NUMERICAL SIMULATION OF ASYMMETRIC EFFECTS IN PLATE ROLLING

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NUMERICKÉ SIMULÁCIE ASYMETRICKÉHO EFEKTU PRI VALCOVANÍ PLECHOV

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Abstrakt

Predný koniec materiálu pri valcovaní hrubých plechov na plechotrati a tiež v prípravnom poradí širokopásovej trati sa často môže ohýbať hore alebo dole. Jednou z príčin týchto javov, ktoré sa nazývajú horný a dolný tlak, je nerovnosť obvodových rýchlostí pracovných valcov. Preto sa v tomto článku študuje krivka zakrivenia valcovaného materiálu.

Práca je venovaná dvojrozmernému prípadu a použitá je metóda konečných prvkov. Štúdium vychádza zo základných geometrických vzťahov a vzájomnej závislosti použitých parametrov. Zvláštna pozornosť sa venovala kinematickým vplyvom pohonu, lebo tieto vplyvy zohrávajú podstatnú úlohu pri valcovaní s horným resp. dolným tlakom.

Je známe, že faktor tvaru takisto ako aj nerovnosť rýchlostí umožňujú popísať valcovanie s horným resp. dolným tlakom. Avšak aj hrúbka valcovaného materiálu pred valcovaním má podstatný vplyv na podmienky ohybu. Bol meraný rozdiel medzi obvodovými rýchlosťami horného a dolného pracovného valca. Na základe zahrnutia meraní do numerickej simulácie môžeme urobiť záver, že nerovnosť rýchlostí je jednou z príčin ohybu.

Tvarový faktor (ktorý závisí od vstupnej hrúbky materiálu) a vstupná hrúbka materiálu sú vhodnými veličinami pre predikciu intenzity a smeru ohýbania sa plechov.

Abstract

Front end of material, which is rolled in heavy plate mills and roughing of hot strip mill stands often bends upwards or downwards. One reason for this phenomenon which is called turn-up and turn-down is a circumferential speed mismatch between the work rolls. Therefore, the curvature of the rolled stock has been investigated.

A two-dimensional finite element study has been performed. It is based on the fundamental geometric relations and the interdependencies of the used parameters are documented. Special attention is directed to the kinematical influences of the drive because they play a substantial part for turn-up or turn-down.

It is well known, that the shape factor as well as the speed mismatch is suitable to describe turn-up and turn-down. However, the initial thickness of the rolling stock has a substantial influence on the bending behaviour. Different circumferential speeds of the upper and lower work roll have been measured. Including these measurements in a numerical simulation, it can be shown that speed mismatch is one cause of warping.

The shape factor (which depends on the entrance thickness) and the entrance thickness are useful reference values for predicting the bending intensity and direction of the rolled stock.

Key words: front end bending in plate rolling, warping phenomenon in plate rolling, ski end control in plate rolling, asymmetry in strip and plate rolling, asymmetrical rolling

1. Introduction

Turn-up and turn-down are rolling phenomena all plate rolling mills battle with. It causes lacks in productivity, bad product quality and sometimes even heavy impacts with expensive downtimes. Juretzek [1] investigated turn-up and turn-down by use of a laboratory mill. Some papers concerning this problem have been published [2, 3, 4, 5]. It is well known that bending and warping of rolled plates are, among other causes, a result of the related speed mismatch of the work rolls. Philipp et al. [6] showed that the shift of the neutral point, i.e. where no curvature occurs, depends on the initial plate thickness and on an existing definite circumferential speed mismatch. Furthermore, the shape factor l_d/h_m and the reduction per pass r have a great influence on front end bending.

According to the above-mentioned parameters, rolled plates either bend upwards or downwards. In the interest of short downtimes and to avoid overloading of the roller table, rolling mill engineers want the plate to be slightly bent upwards. Adjusting the parameters in a proper way, it is possible to reach this goal.

Turn-up is shown in **Fig. 1** Since many different reasons might cause the turn-up and turn-down, engineers and scientists worked already on this problem and a few papers e. g. [7, 8, 9, 10, 11] have been written.

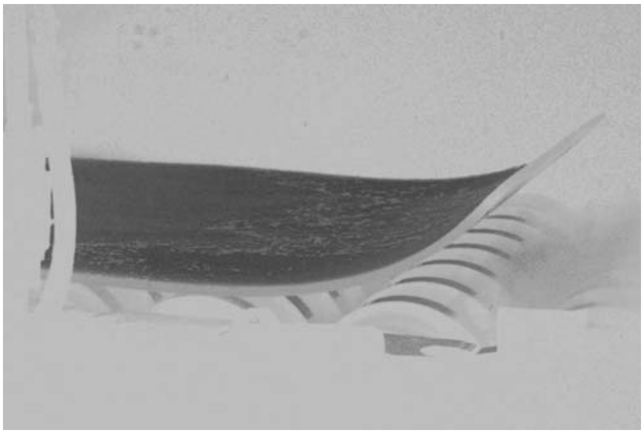

Fig.1 Unwanted turn-up during production

2. Methods and materials

a. Bending and warping in plate rolling

Bending of the rolled material is described by its curvature 1/ρ. **Fig. 2** shows turn-up and turn-down phenomena as they occur caused by fixed but dissimilar circumferential speeds of the work rolls $v_{wr,u}$ and $v_{wr,l}$. However, in practice the rolled stock often warps by changing its bending direction as well as its bending radius ρ_1, ρ_2, ρ_3.

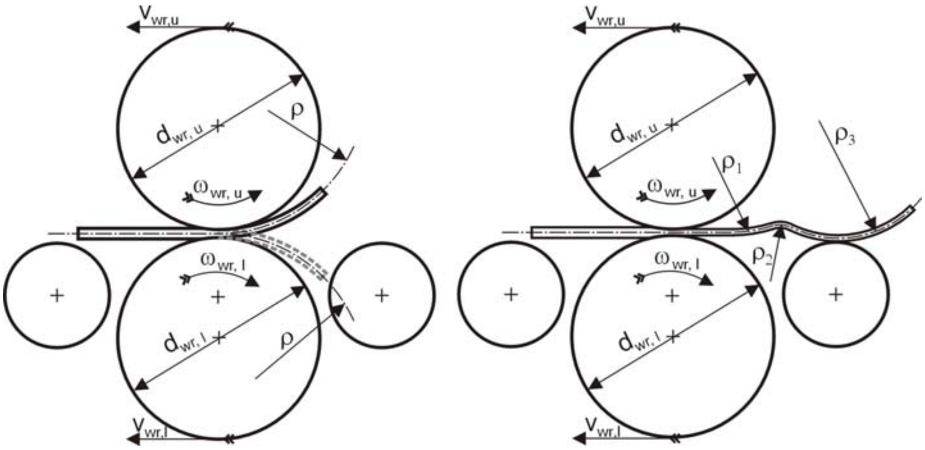

Fig.2 Turn-up, turn-down and warping

One reason for the warping phenomenon above shown is the time-dependent related speed mismatch between the work rolls as a cause of a non-optimised twin drive.

b. Kinematical and geometrical relations

<u>Geometry</u>

The current work is based on the following definitions:

$$\bar{d}_{wr} = \frac{d_{wr,u} + d_{wr,l}}{2} \tag{1}$$

$$h_m = \frac{h_1 + 2h_2}{3} \tag{2}$$

$$\Delta h = h_1 - h_2 \tag{3}$$

$$l_d = \sqrt{\frac{1}{2}\bar{d}_{wr}(\Delta h) - \frac{1}{4}(\Delta h)^2} \tag{4}$$

$$r = \frac{\Delta h}{h_1} \tag{5}$$

where $\bar{d}_{wr}$ [mm] - mean work roll diameter, $d_{wr,u}$ [mm] - diameter of the upper work roll, $d_{wr,l}$ [mm] - diameter of the lower work roll, Δh [mm] - draft per pass in mm, h_1 [mm] - entrance thickness of rolling stock, h_2 [mm] - exit thickness of rolled stock, l_d [mm] - projected arc of contact length, r - reduction per pass.

Kinematics

The difference of the circumferential speed Δv used in the simulation is defined as follows:

$$\Delta v = \frac{v_{wr,l} - v_{wr,u}}{v_{wr,u}} 100 \quad (6$$

where Δv [%] - difference of the circumferential speed of the work rolls,
$v_{wr,u}$ [m/s] - circumferential speed of the upper work roll, $v_{wr,l}$ [m/s] - circumferential speed of the lower work roll.

c. Numerical model

The simulation was done by means of the finite element package ABAQUS. In contrast to the usual explicit code, which is often used for plastic deformation, this model is based on an implicit code ABAQUS/Standard. The advantage of this code is the lack of inertia forces and therefore no unwanted vibration phenomena as well as a higher exactness in the calculations. However, longer CPU-time was the price.

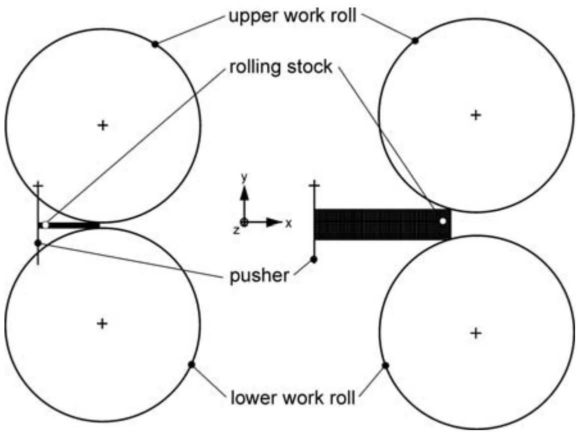

Fig.3 Two-dimensional model

All boundary and initial conditions are shown in **Tab. 1**. The rolling stock was modelled mass free.

Table 1 Initial- and boundary conditions of the model

Symbol	Value
Rolling stock	S235JRG2/ Material-Number: 1.0038, DIN EN 10 025
T	1000 °C
μ_u=μ_l	0.3
$d_{wr,u}$=$d_{wr,l}$	1000 mm
$v_{wr,u}$	2 m/s
$v_{wr,l}$	2.04, 2.06, 2.1 m/s
Δv	2, 3, 5 %
h_1	20, 28, 39, 55, 77, 107, 150 mm
l_d/h_m	0, 0.2, 0.4, 0.6, …, 3

A 2-dimensional model has been built. **Tab. 2** informs about the used elements. The work rolls have been driven with unequal circumferential speeds to induce turn-up and turn-down phenomena.

Table 2 FEM-elements employed in the calculations

Part	Modelled as
rolling stock	CPE4-ELEMENTS
work rolls	RIGID SURFACE
pusher	RIGID SURFACE

Gravity was not considered in the calculation so the curvature $1/\rho$ of the rolled stock is strictly valid only for the head of the rolled stock. The rolling stock is assumed to be elasto-plastic and all physical properties are taken from [12]. The flow stress responds to the modified Hensel and Spittel function [13] (equation (7)).

$$\sigma_Y = 2590 e^{-0.00263\ T} (\varepsilon + 0.002)^{0.3691} e^{-0.00263(\varphi + 0.002)} (\dot{\varepsilon} + 0.01)^{0.131} \quad (7)$$

where σ_Y [MPa] - yield stress, T [°C] - temperature of the rolling stock, ε [%] - strain, $\dot{\varepsilon}$ [1/s] - strain rate and $\varphi = \ln \frac{h_1}{h_2}$.

The temperature of the rolling stock was T = 1000 °C and no heat flux between the rolling stock and the work rolls has been considered. Coulomb friction between rolling stock and work roll were $\mu_u = \mu_l = 0.3$.

3. Analysis of results

Fig. 4 shows the curvature as a function of the shape factor and reduction per pass for the rolled stock with an initial thickness of 28 mm and 107 mm. A curvature less than zero means that the rolled stock bends towards the work roll with the higher circumferential speed. In the left part of **Fig.4** the bending behaviour, depending on the shape factor l_d/h_m, of thin and thick rolling stock is shown. First bending towards the slower work roll occurs. After passing a maximum the curvature decreases till it reaches the neutral point. Note, that in this case the rolled stock leaves the roll gap straight in spite of a speed mismatch. Increasing l_d/h_m, bending towards the faster work roll occurs. In the right half of **Fig. 4** the bending behaviour can be seen as a function of the reduction per pass. Notice the significant shift of the neutral point. The bending intensity of the rolled stock increases with increasing difference between the circumferential speeds Δv of the work rolls. However, the bending intensity decreases with a growing initial thickness of the rolling material.

As the reduction per pass has a wide range of values between neutral points according to thin and thick rolling stock, the shape factor l_d/h_m is a more useful reference value for predicting the bending intensity as well as the bending direction. However, the initial thickness must also be taken into account for predicting the curvature and its sign.

As the upper and lower work roll are coupled by the rolling stock but have two separate drives, the course of Δv as well as of the curvature is according to **Fig. 5**. Due to oscillations the speed mismatch is high at the beginning of rolling. After this transient condition a steady state occurs where $v_{wr,u} \approx v_{wr,l}$. The curvature of the rolled stock correlates very well with the speed mismatch. These time dependent different angular velocities and, as a result, different circumferential speeds obviously cause warping.

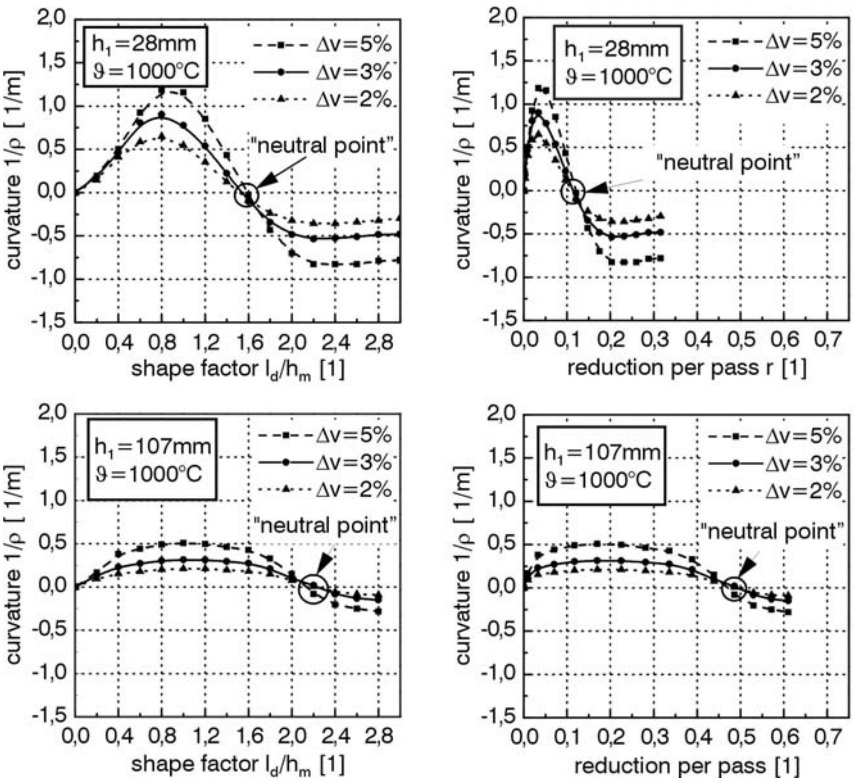

Fig.4 Curvature and drift of the neutral point (steady state condition)

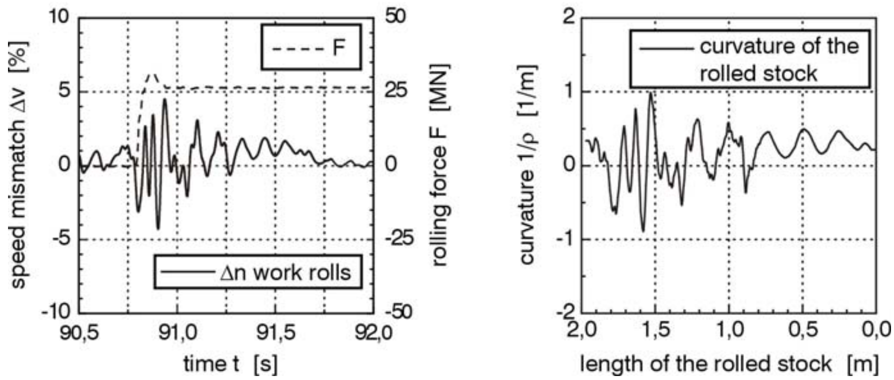

Fig.5 Speed mismatch, rolling force and curvature (transient condition)

As in this simulation the shape factor is l_d/h_m = 0,75 the rolled stock bends towards the slower work roll. Because the initial thickness of the rolled plate was h_1 = 33,68 mm we have a good correlation of curvature between the upper part of **Fig. 4** and **Fig. 5**. However, with the same initial thickness but another shape factor (e. g. $l_d/h_m = 2,2$) the curvature of the rolled stock changes its sign, which means that it bends towards the faster roll.

Conclusions

The entrance thickness of the rolling stock h_1 influences both rolled stock curvature $1/\rho$ and neutral point. Furthermore, thin rolling stock bends much more than thick rolling stock for the same difference of circumferential speed of the work rolls Δv. Thin rolling stock shows its neutral point at lower shape factors than thick rolling stock.

The shape factor l_d/h_m is a useful reference value for predicting the bending intensity as well as the bending direction of the rolled stock. However, the shape factor itself depends on the entrance thickness h_1. Thus the entrance thickness h_1 has to be taken into account too for predicting the curvature and its sign.

The reduction per pass r is not suitable to predict the curvature $1/\rho$ and its sign because of the wide range of values between neutral points according to thin and thick rolling stock [**Fig. 4**].

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