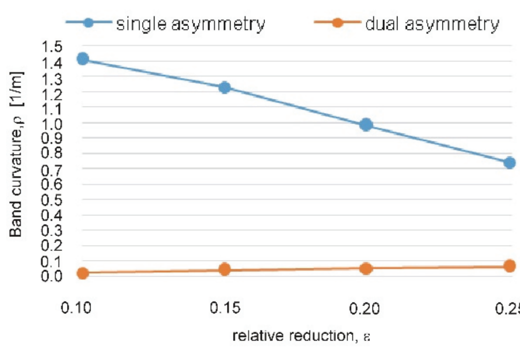


C)

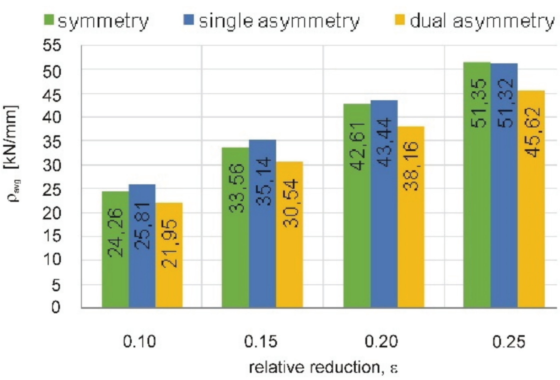
Fig. 3 Distribution of the equivalent strain rate $\dot{\varepsilon}_i$ for rolling of billet with initial thickness h_0 = 70 mm; ε = 0.25: A) symmetry ; B) single asymmetry a_v = 1,10; C) dual asymmetry; a_v = 1,10; a_d = 1,10

2.4. Dual asymmetry

It was found that introduction of second asymmetry causes positive effect on band curvature. **Fig. 4A** shows the effect of introduction single (velocity asymmetry a_v= 1.1) and dual (velocity asymmetry a_v = 1.1 and geometrical asymmetry a_d= 1.1) asymmetry. During research it was found that introduction of second asymmetry allows to obtain almost flat band. It is caused by existence of forced symmetry in the rolling process - linear velocity of band from side of both rolls is almost equal. In effect band could easily enter to the next pass.In addition to smaller band curvature, dual asymmetry allows also to lower values of the average unit pressure p_{avg} - compared with rolling process with single asymmetry. During research it was found that reduction of the average unit pressure occurred in all researched cases, regardless to introduced relative reduction. It was found that introduction of second asymmetry into rolling process of band with shape ratio h_0/D = 0.072 effects on reduction of the average unit pressure value for most cases approximately by 8%. The biggest reduction of the average unit pressure value occurred for relative reduction ε = 0.25 and it was 12% as shown in **Fig. 4B**.For the band shape ratio h_0/D = 0.072 the use of single asymmetry, by reducing the upper roll speed, resulted in practically no reduction in the average unit pressure. Only for maximum tested relative reduction ε = 0.25 the use of single asymmetry resulted on a slight decrease of the average unit pressure value, as shown in **Fig. 4B**.



A)



B)

Fig. 4 Effect of relative reduction ε and the type for rolling of billet with initial thickness h_0 = 70 mm on: A) band curvature ρ; B) average unit pressure p_j;

3. CONCLUSION

Based on the survey the following conclusions were made:

- application of the asymmetric rolling process by varying the peripheral speed of the work rolls for the band shape ratio h_0/D = 0.072 causes an unequal stress and strain distribution between upper and lower part of rolled band,
- application of the asymmetric rolling process by varying the peripheral speed of the work rolls for the band shape ratio h_0/D = 0.072 does not reduce the average unit pressure,
- application of the asymmetric rolling process by varying the diameter and peripheral speed of the work rolls with for the band shape ratio h_0/D = 0.072 affects the reduction of metal pressure on work rolls and allows to obtain flat band.

REFERENCES

[1] PAWELSKI H.: Comparison of methods for calculating the influence of asymmetry in strip and plate rolling, Steel research, no. 71, p. 490÷496, 2000.

[2] MARKOWSKI J., DYJA H., KNAPIŃSKI M., KAWAŁEK A.: Theoretical analysis of the asymmetric rolling of sheets on a leader and finishing stands, Journal of Materials Processing Technology, vol. 138, 2003, p. 183÷188.

[3] SKUZA Z., PRUSAK R., BUDZIK R.: Contemporary elements of system of quality management in metallurgical enterprises, Metallurgy, vol. 50, br. 2, April/June, 2011, p. 137.

[4] SZYIŃSKI P., LABER K., WĄSEK S.: Wpływ współczynnika asymetrii na wartość nacisków i wyginanie się pasma w klatce wykańczającej, Hutnik - Wiadomości Hutnicze 5, s. 382, Warszawa, maj 2012; ISSN 1230-3534 (in Polish)

[5] SZYIŃSKI P., KAWAŁEK A., WĄSEK S.: Analysis of the impact of the asymmetry factor on the band bending and the value of force parameters of rolling process on the finishing stand, International Forum - Competition of Young Researchers „Topical Issues of Rational Use of Natural Resources" 25th - 27th of April 2012 Collection of scientific papers, p. 21, St. Petersburg, April 2012, ISBN 978-5-94211-563-4.

[6] PIESIN A.M., SALGANIK V.M., Dyja H., CHIKISHEV D.N., PUSTOVOITOV D.O., KAWAŁEK A.: Asymmetric rolling: Theory and technology. Hutnik - Wiadomości Hutnicze, nr 5, s. 358÷362, 2012.