Investigation of the wear of rolls in asymmetric rolling

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ABSTRACT

In the present work, both symmetric and asymmetric rolling processes were investigated by means of numerical approaches. From the algorithm presented, values of rolling pressure and sliding velocity in the roll gap were determined. These variables allow the estimation of tribological parameters of a given material. To determine the wear of the rolls and rolled materials the Archard's law has been employed. Results of numerical simulations show that the quantitative characteristics of the wear reveal a slight change for slower roll. Whereas the wear value for the faster roll increases with an increase of roll velocity ratio. It was found that for a given roll velocity ratio, rise of friction coefficient causes insignificant change in the wear value for the slower roll, while this value tends to decrease rapidly for the faster roll.

Keywords: *Asymmetric rolling, Wear, Archard's law, Al alloys, FEM simulation*

1. Introduction

The industrial demand for flat product of metal and alloys is very high, which is basically obtained by the process of rolling. The rolling procedure can be divided into cold and hot rolling depending on the temperature maintained during the rolling process [1, 2, 3]. On the other hand, from the tribological aspect, rolling can be divided into the following groups: rolling with lubricant and dry rolling [1, 2, 4]. However, while applying lubricants [1], the viscosity of the lubricants bears an important part in the wear processes. From another point of view, the rolling process can be subdivided into two more categories such as symmetric and asymmetric rolling depending on the rolling conditions. The more common procedure is the symmetric rolling, where the relative velocities between the two rolls is identical throughout the process. On the other hand, in case of asymmetric rolling the rolls have different peripheral velocity. The advantage of using asymmetric rolling (ASR) over symmetric rolling is that the material suffers significant shear deformation, which cannot be introduced by the conventional rolling. At the same time, the disadvantage associated with the ASR is that the process parameters depend on the peripheral velocities and there is a significant slip between the rolls and the rolled material. It is possible to characterize the technique of ASR, in terms of roll velocity ratio K_V [5]:

$$K_V = \frac{V_{\max}}{V_{\min}}, \tag{1}$$

where, $V_{\max}$ is the peripheral velocity of the roll with a higher velocity and $V_{\min}$ is the peripheral velocity of the roll with a lower velocity.

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It has been observed that, different models for determining the wear values for friction bodies are described in the literature. One of them is the Archard's law. This law is described by considering the amount of loss in volume due to sliding contact between two materials [6]. However, there is a modified form of the Archard-law [7] that deals with the pressure of contact instead of the original model that focuses on considering the force between the contact surfaces. The modified Archard law is given by Eq. (2), which has been used directly in Finite Element modeling to study the subject.

$$\frac{dh}{dt} = k \cdot p \cdot |dv| \tag{2}$$

In Eq. (2), dh/dt is the wear rate [mm/s]; k is the wear coefficient [$\mathrm{mm^3/Nm}$] which can be treated as a material parameter; p is surface pressure between the bodies in contact at the point under test [MPa] and dv stands for sliding velocity at the test point [mm/s].

The described relation is not applicable in the initial and very advanced stages of wear [8]. The initial stage is the early short stage of wear, where small defects bulge out from the surface wear off, so that the wear coefficient value is significantly higher than the wear coefficient values for the subsequent stages. The Advanced stage is the step of the wear process where material fragments detached from the worn surface have a significant abrasive effect. In the initial stage, the wear coefficient may be several times higher than the values for the other stages of the process. The typical wear mechanism for a "Block-on-Ring" type sliding contact is adhesive wear according to [1, 8].

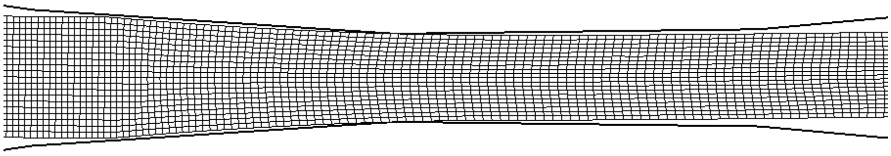
The current contribution aims to study the dry cold rolling process. While using Eq. (1), it has been considered that the radius and friction coefficient of the rolls are identical. Other parameters under consideration are the roughness of the rolls and the plate [2]. The effect of surface roughness is attributed in terms of the friction coefficient value, which is similar to the results presented in literature [2]. In case of employing Eq. (2), the effect of initial wear stages has been neglected. On the other hand, the advanced stage was assumed not to reach optimum stage of the wear process during the whole lifetime of the rolls.

2. Material and method

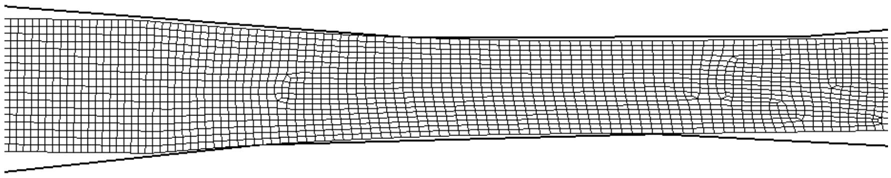
2.1. Material parameters and modelling

In order to investigate the phenomenon of wear of roll cylinders during both symmetric and asymmetric rolling, the commercially available Deform 2D finite element software [10] was employed. In the FEM calculations, the following technological and material parameters were used:

- The rolls were considered as rigid bodies with the diameter of 150 mm.
- The angular velocities of the upper and lower rolls were change between 1.1-2.2 rad/s.
- The calculations were performed for asymmetric ratios K_V ranging between 1-2.
- For the mechanical-strength parameters, the parameters of the material Al-6063 incorporated in the DEFORM-2D software were used [10].
- The initial thickness of sheet was 2 mm, while the final was 1.5 mm.
- The friction coefficient was changed in range from 0.075 to 0.25.
- The wear coefficient for aluminum (Al-6063) was $k_{Al} = 1 \cdot 10^{-5}$ $\mathrm{mm^3/Nm}$.
- The wear coefficient for aluminum changes in the range of $k_{Al} = (0.5-1.5) \cdot 10^{-5}$ $\mathrm{mm^3/Nm}$ [8, 9].
- The wear coefficient for steel was $k_{St} = 5 \cdot 10^{-6}$ $\mathrm{mm^3/Nm}$ [8].



(a)



(b)

Figure 1. *a)* Partially deformed mesh for symmetric rolling (R=75 mm; ω=1.1 rad/s; h_i=2 mm; h_f=1.5 mm; μ=0.15), *b)* Partially deformed mesh for asymmetric rolling (R=75 mm; ω_b=1.1 rad/s; ω_t=0.748 rad/s; h_i=2 mm; h_f=1.5 mm; μ=0.15)

2.2. FEM modeling

The DEFORM 2D software was used to model the rolling process. The peripheral velocity and friction coefficient of the rolls were varied for the different rolling simulations. In all cases, the initial velocity was set to 1.1 rad/s. The modelling was done on a regular mesh of squares with equal time steps. The constructed, partially deformed mesh is shown in Fig. 1/a and Fig. 1/b.

3. Results

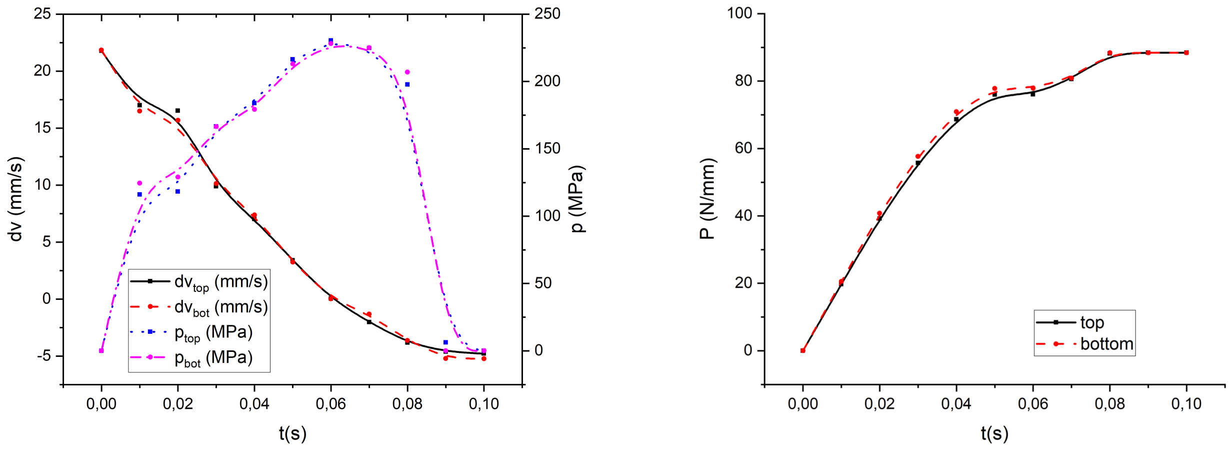
In the simulations represented, the effect of friction coefficient and velocity ratio were investigated for symmetrical and asymmetrical rolling with the same geometry. The model parameters are given in Table 1.

In the FEM model, the surface pressure and the sliding velocity were extracted for the lower and upper points of the plate at different time steps, and the wear value for the points was calculated by employing Eq. (2). An example of data extracted for symmetric rolling is shown in Fig. 2/a. The calculated $\int p \cdot |v| \ dt$ values for the different diagrams are signed by p. Fig. 2/a shows that in the case of symmetric rolling, the pressure and the relative sliding velocity values between the two rolls are nearly identical. The surface pressure at the inlet and outlet of the rolling gap is 0 MPa, with the maximum value at the contact point corresponding to a sliding velocity of 0 mm/s. As shown in Fig. 2/b, the increase in wear values is the same for the lower and upper points.

The extracted data for asymmetric rolling are presented in Fig. 3/a and Fig. 3/b shows that in contrast to symmetric rolling, the two rolls do not experience the same pressure and sliding velocity,

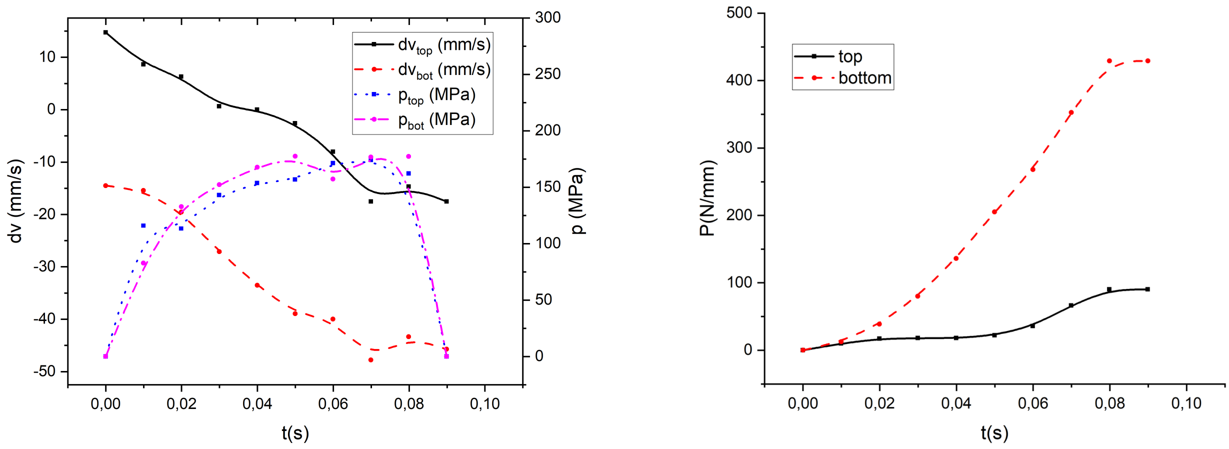
Table 1. Technological parameters used for FEM modelling

Parameter	**Value**
R, [mm]	75
ω_b [rad/s]	1.1
h_i [mm]	2
h_f [mm]	1.5
μ [-]	0.15



(a) (b)

Figure 2. *a)* Simulation results for symmetric rolling, *b)* Increase in wear value for symmetric rolling



(a) (b)

Figure 3. *a)* Simulation results for asymmetric rolling, *b)* Increase in wear value for asymmetric rolling

due to the different velocity of the rolls. The point of adhesion is formed only in the faster roll. The slower roll develops more wear due to the higher sliding velocity.

3.1. Chagning the friction coefficient

The effect of the friction coefficient was investigated in the range $\mu = 0.075 - 0.25$ for the symmetric and asymmetric cases. The geometric parameters of the test are given in Table 2. In the symmetrical case, the peripheral velocities are the same, in the asymmetrical case, the peripheral velocity of the lower roll is 0.748 rad/s.

Table 2. Parameters used for modelling

Deformation mode	Parameter	Value
SR	ω_t [rad/s]	1.1
ASR	ω_t [rad/s]	1.748
SR+ASR	μ [-]	0.075-0.25

Table 3. Wear in symmetric rolling for different friction coefficients

μ [-]	Δh_t [nm]	Δh_b [nm]
0.075	488.5	505
0.085	530	535
0.1	525	515
0.1125	487	476
0.125	515	520
0.1375	498.5	479
0.15	498.5	510
0.1625	460.5	505
0.175	427	436
0.1875	434	421
0.2	459.5	472
0.2125	515	451.5
0.225	600	535

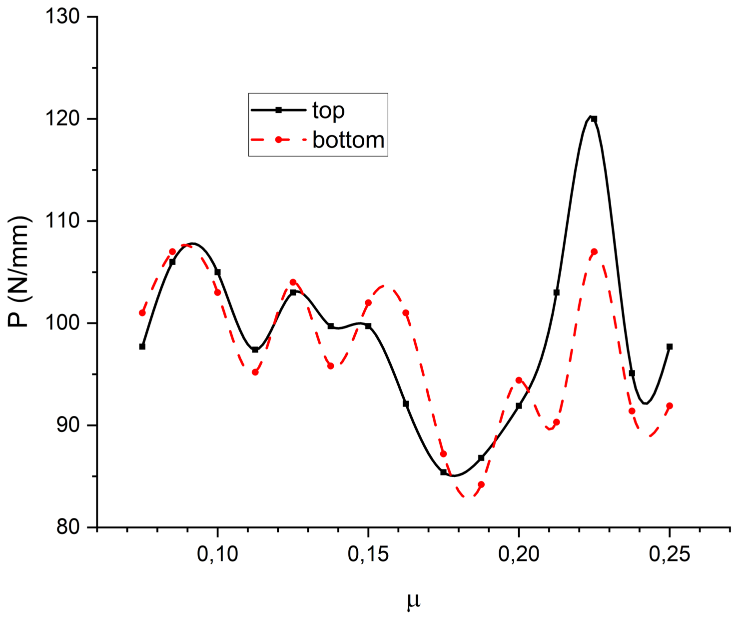


Figure 4. Wear values for symmetrical rolling

For symmetrical rolling, the wear values for different friction factors are given in Table 3 and Fig. 4. For asymmetric rolling the same values are given in Table 4 and Fig. 5.

Table 4. Wear in asymmetric rolling for different friction coefficients

μ [-]	Δh_t [nm]	Δh_b [nm]
0.065	2915	444.5
0.07	2795	458
0.075	2545	398.5
0.1	2470	465.5
0.125	1865	445
0.15	1830	505
0.175	1755	515
0.2	1350	610
0.225	1010	790
0.25	930	750

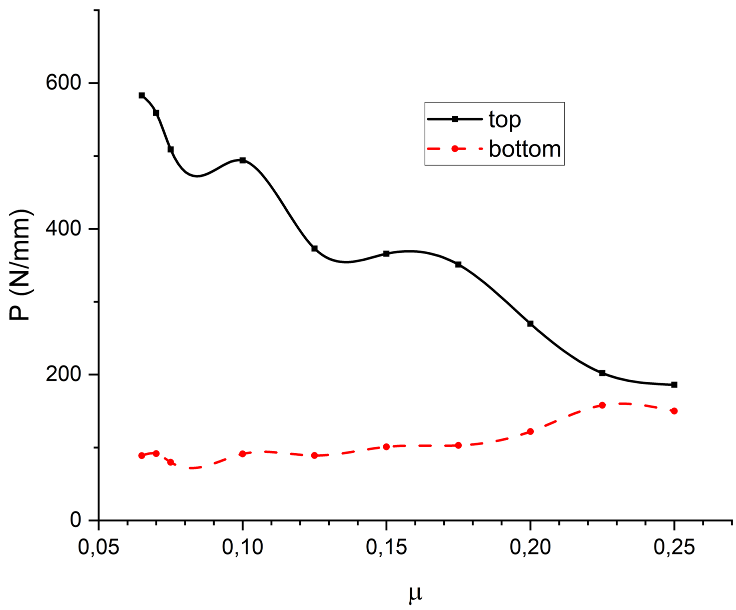


Figure 5. Wear values for asymmetrical rolling

It can be concluded from Table 3 and Fig. 4 that in the case of symmetric rolling, the wear value does not depend on the value of the friction coefficient. In the asymmetric case, as shown in Fig. 5 and Table 4, the wear value for the slower roll does not change significantly and the wear value for the faster roll decreases significantly.

For both rolls in symmetric rolling the following functions can be fitted to the wear values according Eq. (3) and (4).

$$\Delta h_{V\ \max}(\mu, K_V = 1) = k(-12.14\mu + 100.67)\ (R^2 = 0.682) \tag{3}$$

$$\Delta h_{V\ \min}(\mu, K_V = 1) = k(-63.928\mu + 107.4)\ (R^2 = 0.735) \tag{4}$$

For asymmetric rolling the Eq. (5) and (6) can be used.

$$\Delta h_{V\ \max}(\mu, K_V = 1.5) = k(-2091.9\mu + 689.949)\ (R^2 = 0.9652) \tag{5}$$

$$\Delta h_{V\ \min}(\mu, K_V = 1.5) = k(356.02\mu + 55.07)\ (R^2 = 0.821) \tag{6}$$

3.2. Effect of roll velocity ratio

As in the previous study [5], the effect of roll velocity ratio on wear was investigated. The test results are shown in Table 5 and Fig. 6. As shown in Fig. 6 and Table 5, when the velocity ratio is changed, the wear on the slower roll does not change significantly, while the wear on the faster roll increases substantially. The fitted functions for different velocity ratio are the Eq. (7) and (8):

$$\Delta h_{V\ \max}(\mu = 0.15, K_V) = k(481.85K_V - 368.92)\ (R^2 = 0.9485) \tag{7}$$

$$\Delta h_{V\ \min}(\mu = 0.15, K_V) = k(17.141K_V + 62.985)\ (R^2 = 0.821) \tag{8}$$

4. Summary

It has been observed that in symmetric rolling the effect of the friction coefficient on wear is negligible, while in the asymmetric case the wear decreases with increasing the friction coefficient for the rolls with higher velocity. In asymmetrically rolled materials, the wear coefficient does not affect the wear behavior of rolls with lower velocity.

The effect of the velocity ratio was also examined. It has been reported that, with an increase in the velocity ratio; there is a rise in the amount of wear on the faster roll and negligible on the slower one. With further studies, the results can be extended to other geometries and materials. It is important to mention that the analytical functions derived are based on results presented in the current study are of approximative nature and reveal the trend of the wear involved in rolling process.

Table 5. Wear in asymmetric rolling for different K_V values

K_V [-]	Δh_t [nm]	Δh_b [nm]
1.0	442	442
1.05	384.5	515
1.1	412	805
1.25	387	1265
1.5	450.5	2145
1.75	458	2465
2.0	497.5	2700

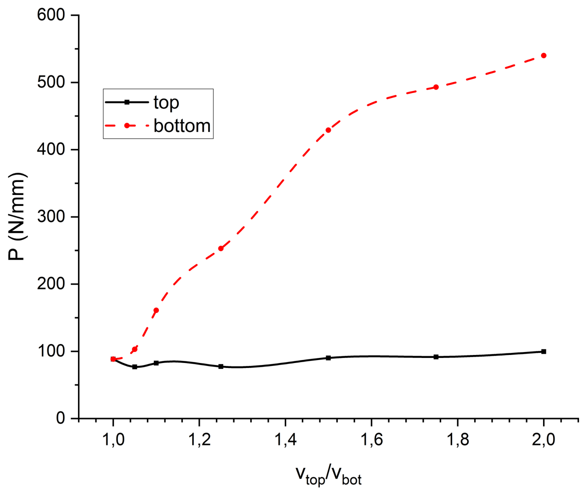


Figure 6. Wear values for different rolling velocities

5. References

[1] Z. Hui, W. Manxing, *A study of wear mechanisms in the cold rolling of aluminium strip*, Journal of Materials Processing Technology 31(1–2), 1992, pp. 235–243. CrossRef

[2] W. da S. Labiapari, C.M. de Alcântara, H.L. Costa, J.D.B. De Mello, *Wear debris generation during cold rolling of stainless steels*, Journal of Materials Processing Technology 223, 2015, pp. 164–170. CrossRef

[3] J. Valíček, M. Harničárová, M. Kušnerová, J. Zavadil, R. Grznárik, *Method of Maintaining the Required Values of Surface Roughness and Prediction of Technological Conditions for Cold Sheet Rolling*, Measurement Science Review 14(3), 2014, pp. 144–151. CrossRef

[4] M. Tahir, *Some aspects on lubrication and roll wear in rolling mills*, Division of Materials Forming Department of Production Engineering Royal Institute of Technology, KTH, Stockholm, 2003, url

[5] A. Pesin, D. Pustovoytov, T. Shveyova, M. Sverdlik, *Finite Element Modeling of Roll Wear during Cold Asymmetric Sheet Rolling of Aluminum Alloy 5083*, MATEC Web of Conferences, 26, 2015, 01010, CrossRef

[6] J.F. Archard, *Contact and Rubbing of Flat Surfaces*, Journal of Applied Physics 24, 1953, p. 981. CrossRef

[7] A. Fischer, K. Bobzin, *Friction, wear and wear protection*, International Symposium on Friction, Wear and Wear Protection 2008, Aachen, Germany, Presented at the International Symposium on Friction, Wear and Wear Protection, Weinheim, Germany: Wiley-VCH. 2009, CrossRef

[8] G. Straffelini, *Friction and Wear*, Cham: Springer International Publishing, 2015, CrossRef

[9] E. Avcu, *The influences of ECAP on the dry sliding wear behaviour of AA7075 aluminium alloy*, Tribology International 110, 2017, pp. 173–184. CrossRef

[10] J. Fluhrer, DEFORM(TM) 2D Version 8.1 User's Manual, Scientific Forming Technolgies Corporation, url