Quantitative evaluation of relative sliding between billets and rolls in hot rolling

B. Tian, S. Kleber, C. Turk, S. Tolliner, S. Schneller, P. Markiewicz

In rolling process relative sliding happens due to the different velocities between billets and work rolls. The sliding affects the roll wear, the tribological characteristics and the failure of rolls. Quantitative evaluations of the relative sliding are essential to the failure analysis and damage prediction of rolls.

The velocity and the distance of the relative sliding are investigated with finite element simulation and evaluated at different billet sizes, reduction ratios, frictions, rolling temperatures and velocities, and compared between flat and caliber rolling. The velocity and the distance are increased with increasing the billet size, the reduction ratio and the rolling speed, and reduced with increasing the friction coefficient and the temperature inhomogeneity on the cross section of billets. The influence of the caliber rolling on the relative sliding is significant as the width of billets beyond that of the caliber.

KEYWORDS: SLIDING, VELOCITY, DISTANCE, HOT ROLLING, FINITE ELEMENT SIMULATION

INTRODUCTION

Relative movement between workpieces and tools takes place in most cases of metal manufactures and productions. This movement results in tool wear and contributes to tribological characteristics at the contact surface [1,2]. In rolling process workpieces are moved by frictions with work rolls. Due to plastic deformation, the movement of materials at the contact surface cannot be exactly the same as the rotation of rolls. The speed is different between workpieces and rolls except on the neutral point line. Relative sliding always takes place in the rolling process. Roll wear and failures are complicatedly originated and influenced by the relative sliding, roll forces, surface conditions, frictions, lubrications and so on. Evaluations and analysis of these interactive factors can provide crucial information to reduce roll wear and to prevent the unexpected failures of rolls. The relative sliding is one of the key influencing factors concerning deterioration of work rolls [3,4].

Quantitative evaluations of the relative sliding are important not only to improve the performance of

B. Tian, S. Kleber, C. Turk, S. Tolliner, S. Schneller, P. Markiewicz
voestalpine BÖHLER Edelstahl GmbH & Co KG, Austria

work rolls, but also to optimize rolling schedules. With applications of finite element method (FEM), the influences of the billet size, the reduction ratio, the friction coefficient, the rolling temperature and speed on the velocity and the distance of the relative sliding are investigated and compared between the flat and caliber rolling.

METHOD

Finite element simulation with a one quarter and non-isothermal model has been carried out for hot rolling using the software DEFORM™ 3D. The rectangular or the quadratic (Q) cross section of billets has a size ranging from 206 to 440 mm. The initial temperature difference between the surface and the center on the cross section is noted as T_d, as defined in Fig.1a. The flat roll has a diameter of 778 or 950 mm. The caliber roll has a box shape with a width of 251 mm at the top and a diameter of 778 mm. Both rolls rotate at a constant initial temperature and angle velocity.

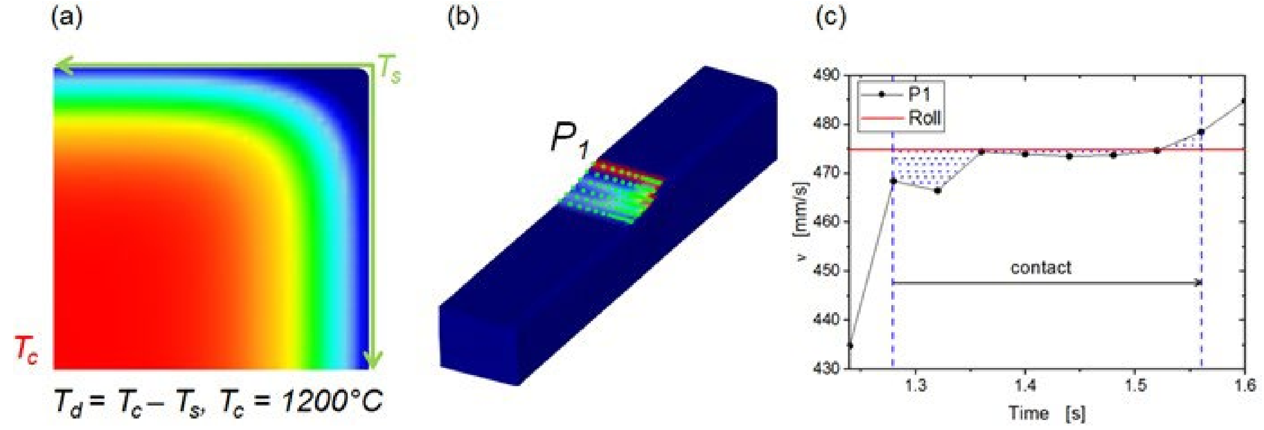

Fig. 1 - a) Temperature distribution on the cross section. (b) Δv at the contact surface. (c) v at the contact node P1 vs. time. The area of the pointed zone is Δs for P1.

To evaluate the relative sliding, the mean value of the velocity and the total distance of the sliding in the contact region are employed. The relative sliding velocity (Δv) is defined as the mean difference in the velocity at the contact node between the billet and the roll, as shown in Fig.1b and 1c.

$$\Delta v = \frac{\sum_{i=1}^{N} Abs(v_i - v_R)}{N} \tag{1}$$

v_i is the velocity at the contact node, v_R the velocity of the roll, N the number of the contact nodes. The relative sliding distance (Δs) is the area of the velocity difference between the contact node and the roll, summed for all contact nodes in the contact region (Fig.1c for one contact node P1). Δs can be calculated as:

$$\Delta s = \sum_{i=1}^{M} \sum_{j=1}^{k-1} Abs\left(\frac{(v_{i,j} + v_{i,j+1})}{2} - v_R\right)\Delta t \tag{2}$$

M is the number of the contact lines, k the number of the contact nodes (k>1) on each contact line, Δt the time step in the simulation. The reduction ratio is calculated with $\Delta H/H_0 = (H_0 - H_1)/H_0$. H_0 and H_1 are the billet height before and after rolling, respectively.

RESULTS

The relative sliding velocity (Δv) and the distance (Δs) increase with increasing the billet height, as shown in Fig.2a and 2b respectively. At the same height, Δv does not change, while Δs increases slightly with increasing the billet width. The variations in Δv and Δs depend significantly on the reduction in the billet height, but not on the billet width.

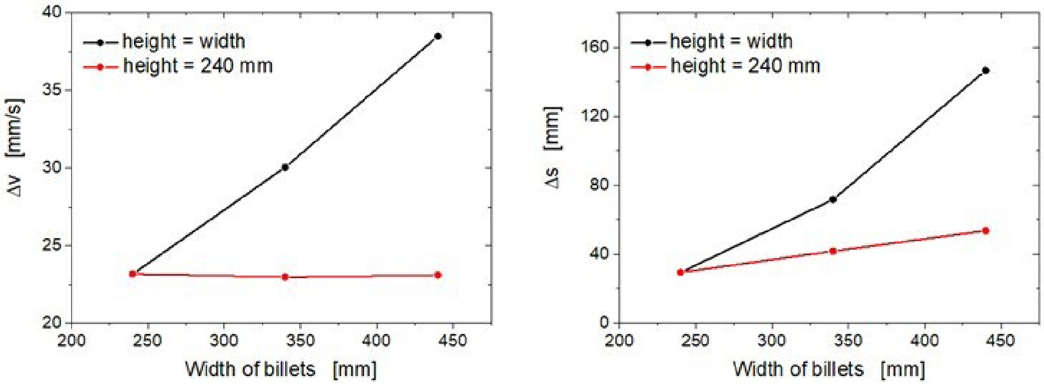

Fig. 2 - Increases in Δv (a) and Δs (b) with the billet size. The reduction ratio ($\Delta H/H_0$) is 0.15. Flat rolling.

Δv and Δs increase with increasing the reduction ratio ($\Delta H/H_0$), as shown in Fig.3a and 3b, respectively. The increases of Δv and Δs with $\Delta H/H_0$ are nearly linear.

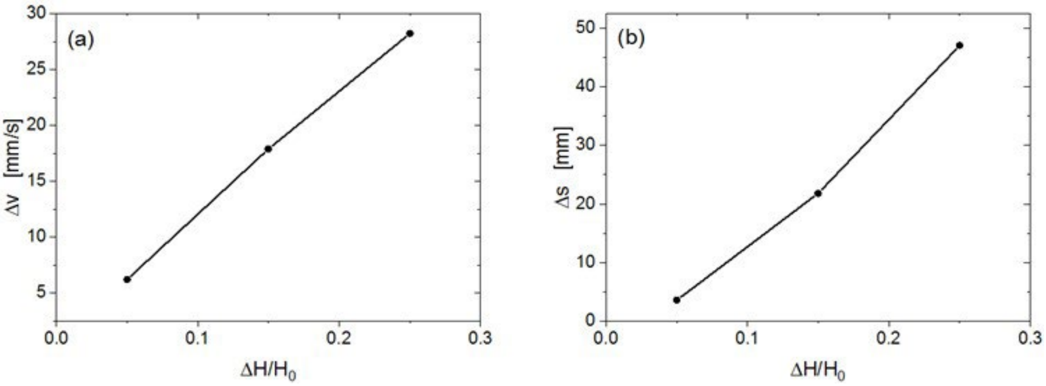

Fig.3 - Increases in Δv (a) and Δs (b) with increasing $\Delta H/H_0$. The cross section of the billet (Q) is 240 mm. Flat rolling.

The effect of the friction coefficient (m) on Δv and Δs is shown in Fig.4. Both Δv and Δs decrease with increasing m. As compared to those with the size or the reduction ratio, the variations in Δv and Δs with m are merely within 15% and are more significant as m is smaller than 0.80.

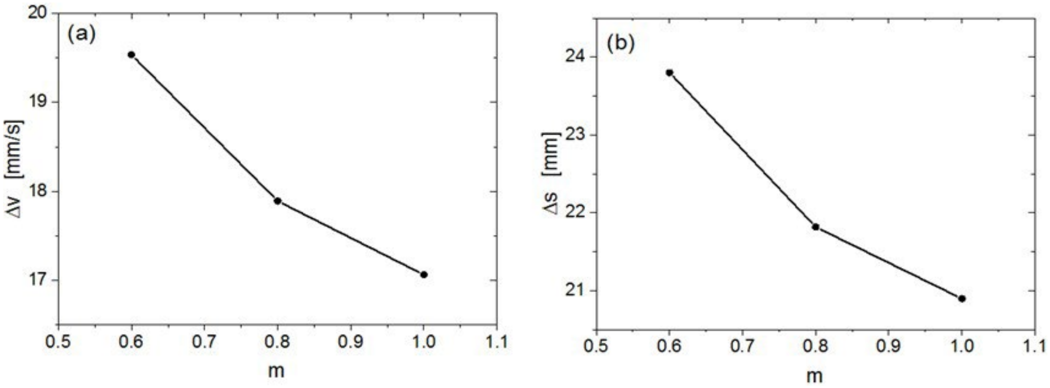

Fig.4 - Decreases in Δv (a) and Δs (b) with increasing the friction coefficient. Q = 240. $\Delta H/H_0$ = 0.15. Flat rolling.

The influences of T_d (Fig.1a) on Δv and Δs are shown in Fig.5. Δv and Δs decrease with increasing T_d. The relative sliding velocity and the distance are increased with a homogeneous temperature distribution on the cross section of billets. The variations in Δv and Δs with T_d are approximately 50% as the T_d is within 200°C.

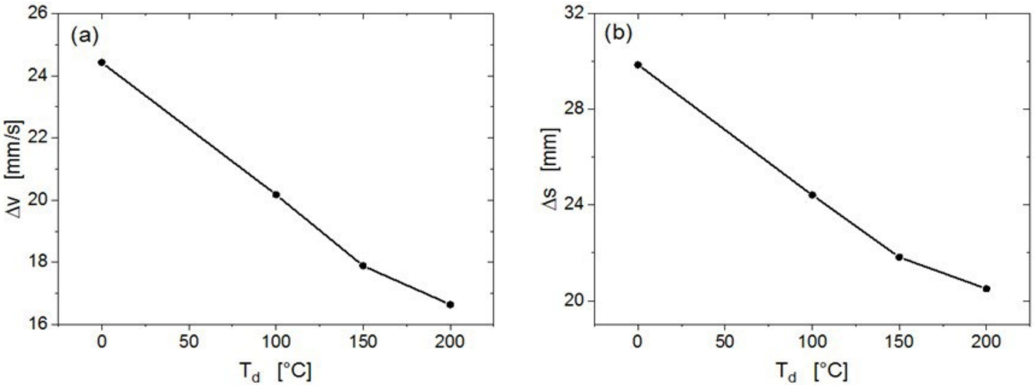

Fig. 5 - Decreases in Δv (a) and Δs (b) with T_d. Q = 240. $\Delta H/H_0 = 0.15$. Flat rolling.

Fig.6 shows the Δv and Δs increasing with increasing the roll speeds (v_R). The increase in Δv with v_R is significant and nearly linear. In a contrast, the increase in Δs is below 13.5%.

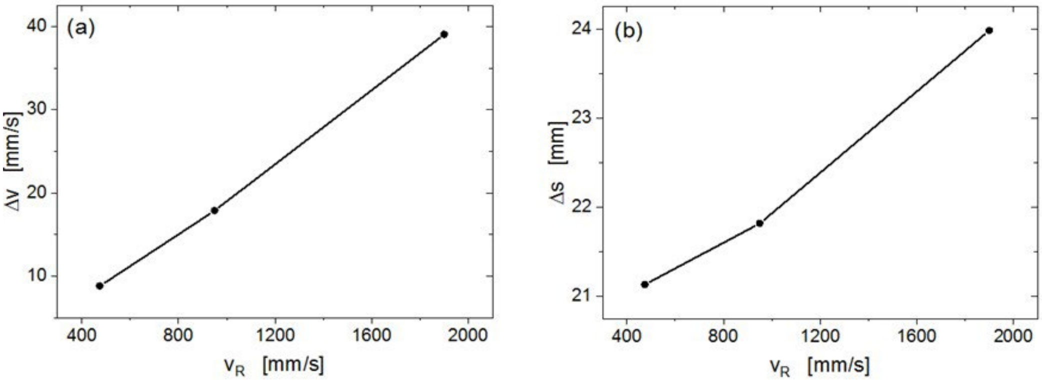

Fig. 6 - Increases in Δv (a) and Δs (b) with v_R. Q = 240. $\Delta H/H_0 = 0.15$. Flat rolling.

Δv and Δs at the different billet widths but the same billet height are shown in Fig.7. The caliber rolling is similar to the flat one as the billet width (206 mm) is much smaller than that of the caliber (251 mm). For the flat rolling Δv and Δs increase slightly with increasing the billet width. For the caliber rolling, Δv decreases slightly as the billet width equals to that of the caliber. The remarkable increases in Δv and Δs appear as the billet width is beyond the width of the caliber.

DISCUSSION

The relative sliding between rolls and workpieces is a well known phenomenon in rolling process. It affects not only the deterioration of work rolls, but also the surface qualities of the rolling products. Nevertheless, the quantitative measurements of the relative sliding have been proved to be difficult [5].

Finite element method (FEM) has been widely used in the simulation of rolling processes. The relative sliding can be quantitatively evaluated with the help of FE simulation. The advantages are that the complicated influencing factors under harsh working conditions can be excluded or simplified, and the time- and cost-consuming experiments or measurements are avoidable. However, the quantities in FEM depend on the settings in the simulation models, for example, the size and the shape of the elements. The parameters in the relative sliding are comparable merely with the same selective settings in the simulations. The accuracy of the evaluation can be improved by employing fine meshes, while, a compromise has to be made between the precision of the results and the consumed CPU time. The present investigation of the relative sliding with FEM paves a way to quantify the influencing factors like the geometric settings and the working conditions in the hot rolling. This method has a great potential in developing damage models, predicting roll wear and optimizing rolling schedules.

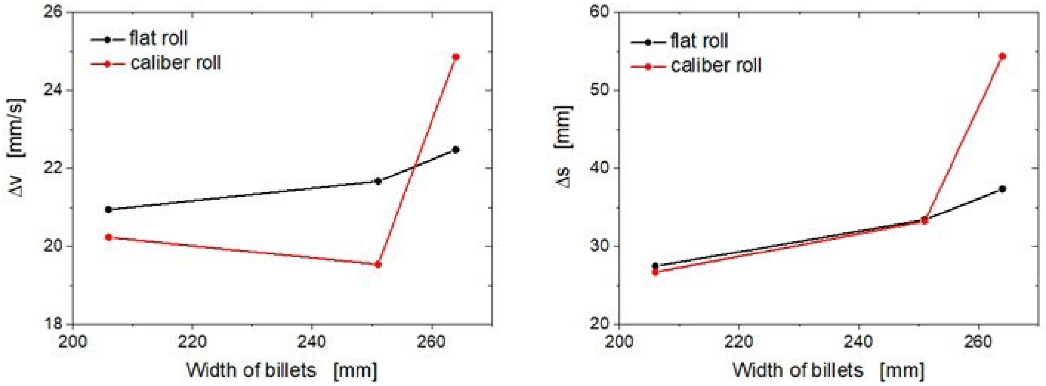

Fig.7 - Variations in Δv (a) and Δs (b) with the billet width. $\Delta H/H_0 = 0.15$. H0 = 251 mm. Flat and caliber rolls have the same diameter of 778 mm.

CONCLUSION

The relative sliding velocity and the distance are dominantly increased with increasing the billet height and the reduction ratio. Their variations with the temperature difference on the cross section of billets are moderate. The relative sliding velocity but not the sliding distance is sensitive to the rolling speed. The influence of the friction coefficient on the velocity and the distance is not remarkable.

As compared to the flat one, the effect of the caliber rolling on the relative sliding velocity and distance gets to be significant when the billet width is over the width of the caliber.

REFERENCES

[1] Zhang S, Hodgson PD, Cardew-Hallb MJ, Kalyanasundaram S. A finite element simulation of micro-mechanical frictional behaviour in metal forming. J Mater Proc Technol. 2003;134:81–91.

[2] Wang Z, Nakamura T, Dohda K, Obika T. FEM analysis of contact mechanism in press-forming of lubricant pre-coated steel sheet. J Mater Proc Technol. 2003;140:514–19.

[3] Kramer P, Groche P. Defect detection in thread rolling processes – Experimental study and numerical investigation of driving parameters. Inter J Machine Tools and Manufacture. 2018;129:27–36.

[4] Ma B, Tieu AK, Lu C, Jiang Z. A finite-element simulation of asperity flattening in metal forming. J Mater Proc Technol. 2002;130-131:450–55.

[5] Kim HH, Kim SJ, Yoon SM, Choi YJ, Lee MC. Sliding mode control with sliding perturbation observer-based strategy for reducing scratch formation in hot rolling process. Appl. Sci. 2021;11:5526. https://doi.org/10.3390/app11125526.

TORNA ALL'INDICE >