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The analysis of the asymmetric plate rolling process

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Analysis and modelling

ABSTRACT

Purpose: The analysis of asymmetric band rolling in the finishing stand of a plate rolling mill has been carried out within the present study with the aim of establishing the effect of the speed asymmetry factor, av, on band bending during the rolling process and determining the strain velocity distributions of the rolled material in the roll bite region.

Design/methodology/approach: The simulation of metal flow in the asymmetric roll bite region was performed using the program FORGE 2D. The development of numerous branches of the steelmaking industry imposes increasingly high demands on steel product manufacturers, which can only be met by products manufactured according to the state-of-the-art plastic working technologies. One of the major plastic working technologies is asymmetric rolling.

Findings: The analysis shows that the band bends most often toward the lower-speed roll. Increasing the value of the speed asymmetry factor causes an increase in the advance, while the force parameters decrease with increasing asymmetry factor a_v.

Practical implications: Asymmetric rolling is achieved by differentiating working roll diameters, roll rotational speeds, or roll surface roughness. In industrial practice, one or a combination of the above-mentioned parameters is used.

Originality/value: In order to improve the asymmetric plate rolling process, the analysis of the following parameters must be carried out: band temperature, the magnitude of rolling reduction, the magnitude of yield stress for particular steel grades, roll rotational speeds and roll diameters.

Keywords: Numerical techniques; FEM; Asymmetric plate rolling process

1. Introduction

It follows from numerous studies that in asymmetric rolling the magnitude of the overall roll separating forces considerably decreases and, as a consequence, the limiting rolling reductions of rolling mills can be increased [1÷7] Owing to this, the rolling of hardly deformable alloys is possible. By applying asymmetric rolling, the flatness of rolled plates can be improved, and also the intended final plate dimension is more easy to achieve. Asymmetric rolling is achieved by differentiating the speeds of rolls of an identical diameter, or by using different-diameter rolls with equal angular speeds [8÷14]. Asymmetric rolling occurs during rolling in rolls of different friction conditions, as well as in a number of other cases, where physical conditions of contact with two rolls are not equal.

A theoretical analysis of the process of asymmetric plate rolling in the finishing stand of a plate rolling mill was carried out in this work. Based on the investigation carried out, the effect of the speed asymmetry factor, a_v, on band bending in the asymmetric rolling process was established, and the distributions of rolled metal strain velocities in the roll bite region were determined. The analysis was performed for plates of the initial thickness, h_0, ranging from 14 to 50mm and for relative rolling reductions varying in the range of 3÷30%. A software application, FORGE 2D [15], relying on the finite element method was used for the studies. The performed analysis made it possible to establish the effect of the speed asymmetry factor, a_v, on the curvature of band on exit from the deformation region and to determine the distribution of strain velocity components in the asymmetric plate rolling process. The theoretical analysis of the asymmetric plate rolling process makes it possible to avoid costly tests and achieve considerable savings at the plate rolling mill department.

2. Material used for investigation

The Investigation was carried out on S355J2G3 steel specimens. Chemical composition of the steel investigated is given in Table 1.

Table 1.
Chemical composition of steel S355J2G3, [%]

C	Mn	Si	P	S	Cr
0.15	1.36	0.33	0.017	0.03	0.05
Ni	Mo	Cu	Al	N2	V
0.089	0.03	0.23	0.03	0.0092	0.001
Nb	B	Ti	Sn	Ca	Zn
0.002	0.0003	0.002	0.018	0.0007	0.003

Data obtained from the deformation of S355J2G3 steel specimens were approximated with Henzl-Spiettel's equation:

$$\sigma_s = A_1 \varepsilon^{a_2} \dot{\varepsilon}^{a_3} \exp(a_4 T) \tag{1}$$

where:

ε – actual strain, $\dot{\varepsilon}$ – strain velocity,

T – temperature, σ_s – yield stress.

The approximation was performed for rolling temperatures in the range of T=800÷1050°C, strain velocities in the range from 1 to 70s^{-1} and an actual strain of $\dot{\varepsilon}$=0.03÷0.3.

Table 2.
Values of the coefficients of Equation 1 for steel S355J2G3

Description of coefficient	Value
A_1, MPa	1436.3
a_2	0.2717
a_3	0.1428
a_4	1.9153*10-3

The coefficients given in Table 2 were used in the computer simulation of the asymmetric rolling process using the FORGE 2D program.

It was assumed that the diameters of the both rolls were equal, amounting to D=1000mm, the upper roll speed amounted to n=50 rpm and it was constant, while the lower roll speeds were variable, amounting to, respectively:

- for a_v = 3% - n = 39.93 rpm,
- for a_v = 5% - n = 39.17 rpm,
- for a_v = 8% - n = 38.21 rpm,
- for a_v = 10% - n = 37.45 rpm,
- for a_v = 15% - n = 35.73 rpm.

3. Investigation results and their analysis

The results of simulation of asymmetric plate rolling are presented in Tables 3 and 4 and in Figs. 1÷3.

Table 3.
Results of asymmetric plate rolling simulation

h_0	h_1	Δh	I_d	s_w	a_v	ε
[mm]	[mm]	[mm]	[mm]	%		%
50	46	4	44.721	0.95	1.03	8
50	46	4	44.721	2.87	1.053	8
50	46	4	44.721	5.45	1.08	8
50	46	4	44.721	7.6	1.102	8
50	46	4	44.721	12.78	1.155	8
50	42.5	7.5	61.237	2	1.03	15
50	42,5	7,5	61,237	3,95	1,053	15
50	42.5	7.5	61.237	6.55	1.08	15
50	42,5	7.5	61.237	8.72	1.102	15
50	42,5	7.5	61.237	13.95	1.155	15
50	35	15	86.60	3	1.03	30
50	35	15	86.60	4.97	1.053	30
50	35	15	86.60	7.6	1.08	30
50	35	15	86.60	9.79	1.102	30
50	35	15	86.60	15.08	1.155	30

Table 4.
Results of simulation of the asymmetric rolling of specimens with dimensions of h_0=22mm and h_1=20.4mm for different speed asymmetry factors a_v and a rolling reduction of 8%

a_v	$p_{śr}$ [MPa]	P[MN]	σ_y [MPa]	S_w [%]	Xn_g/ld_g	Xn_d/ld_d
1.03	1.8	40.7952	0.12	1.4	0.442	0.442
1.053	1.754	39.752	0.117	3.32	0.453	0.445
1.08	0.834	18.901	0.058	5.95	0.461	0.465
1.102	0.83	18.81	0.56	7.6	0.491	0.490
1.155	0.809	18.355	0.054	13.2	0.513	0.515

It was found from the investigation carried out that, for specimens with initial thicknesses of h_0=14mm, h_0 = 16mm, h_0= 22mm, h_0=35mm, h_0 =50mm, a bending of the band occurred toward the lower angular-speed roll, irrespective of the values of rolling reduction and speed asymmetry factors. However, during rolling a specimen of a thickness of h_0 =27mm, for a rolling reduction of ε =15%, a straight band was obtained; whereas, for some asymmetry factors, the band was bending toward the upper roll with a higher angular speed. A similar situation occurred during rolling a specimen of a thickness of h_0 = 18mm for a rolling reduction of ε = 8%.

The values of the strain velocity components, $\dot{\varepsilon}_x$, $\dot{\varepsilon}_{xy}$, increased with increasing rolling reduction and with increasing speed asymmetry factor, which is shown in Figs. 1 and 2. A sample distribution of the stress intensity, σ_i, is illustrated in Fig. 3.

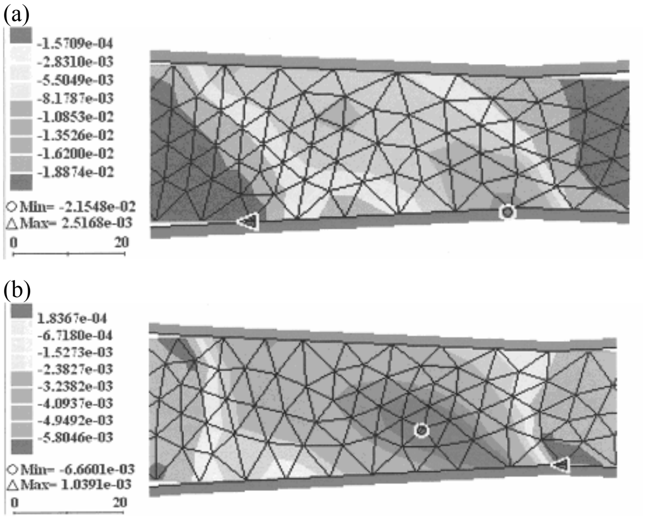

Fig. 1. Fields of strain intensity components: (a) $\dot{\varepsilon}_x$, (b) $\dot{\varepsilon}_{xy}$; a_v=1.155, v_g>v_d, ε=15%, h_0=16mm

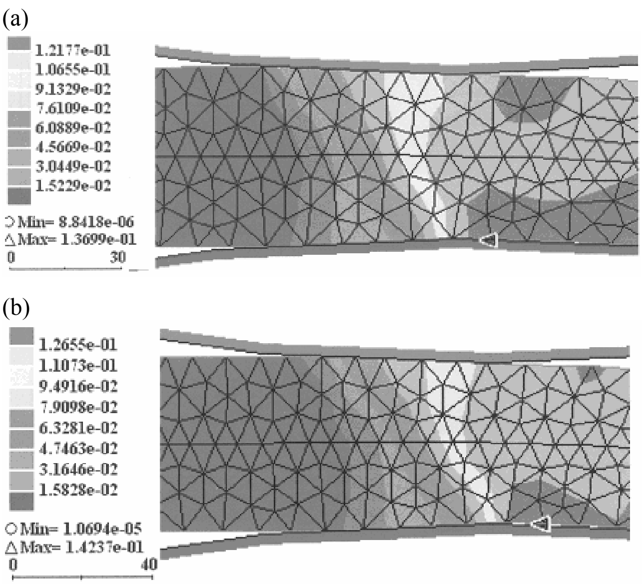

Fig. 2. Fields of strain velocity intensities $\dot{\varepsilon}_i$: a) for an asymmetry factor of a_v=1.05, v_g>v_d, and a relative rolling reduction of ε=8%, h_0=35mm, b) for an asymmetry factor of a_v=1.08, v_g>v_d, and a relative rolling reduction of ε=8%, h_0=35mm

It follows from the data in Figs. 1 and 2 that the strain intensity increased with increasing speed asymmetry factor a_v faster on the side of the upper (higher rotation speed) roll, which is indicated by the higher friction coefficient at the contact between the metal and the higher-speed roll. Therefore, the advance zone length x_n on the faster roll side also increased, and then a bending of the rolled band toward the lower band followed.

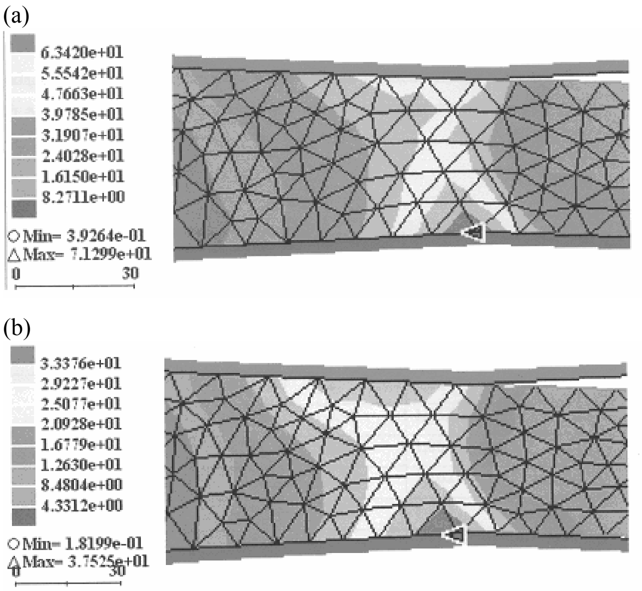

Fig. 3. Fields of stress intensities σ_i; a) for an asymmetry factor of a_v=1.102, v_g>v_d, and a relative rolling reduction of ε=15%, h_0=27mm, b) for an asymmetry factor of a_v=1.155, v_g>v_d, and a relative rolling reduction of ε=15%, h_0=27mm

The value of x_n/l_d (where: x_n – advance zone length, l_d – contact arc projection length) for the both (upper and lower) rolls was determined by the geometric method using the AutoCAD 2000 program. 4.

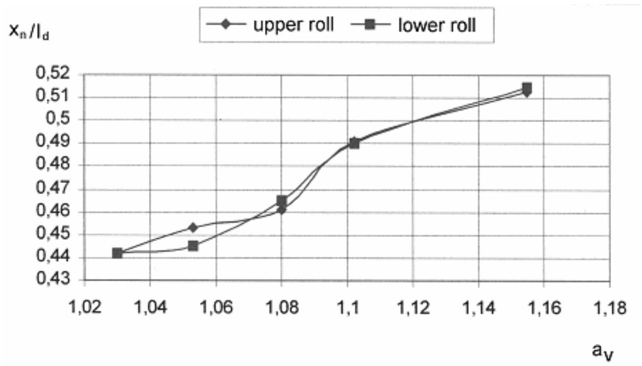

Fig. 4. Effect of the asymmetry factor a_v on the advance zone length for h_0 = 22mm and ε = 8%

The data shown in Fig. 4 indicate that, in the asymmetry factor range of a_v=1.03÷1.07, the advance zone length on the upper roll is larger than the advance zone length on the lower roll. Whereas, in the asymmetry factor range of a_v=1.07÷1.09, the advance zone length on the lower roll is larger than the advance zone length on the upper roll. For a_v=1.09÷1.13, the lengths of the advance and delay zones are equal. For values of the asymmetry factor a_v above 1.13, the length of the advance zone on the lower roll side is larger.

4. Findings and conclusions

From the performed analysis of the asymmetric plate rolling process the following conclusions have been drawn:

- one of the most important parameters of the asymmetric rolling process is the strain velocity, which has an effect on the bending of band on exit from the roll bite region;
- the analysis shows that the band bends most often toward the lower-speed roll;
- introducing a speed asymmetry for rolls of an equal diameter results in a bending of the band; in specific conditions, the bending occurs most often toward the lower angular-speed roll;
- the band bending direction is determined by numerous factors, which is indicated by the band bending toward the higher-speed roll or by obtaining a nearly straight band for equal roll diameters, for $v_g > v_d$, with a decisive influence on the band bending being exhibited by the magnitude of rolling reduction at a specific value of the asymmetry factor;
- increasing the value of the speed asymmetry factor causes an increase in the advance, while the force parameters decrease with increasing asymmetry factor a_v.

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