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THE ANALYSIS OF THE ASYMMETRIC PLATE ROLLING PROCESS IN THE FINISHING STAND 3600

ANALIZA ASYMETRYCZNEGO PROCESU WALCOWANIA BLACH GRUBYCH W KLATCE WYKAŃCZAJĄCEJ 3600

In order to enhance the quality of plates, various solutions are being implemented, including normalizing rolling, the process of rolling followed by accelerated cooling, as well as new roll gap control systems. The hydraulic positioning of rolls and the working roll bending system can be mentioned here. The implementation of those systems results in increased loads of the rolling stands and working tools, that is the rolls. Another solution aimed at enhancing the cross-sectional and longitudinal shape of rolled plate is the introduction of asymmetric rolling, which consists in the intentional change of the stress and strain state in the roll gap. Asymmetric rolling systems have been successfully implemented in strip cold rolling mills, as well as in sheet hot rolling mills.

The paper present results of studies on the effect of roll rotational speed asymmetry and other rolling process parameters on the change in the shape of rolled strip and the change of rolls separating force for the conditions of normalizing rolling of plates in the finishing stand. The variable process parameters were: the roll rotational speed asymmetry factor, a_v; the strip shape factor, h_0/D; and the relative rolling reduction, ε. Working rolls of the diameter equal to 1000 mm and a constant lower working roll rotational speed of n = 50 rpm were assumed for the tests. The asymmetric rolling process was run by varying the rotational speed of the upper roll, which was lower than that of the lower roll. The range of variation of the roll rotational speed factor, $a_v = v_d/v_g$, was 1.01÷1.15. A strip shape factor of h_0/D = 0.05÷0.014 was assumed. The range of rolling reductions applied was ε = 0.08÷0.50. The material used for tests was steel of the S355J2G3 grade. For the simulation of the three-dimensional plastic flow of metal in the roll gap during the asymmetric hot rolling of plates, the mathematical model of the FORGE 2008®program was used.

For the mathematical description of the effect of rolling parameters on the strip curvature and rolls separating force the special multivariable polynomial interpolation was used. This method of tensor interpolation in Borland Builder programming environment was implemented.

On the basis of the carried out analysis can be state, that by using the appropriate relative rolling reduction and working roll peripheral speed asymmetry factor for a given feedstock thickness (strip shape ratio) it is possible to completely eliminate the unfavorable phenomenon of strip bending on exit from the roll gap, or to obtain the permissible strip curvature which does not obstructs the free feed of the strip to the next pass or transferring the plate to the accelerated plate cooling stations. Additionally by introducing the asymmetric plate rolling process through differentiating working roll peripheral speeds, depending on the asymmetry factor used, the magnitude of the total roll separating force can be reduced and, at the same time, a smaller elastic deflection of rolling stand elements can be achieved. As a result smaller elastic deflection of the working rolls, smaller dimensional deviations across its width and length finished plate can be obtained.

Keywords: numerical modelling, asymmetric rolling, strip shape, strip bending, pressure of the metal on the rolls

W celu poprawy jakości blach grubych stosowane są różne rozwiązania obejmujące walcowanie normalizujące, przyspieszone chłodzenie po walcowaniu, jak również nowe systemy sterowania szczeliną walcowniczą. Należy również wspomnieć o systemach hydraulicznej nastawy walców oraz przeginania walców roboczych. Zastosowania tych systemów powoduje wzrost obciążenia klatki walcowniczej i jej osprzętu, jak również walców. Innym rozwiązaniem powodującym poprawę wzdłużnego i poprzecznego kształtu walcowanych blach jest wprowadzenie walcowania asymetrycznego, które wprowadza kontrolowaną zmianę stanu naprężenia i odkształcenia w kotlinie walcowniczej. Systemy asymetrycznego walcowania były skutecznie zastosowane podczas walcowania taśm na zimno oraz w walcowniach gorących podczas walcowania cienkich blach.

W artykule przedstawiono wyniki badań wpływu asymetrii prędkości obrotowej walców i innych parametrów procesu na zmianę kształtu walcowanego pasma oraz zmianę siły nacisku na walce w warunkach walcowania normalizującego blach grubych w klatce wykańczającej. Zmiennymi parametrami procesu były: współczynnik asymetrii prędkości obrotowej walców, a_v; współczynnik kształtu pasma, h_0/D; oraz gniot względny, ε. Do badań założono średnicę walców roboczych równą 1000 mm i stałą wartość prędkości obrotowej dolnego walca n = 50 obr/min. Warunki asymetrycznego procesu walcowania uzyskano przez zróżnicowanie prędkości obrotowej górnego walca, którą przyjmowano niższą niż walca dolnego. Zakres zmian współczynnika

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asymetrii prędkości obrotowych $a_v = v_d/v_g$ przyjęto: 1,01÷0,15. Założono współczynnik kształtu pasma h_0/D w zakresie 0,05÷0,014 oraz przyjęto wartości gniotu względnego ε w przedziale: ε = 0.08÷0.50. Badanym materiałem była stal w gatunku S355J2G3. Do symulacji trójwymiarowego, plastycznego płynięcia metalu w kotlinie walcowniczej podczas asymetrycznego walcowania blach grubych na gorąco wykorzystano model matematyczny programu FORGE 2008®.

W celu matematycznego opisu wpływu parametrów walcowania na krzywiznę pasma i siłę nacisku metalu na walce zastosowano interpolację wielomianem wielu zmiennych. Metodę interpolacji tensorowej zaimplementowano w środowisku programowym Borland Builder.

Na podstawie przeprowadzonej analizy można stwierdzić, że zastosowanie odpowiedniego gniotu względnego i współczynnika asymetrii prędkości obwodowych walców, dla danej wartości wysokości początkowej pasma (współczynnika kształtu pasma) umożliwia całkowite wyeliminowanie niekorzystnego zjawiska wyginania się pasma po wyjściu z kotliny walcowniczej lub uzyskanie dopuszczalnej krzywizny pasma, która nie zakłóca wprowadzenia pasma do kolejnego przepustu lub jego transportu do urządzeń chłodzących. Dodatkowo przez wprowadzenie procesu walcowania asymetrycznego, w zależności od zastosowanego współczynnika asymetrii, można uzyskać zmniejszenie siły nacisku metalu na walce, a jednocześnie zachodzi zmniejszenie sprężystego ugięcia elementów klatki walcowniczej. Dzięki zmniejszeniu sprężystego ugięcia klatki walcowniczej uzyskuje się końcową blachę o zmniejszonych odchyłkach wymiarowych wzdłuż jej szerokości i długości.

1. Introduction

Hot rolled plates are used in ship building industry, used for industrial boilers, gas and oil pipes. The consumers of these plates are constantly increasing their requirements as for strength and plastic properties as well as dimension deviations.

In order to improve the quality of hot rolled plates, normalizing rolling, rolling with accelerated cooling and new systems for shaping of the deformation zone are introduced. Implementation of these systems causes an increased load on mills and working instrument, i.e. rolls.

Another competitive solution for these methods is the use of asymmetric rolling, which means the aimed change in the strain and deformation in the deformation zone and contrary to the previous systems does not influence the increase in the load on the gears but on the other hand influences the decrease in the total pressure forces of the metal on the rolls.

In many scientific works carried out in the Institute of Modeling and Automatization of Materials Forming Processes of Czestochowa University of Technology it was stated that due to the use of the asymmetric rolling process of hot plates it was possible to obtain the geometry quality of the plates [1-5]. The system of the asymmetric rolling means direct impact on the strip placed in the deformation zone in which due to implementation of the asymmetric rotational speed of the working rolls a longitudinal tensile stress appears whose influence is similar to the influence of the pull and backward pull in the continuous mills.

The tensile influences on the decrease in the specific pressure in the deformation zone and the increased leveling of the misdistribution of the thickness of the rolled strip at the elasticity properties cost. At that, the control of the thickness distribution along the strip length, evenness and the cross shape of the strip takes place at a reduced full pressure of the metal on the roll. However, an incorrect choice of the asymmetry ratio with the remaining variable parameters of the rolling process can influence the extreme strip bending when the strip leaves the deformation zone. The strip bending can make the technological process difficult to carry out. That is why before applying asymmetric rolling in the industrial conditions it is necessary to conduct a lot of theoretic study in order to determine the range of the acceptable asymmetry ratios for the remaining variable parameters of the process at which flat strips are obtained or the strips with insignificant bending and at the same time the fall of the metal pressure on the rolls [6-10].

The asymmetric rolling process can be implemented in many different ways:

- using working rolls with different diameters;
- using rolls with different roughness;
- differentiating the rotational and/or peripheral speed of the working rolls;
- rotating one roll only.

In real conditions of the plate roll-mill the most effective way of implementation of the asymmetry is differentiating the rotational speed of the working rolls because the asymmetry can be used alternatively (the higher velocity of the lower roll first and then of the upper roll) which causes that these rolls will be drive rolls, that is why the extreme overcharge of their drives will be prevented. The possibility of changing the given asymmetry coefficient value from pass to pass is also important.

The additional value of implementation of the asymmetric rolling process is the reduction of the working rolls wear due to the reduced pressure of the metal on the rolls.

2. Methodology of the research

The work presents the result of the research on asymmetric rolling of the hot plates in the finisher of the mill 3600. This research was carried out in order to determine the possibilities of the strip shape control (bending after leaving the deformation zone) on this mill and the change in the pressure of the metal on the rolls depending on the value of the rotational speed asymmetry coefficient of the working rolls and the technological parameters of the rolling process: reduction of the cross-sectional area ε, the temperature of the process, the ratio coefficient of the strip shape h_0/D. The material taken for the analysis is grade S355J2G3 steel.

In order to determine the real curves of hardening of this steel for the conditions which appear in the real rolling process of the hot plates (deformations and temperatures), the test was performed using Gleeble 3800 device. Then the hardening curves for this steel grade were determined and put into the FORGE 2008®software [11].

The mathematic model of the FORGE 2008®software was used for 3D simulation of the plastic flow of the metal in the deformation zone during asymmetric rolling of the hot plates. This software is based on the finite-element method and enables simulating the thermo-mechanical metal forming processes.

The research assumed the working rolls with the diameter = 1000 mm and the constant rotational speed of the lower working roll n = 50 rpm. The asymmetric rolling process was implemented via the change in the upper roll rotational speed v_g – which is smaller than the speed of the lower roll v_d. The range of change in the spinning speed coefficient $a_v = v_d/v_g$ is 1.01÷1.15. It was assumed that the coefficient of the strip shape h_0/D = 0.050÷0.014. The range of reduction of the cross-sectional area was within the range ε = 0.08÷0.50. The temperature of the rolled strip was changed depending on the initial height h_0 in the range of 950÷850°C, which is used for normalizing rolling.

To determine the roll force of the strip for the tested range of the charging material thickness relating to the asymmetric process the polynomial tensor interpolation was used [12].

This method aims at finding the coefficients of the interpolating polynomial of many variables with the degree depending on the number of variables and the number of interpolated points.

For the common instance, for k – undependable variables, the coefficients a_{j_1}............a_{j_k} of the interpolating polynomial fulfill the equation:

$$W(x_l, ..., x_k) = \sum\nolimits_{0\leqslant j_l \leqslant p_l, ..., 0\leqslant j_k \leqslant p_k} a_{j_l......j_k} x_l^{j_l} ......x_k^{j_k} \qquad (1)$$

for the processes x1,............, xk with the matrix of measurements:

$$\begin{bmatrix} x_{10} & ...... & x_{1p_1} \\ ...... & ...... & ...... \\ x_{k0} & ...... & x_{kp_k} \end{bmatrix}$$

→measurements for the process x_1 from step 0 to step p_1

→measurements for the process x_k from step 0 to step p_k

and the matrix of the results:
[measurement results $^{x_{1i_1}}$,.........$^{x_k i_k}$] = $^{[w_{i_1}}$.........$^{ik]}$, 0⩽i1p1,.........,0⩽i_k ⩽p_k
are given as formulae:

$$a_{j_1......j_k} = \sum\nolimits_{0\leqslant i_1 \leqslant p_1, ..., 0\leqslant i_k \leqslant p_k} (-1)^{I^+ + J^+} w_{i_1......i_k} \frac{\tau_{p_1-j_1}\left(X_{10}, ..., \hat{X}_{1i_1}, ..., X_{1p_1}\right)}{\Pi_{1i_1}} \frac{\tau_{p_k-j_k}\left(X_{k0}, ..., \hat{X}_{ki_k}, ..., X_{kp_k}\right)}{\Pi_{ki_k}} \qquad (2)$$

where: τ_l are basic symmetric polynomials on the given variables without variable with dash:

where: I+ =i_1+.....+i_k, J+ = j_1+.......+j_k and

$$\Pi_{1i_1} = \left(X_{1p_1} - X_{1i_1}\right) ... (X_{1i_1+1} - X_{1i_1})(X_{1i_1} - X_{1i_1-1}) ... (X_{1i_1} - X_{10})$$

$$\Pi_{ki_k} = \left(X_{kp_k} - X_{ki_k}\right) ... (X_{ki_k+1} - X_{ki_k})(X_{ki_k} - X_{ki_k-1}) ... (X_{ki_k} - X_{k0}).$$

The polynomial tensor interpolation method gives one solution for the chosen area of the measuring points.

3. Research results and discussion

On the basis of the carried out analyses it was stated that the most influence on the roll force of the strip during the process of asymmetric rolling have the following process parameters: reduction of the cross-sectional area, the coefficient of the asymmetry of the rotational speed of the working rolls and the shape ratio of the strip. That is why, the polynomial tensor interpolation of the change in the pressure of the metal on the rolls was made for three undependable variables.

For the analyzed case of the three variables:

– $X_1 = h_0/D$ (coefficient of the strip shape),

– $X_2 = a_v$ (coefficient of the asymmetry of the rotational speed of the working rolls),

– $X_3 = \varepsilon$ (reduction of cross-sectional area),

in the range:
X_{10} = 0.014; X_{11} = 0.016; X_{12} = 0.018; X_{13} = 0.022; X_{14} = 0.027; X_{15} = 0.035; X_{16} = 0.050 – for the shape coefficient,
X_{20} = 1.01; X_{21} = 1.02; X_{22} = 1.03; X_{23} = 1.05; X_{24} = 1.08; X_{25} = 1.10; X_{26} = 1.15 – for the coefficient of the asymmetry of the spinning speed of the working rolls,
X_{30} = 0.08; X_{31} = 0.15; X_{32} = 0.20; X_{33} = 0.25; X_{34} = 0.30; X_{35} = 0.40; X_{36} = 0.50 – for the reduction of cross-sectional area.

The interpolating polynomial for the fractional change of the roll force of the strip in relation to the symmetric process looks like:

$$\boldsymbol{\rho = W(X_1, X_2, X_3) = a_{000} + a_{100}X_1 + a_{010}X_2 + a_{001}X_3 + ... + a_{666}X_1^6 X_2^6 X_3^6} \qquad (3)$$

where: coefficients $a_{000}, a_{100}, a_{010}, a_{001}, ... a_{666}$ depend on the measured values $w_{000}, w_{100}, w_{010}, w_{001}, ... w_{666}$ of the roll force of the metal as well as on values $X_{10}, ... X_{36}$ of the assumed ranges.

For the practical use of the elaborated algorithm of the tensor polynomial interpolation, a computer program which uses the software environment C++ Borland Builder version 5.0 was created. It is used for calculating the coefficients of the interpolating polynomial and the value of the given polynomial at any point of the input variables in the interpolated as well as extrapolated area.

The exemplifying research results of the influence of the asymmetric rolling process on the change in the roll force of the strip related to the process of symmetric process is presented in Figures 1 and 2.

It follows from the data presented in Figures 1 that for the coefficient of the strip shape h_0/D=0.027 rolled asymmetrically, when using smaller reduction ε =0.08÷0.10, for the whole range of coefficient changes a_v =1.01÷1.15, the decrease in the specific pressure value was not stated; however, a small increase in the value $p_{śr}$ was noticed. For reductions ε>0.10 after implementation of asymmetric rolling the decrease in the specific pressure value was about 11% for ε =0.15 i a_v =1.15.

For the coefficient of the strip shape h_0/D=0.014 the biggest decrease in the pressure appeared during the reduction ε =0.08÷0.30 for the whole range of the change in the coefficient a_v =1.01÷1.15 and was from some percent for smaller values of the coefficient a_v =1.01÷1.05 to about 27% at a_v>1.05 (Fig. 2). The influence of the reduction from the

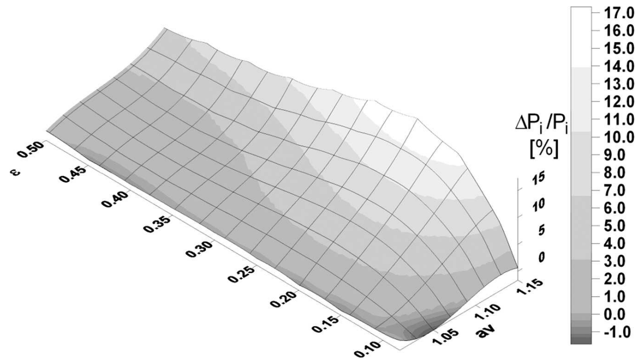

Fig. 1. The relative change in the roll separating force in relation to the symmetric rolling process in the functional relation of the reduction and asymmetry coefficient for the coefficient of the strip shape h_0/D=0.027 determined from the interpolation of the research results

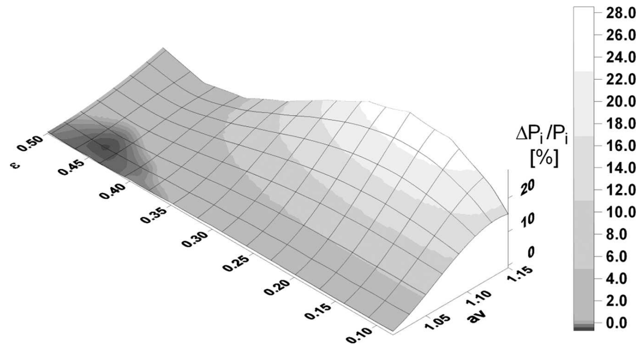

Fig. 2. The relative change in the roll separating force in relation to the symmetric rolling process in the functional relation of the reduction and the coefficient of the asymmetry for the coefficient of the strip shape h_0/D=0.014 determined from the interpolation of the research results

range of ε =0.40÷0.50 on the decrease in the roll force during asymmetric rolling of this furnace charge was smaller (about 5%); however, at small values of the coefficient of the velocity asymmetry (a_v =1.01÷1.03) the decrease in the value of the specific pressure was not noticed, although there was a little increase in the value $p_{\acute{s}r}$. The exemplifying research results of the influence of the reduction of cross-sectional area ε on the strip bending value and constant values of the strip shape coefficient is shown in Fig. 3 and 4.

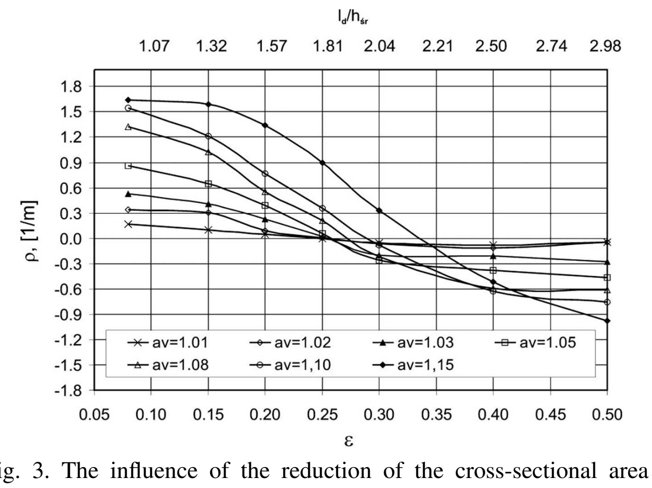

Fig. 3. The influence of the reduction of the cross-sectional area for different values of the asymmetry coefficient a_v and the constant value of the strip shape coefficient h_0/D = 0.05

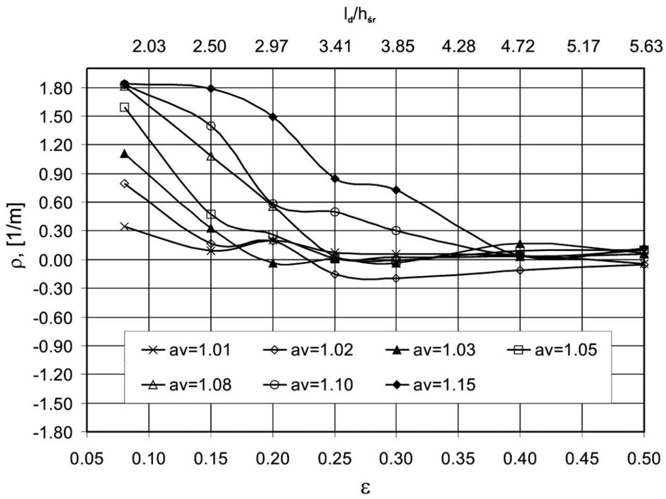

Fig. 4. The influence of the reduction of the cross-sectional area ε on the strip bending for different values of the asymmetry coefficient a_v and the constant value of the strip shape coefficient h_0/D = 0.014

It follows from the analysis of the curvatures of the strip shown in Figure 3 that for the strip shape ratio h_0/D = 0.05 the strip flows horizontally after leaving the deformation zone for the reductions in the range of ε = 0.25÷35 and for a_v =1.01÷1.05. For reductions ε in the range of 0.4÷0.5 (currently used in plate rolling mills during normalizing rolling of the tested steel grade) it is possible to use the asymmetric rolling process, however, only for small values of the asymmetry rotational speed coefficients a_v =1.01÷1.02. The determined curvature of the strip is very small for these values a_v and is about $\rho \approx$-0.11÷-0.05 and should not interfere with the rolling process.

For the strip shape ratio h_0/D = 0.014 (Fig. 4) the straight strip can be obtained for the reduction ε =0.18÷0.50 with different asymmetry coefficient values a_v. Thus, the widest range of the reduction can be used for the coefficient a_v =1.03. For the asymmetry coefficients a_v =1.01÷1.08 (apart from a_v =1.02) the straight strip or the strip with minimum bending can be obtained for the reductions ε =0.25÷0.50. However, for the reductions ε =0.40÷0.50 of the strip with minimum bending can be obtained for all tested asymmetry coefficients a_v =1.01÷1.15.

To determine the strip bending after the process of the asymmetric rolling of the hot plates in the finishing stand of the mill 3600 the method of the polynomial tensor interpolation was applied. The undependable variables were: the pressure, the coefficient of the rotational speed of the working rolls and the strip shape coefficient. The temperature of the process was not considered as an undependable variable because on the bases of the carried out analysis it was stated that the range of the temperature change of the strip in the rolling process was about 100°C and had insignificant influence on the strip bending value (Tab. 1).

– $x_1 = h_0/D$ (strip shape coefficient),

– $x_2 = a_v$ (coefficient of the asymmetry of the spinning speed of the working rolls),

– $x_3 = \varepsilon$ (reduction of the cross-sectional area),

in the ranges:

x_{10} = 0.014; x_{11} = 0.016;x_{12} = 0.018; x_{13} = 0.022; x_{14} = 0.027; x_{15} = 0.035; x_{16} = 0.050 – for the shape coefficient,

x_{20} = 1.01; x_{21} = 1.02; x_{22} = 1.03; x_{23} = 1.05; x_{24} = 1.08; x_{25} = 1.10; x_{26} = 1.15 – for the coefficient of the asymmetry of the spinning speed of the working rolls,
x_{30} = 0.08; x_{31} = 0.15; x_{32} = 0.20; x_{33} = 0.25; x_{34} = 0.30; x_{35} = 0.40; x_{36} = 0.50 – for the reduction of the cross-sectional area ε.

The interpolating polynomial for the strip bending is as follows:

$$\rho = W(x_1, x_2, x_3) = a_{000} + a_{100}x_1 + a_{010}x_2 + a_{001}x_3 + \ldots\ldots\ldots\ldots + a_{666}x_1^6 x_2^6 x_3^6 \tag{4}$$

where: coefficients $a_{000}, a_{100}, a_{010}, a_{001}, \ldots\ldots\ldots a_{666}$ depend on the variable values $w_{000}, w_{100}, w_{010}, w_{001}, \ldots\ldots\ldots w_{666}$ of the strip bending as well as on the value $x_{10}, \ldots\ldots\ldots x_{36}$ of the assumed ranges.

Figures 5 and 6 present the results of the strip bending change in the pressure function ε and the asymmetry coefficient a_v for the chosen strip shape coefficients: h_0/D = 27 mm and 14 mm.

It follows from the data presented in Fig. 5 that for the strip shape ratio h_0/D = 0.027 and the reduction $\varepsilon \approx$0,15 the flat strip and the strip with relatively little bending can be obtained for a_v =1.01÷1.05 and for a_v =1.01÷1.03 and the reduction $\varepsilon \approx$0.50. For the whole tested range of the value a_v and ε =0.08÷0.15 the strip bends towards the roll with higher rotational speed (v_d).

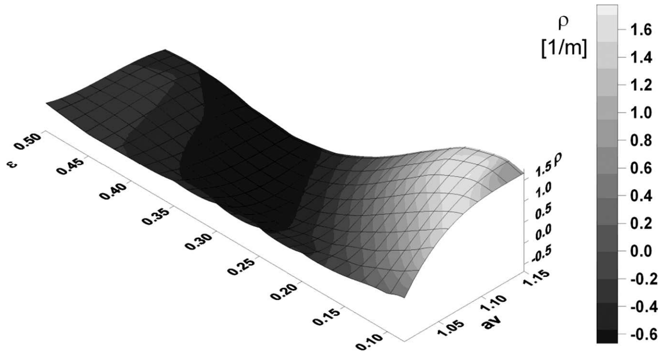

Fig. 5. The change in the strip curvature in the reduction function and the asymmetry coefficient for the strip shape coefficient value h_0/D=0.027 determined from the test results interpolation

TABLE 1

The influence of the strip temperature (h_0 = 27 mm) on the bending half-line and curvature of the strip after the rolling process

reduction, ε %	asymmetry coefficient	bending half-line, m			strip curvature, m			l_d,m	l_d/h_{av}
		850°C	900°C	950°C	850°C	900°C	950°C		
8	1.01	4.87	4.96	4.70	0.21	0.20	0.21	0.3286	1.2677469
	1.05	1.05	1.04	1.05	0.95	0.96	0.95		
	1.10	0.67	0.66	0.67	1.49	1.51	1.49		
	1.15	0.65	0.65	0.65	1.53	1.53	1.53		
15	1.01	-77.86	-86.56	-80.97	-0.01	-0.004	-0.01	0.45	1.8018018
	1.05	17.21	17.56	17.39	0.06	0.057	0.06		
	1.10	1.44	1.38	1.34	0.74	0.72	0.74		
	1.15	0.77	0.77	0.76	1.30	1.30	1.30		
30	1.01	-8.12	-7.94	-8.52	-0.12	-0.12	-0.12	0.06364	2.7729847
	1.05	-1.59	-1.65	-1.73	-0.58	-0.60	-0.58		
	1.10	-1.01	-1.07	-1.12	-0.89	-0.93	-0.89		
	1.15	-1.52	-1.58	-1.59	-0.63	-0.63	-0.63		
40	1.01	-16.07	-16.28	-16.49	-0.15	-0.15	-0.15	0.07348	3.40185
	1.05	-2.28	-2.41	-2.48	-0.40	-0.41	-0.40		
	1.10	-1.21	-1.21	-1.27	-0.78	-0.83	-0.78		
	1.15	-1.00	-1.03	-1.07	-0.94	-0.97	-0.92		
50	1.01	-35.92	-33.56	-36.54	-0.03	-0.03	-0.03	0.08216	4.0572839
	1.05	-8.67	-8.82	-8.56	-0.12	-0.11	-0.12		
	1.10	-3.21	-3.43	-3.39	-0.29	-0.29	-0.29		
	1.15	-1.79	-1.82	-1.83	-0.54	-0.55	-0.54		

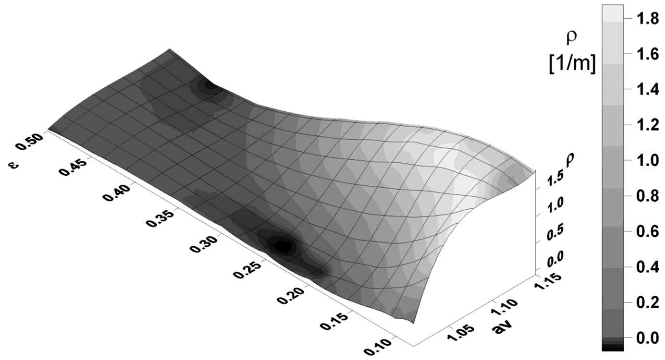

Fig. 6. The change in the strip curvature in the and the asymmetry coefficient for the strip shape coefficient value $h_0/D=0.014$ determined from the test results interpolation

The application of the asymmetric rolling process for the strip shape coefficient $h_0/D=0,014$ would allow obtaining the straight strip or the strip with a relatively small curvature, for a_v =1.01÷1.15 and the reduction ε =0.40÷0.50 and for a_v =1.01÷1.08 and the ε =0.25÷0.30. The straight strip can also be obtained when a_v =1.03 and $\varepsilon \approx 0.20$. For all applied reductions, when $a_v>1.03$ the strip when leaving the deformation zone will always be bended towards the roll with the lower rotational speed (v_g) (Fig. 6).

On the basis of the carried out analysis it was determined for which values of the coefficient of the rotational speed asymmetry and other variable parameters of the process a decrease in the pressure of the metal on the rolls will occur and simultaneously the strip will be straight or with little bending which does not interfere with the further rolling process. The above described method of polynomial tensor interpolation can be applied for foreseeing the strip bending value as well as its direction during asymmetric rolling between the measurement points in the whole tested range of the process parameters changes.

4. Conclusions

On the bases of the carried out analysis the following was concluded:

– in the finishing stand of the mill 3600 for the given values of the strip shape coefficient it is possible to control the strip bending put in horizontally into the deformation zone by choosing the right values of the coefficients of asymmetry of the rotational speed of the working roll and the reduction of the cross-sectional area;
– implementing the asymmetric process of plate rolling by differentiating the rotational speed of the working rolls, depending on the applied asymmetry coefficient, it is possible to shape the strip bending after it leaves the deformation zone as well as decrease the total pressure of the metal on the rolls;
– applying the right reduction of the cross-sectional area and the coefficient of the asymmetric rotational speed of the working rolls, for the given thicknesses of the charging material (the strip shape coefficient) it is possible to eliminate the unfavorable strip bending completely after leaving the deformation zone or to obtain the accepted strip bending which does not influence on the free putting in the strip to the following pass or transporting the plates to the accelerated cooling equipment.

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