Irregularity in Friction Hills during the Cold Rolling of Materials

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ABSTRACT: Among the cold rolling parameters, the pressure distribution or friction hill within the roll gap is one of the most significant one. Almost all of the previous works in this regard are based on laboratory simulations rather than industrial mill conditions though the situations can be completely different. In this study, following determination the coefficient of friction (COF), the friction hills for the real industrial mills were obtained by Matroll software. After carrying out various industrial cold-roll passes on 3003 aluminum alloy and low carbon steel, the friction hills were plotted for industrial cases. The new findings indicate that there are some kinds of irregularities in the real industrial friction hills that are different from those reported for laboratory cases. The results show that this happens when the COF values during industrial rolling are too low.

Key words: Friction hill, Cold rolling, Coefficient of friction, Steel and aluminium rolling

1 INTRODUCTION

Without the knowledge of the effectiveness of the coefficient of friction (COF), the satisfactory operation of commercial rolling facilities is very difficult to achieve. Moreover, it may become more difficult to use mathematical models of the cold rolling process for engineering purposes [1-4].

In the cold rolling process, friction along the arc of contact at the roll-strip interface is necessary for the transmission of deformation energy from the work rolls to the strip. If the frictional forces are too small, the peripheral speed of the roll will exceed the exit speed of the strip. In other words, the rolls will skid in this case. By contrast, larger coefficients will result in a forward or positive slip of the strip, in fact in such a case, the exit speed of the strip in excess of the peripheral speed of rolls.

The surface quality of sheet is another property influenced strongly by the changes occurred in the COF; in general, the brightness of sheet increases as the effective COF increases and vice versa [5]. In other words, a high value of COF, by employing the poorer types of lubricants, enhances the luster of the rolled strip. However, with poor lubricants, detritus may become embedded in the rolls (i.e. roll pick-up). If this happens, it can degrade the appearance of rolled strip. That is because, in case of high value of COF, e.g. employing poor lubricants, the rolls become worn through the processing of strip so that, if they are initially rough, they tend to become smoother. By contrast, when the COF is low, e.g. using good lubricants, of course, the wear rate is minimized. It should be mentioned that poor lubricity can also damage the work roll surface, resulting in forming a micro-uneveness of the work roll surface. This is attributed to different wear rates on the surface on a microscopic scale [6]. Therefore, a strong correlation exists between the general appearance of the rolled strip and the COF changes in the roll bite.

Regarding the other rolling parameters, increasing the friction in rolling increases the degree of nonuniformity in the deformation zone of rolled stock, increases the rolling force and rolling power as well as the forward slip. The increased rolling force, attributed to the excessive friction in the roll bite, increases the frictional energy dissipation along the arc of contact as well as the bearing losses associated with the mill. To some extent, however, this increased energy supplied by spindles is offset by slightly increased throughout of the mill stand due to the increased forward slip of the strip as it emerges from the roll bite [7].

In the present work, an attempt has been made to study the irregularities observed in friction conditions and friction hills during the industrial cold rolling of aluminum and steel.

2. TECHNICAL PROCEDURE

The Matroll software, developed by authors [8,9], is based upon years of practical and experimental observations from cold rolling of metal strips especially aluminium. This software has the capability to operate on windows since it is developed using Visual Delphi 6. During the software operation, the rolling equations pertaining to about 25 parameters are solved using a numerical approach.

One of the significant features of the Matroll is that, contrary to the other models, none of input parameters owns presumed value. In other words, all

the rolling parameters are calculated or measured according to the constitutive equations of rolling theory. This led to the complexity as well as widespread of the algorithm used in Matroll software. To provide the accurate result, the real conditions of industrial rolling process are considered in the software. For example, as the strip rolling process is a plane strain deformation (i.e. no lateral spread), it was necessary as the first step to obtain the flow stress-draught curves, so called S-r diagrams. To do this, the plain–strain compression tests (Ford test) were carried out. The results are then fed into the software as subprograms. For instance, to obtain the flow-stress of workpiece after a few passes, Matroll goes back to subprograms in order to calculate the equivalent reduction and then refers to S-r curve so as to determine the flow stress corresponding to the total reduction of workpiece. Therefore, the S-r curves, which are considered in Matroll, are of the most important requirements for simulating flat-rolled products.
For saving the space, only are the characteristics of industrial mill for aluminium rolling mentioned here. These are as follows:

Aluminum Mill: Industrial four-high reversing mill
Back up diameter: 1000 mm
Work roll diameter: 400 mm
Lubricant: light mineral oil with 4% additives
Entry and exit gauges: 7 mm and 0.3 mm respectively
Rolling speed: 0 to 400 m/min

Using Matroll software, the COF values and friction hills were obtained for many passes carried out on the industrial mills. These were done for rolling both aluminium alloy 3003 and low carbon steel.

As for obtaining the COF, Avitzur [10] suggests the following equation. Compared to other methods to calculate the COF [11-16], this equation is believed that is more completed one, including more important parameters affecting the rolling process and COF. Avitzur's equation used in Matroll is as follows:

$$\mu = \frac{\frac{1}{2}\sqrt{\frac{h_f}{R'}}\left[\ \ln\left(\frac{h_f}{h_0}\right)+\left(\ \frac{1}{4}\sqrt{\frac{h_f}{R'}}\sqrt{\frac{h_0}{h_f}-1}\ \right)+\frac{t_0-t_f}{\frac{2}{\sqrt{3}}\sigma}\ \right]}{\left\{\left[\left(\ln\frac{h_0}{h_f}-1\right)\times\frac{(t_f-t_0)}{\frac{2}{\sqrt{3}}\sigma\sqrt{\frac{h_f}{h_0}-1}}\ \right]-\left[\left(\frac{1}{\frac{2}{\sqrt{3}}\sigma}\left(t_f-\frac{t_f-t_0}{\frac{h_f}{h_0}-1}\right)-1\right).\tan^{-1}\sqrt{\frac{h_0}{h_f}-1}\ \right]\right\}}$$

Where h_o and h_f are respectively the entry and exit thicknesses, t_o and t_f are also respectively the back and front tensions, R' is the flattened roll radius and $2/\sqrt{3}\sigma$ is the flow stress of the strip being rolled.

3 RESULTS

The industrial amounts of COF determined by Matroll software for both aluminium and steel are summarized in Table I. The friction hills plotted also by Matroll software for industrial steel mills are shown in Figures 1 to 3. As it is observed, for the passes that COF value is almost reasonable, the friction hills show their normal trend, whereas in cases that this amount is low, there are some kinds of irregularities in the pressure distribution curves. It is interesting that the same happened for real industrial rolling of aluminium, Figures 4 to 6. Regarding the irregularities in friction hills, while the workpiece is being rolled, any instantaneous changes in rolling conditions that consequently results in lowering the COF values are most likely responsible for the observed abnormalities. Among these changes in the roll gap or deformation zone during rolling can be variations in lubricity conditions, roll temperatures or thermal crowns, roll bending, front and back tensions and roll force. To compensate for any of these changes, the operator should take measures so as to increase the effective COF, i.e. by varying the mentioned parameters in the way of increasing COF.

Table I – The industrial amounts of COF determined by Matroll software.

	PASS 1	PASS 2	PASS 3
COF vales of Steel	0.048	0.027	0.025
COF vales of Aluminum	0.052	0.022	0.031

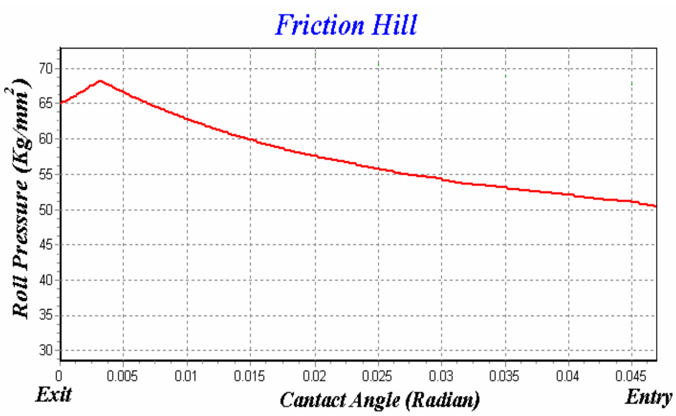

Fig.1. Friction hill for the first pass of steel rolling

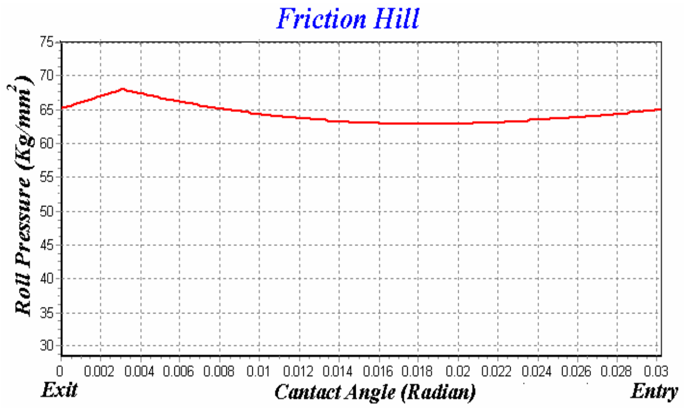

Fig.2. Friction hill for the second pass of steel rolling

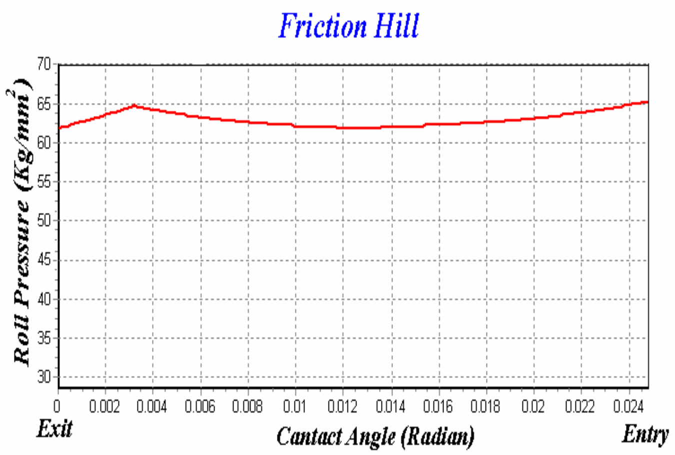

Fig.3. Friction hill for the third pass of steel rolling

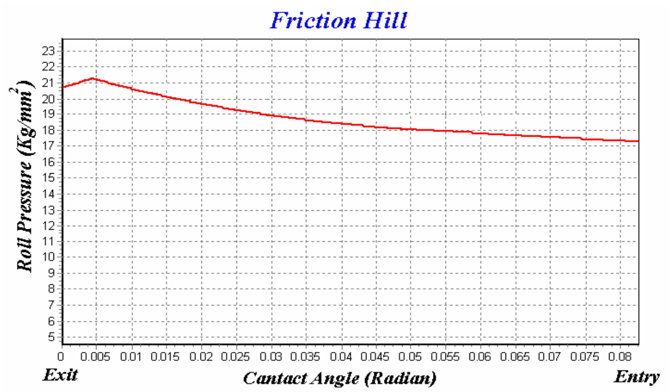

Fig.4. Friction hill for the first pass of aluminium rolling

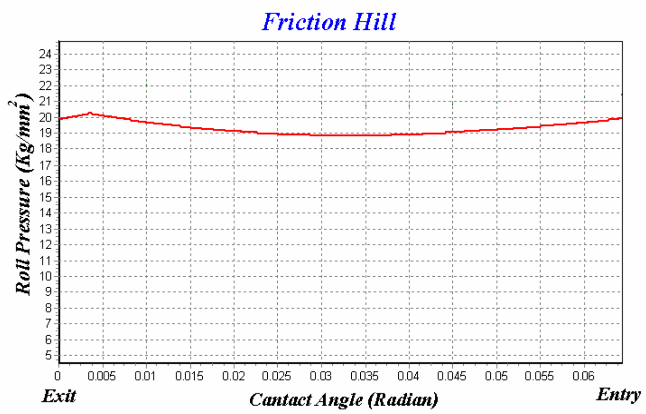

Fig.5. Friction hill for the second pass of aluminium rolling

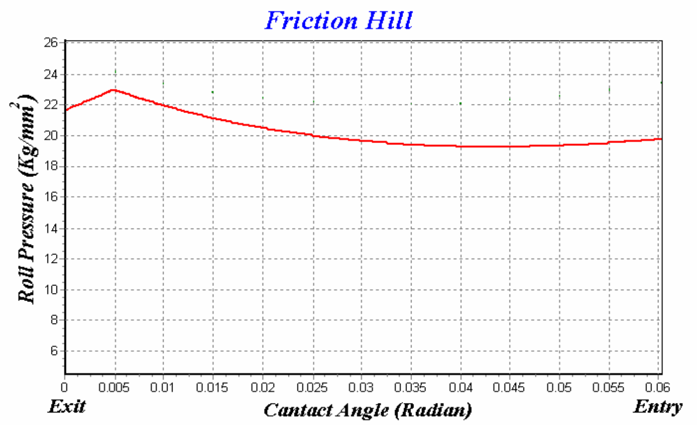

Fig.6. Friction hill for the third pass of aluminium rolling

4 DISCUSSION

Referring to Figures 2, 3, 5 and 6**,** the diagrams of pressure distribution (i.e. the friction hills) over the entry side of the arc of contact exhibit interesting features. As shown for curve 2 in Figure 7, in the entry zone, there is a segment over which the angles of contact are greater than the angle of friction, i.e. tan $\varphi > \mu$. In other words, in this specific region, the friction hill is characterized by a fall rather than by a rise, i.e. a lower COF. By contrast, for curve 1 that represents the theoretical friction distribution, the changes in friction follow the general condition (tan $\varphi < \mu$) along the whole contact arc. Therefore, the abnormal friction distribution (tan $\varphi > \mu$) may take place at the beginning of the contact arc in a real industrial mill, i.e. in the entry zone of Figures 2, 3, 5 and 6. These findings are in agreement with those reported by Tselikove [17].
Thus, it can be concluded here that the real pressure distribution or friction hill for an *industrial* level is not necessary the same as the theoretical or predicted one, at least for some cases. This is another finding that confirms, during industrial rolling, the COF is not constant over the whole arc of contact.

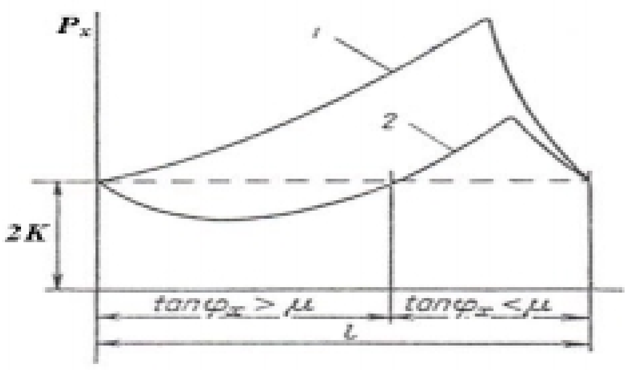

Fig. 7.Depending theoretical friction hills on the friction angle; 1) tan $\varphi < \mu$ along the whole contact arc, 2) tan $\varphi > \mu$ at the beginning of the contact arc [17].

If the frictional forces are considerably in excess of those corresponding to minimal frictional requirements, then difficulties may be encountered in obtaining satisfactory rolling conditions in that the rolling forces may be so large that employing roll bending gives the rolled strip a poor shape or an inadequate degree of flatness. Moreover, the dissipation of the excessive frictional energy may result in abnormally high roll and strip temperatures. In the case of former, nonuniform heating of the rolls may affect the ease of attaining satisfactory rolled strip shape, whereas the latter may be detrimental with respect to the quality of the strip if used for the critical applications [9].

In addition, increased friction also produces a more lustrous finish on the rolled strip, on account of the increased buffing action of the rolls on the strip surfaces.

Regarding the general appearance of rolled strip (reflectivity, gloss, lustre or shininess etc.), one can conclude that the surface finish of the strip is, in part, dependent on changes in COF during rolling. That is because, the changes in friction in the roll gap affects the amount of buffing the strip receives from the roll surface prior to its emergence from the roll bite.

With respect to lubricity, the ability of a lubricant film to resist an applied pressure without rupture is defined as the lubricant film strength. During rolling, severe stresses may arise from roll flattening, thermal changes and wear. These can readily lead to rupturing the lubricant film. Consequently, a high value of COF is obtained because of direct contact between the roll surface and strip. By contrast, any change that occurs in the reverse direction tends to lower the COF during rolling. Therefore, the load bearing capacity or the strength of lubricant film plays an important role in the COF provided in the roll gap [16].

Concerning the tensions, any change in the strip tensions during rolling, of course to some extent, can change the strip surface quality by affecting the COF values. This is due to the fact that the position of neutral point, and in turn the COF values, is affected by changes in the ratio of the back to the front strip tensions. It is believed that increasing this ratio during rolling moves the neutral point towards the exit plane, i.e. towards decreasing the COF that in turn results in a duller strip. By contrast, decreasing the ratio has an inverse effect that tends to produce brighter strip, i.e. increasing the COF amounts by moving the neutral point in the opposite direction.

5 CONCLUSIONS

1. Irregularities were observed in friction hills of industrial rolling of steel and aluminium. These happen when any changes in a given set of rolling conditions causes a decrease in COF.
2. For the industrial passes that COF value is almost reasonable, the industrial friction hills show their normal trend, whereas in cases that this amount is low, there are some kinds of irregularities in the pressure distribution curves.

References

1. Z.Y. Jiang and A.K. Tieu, A 3-D Finite Element Method Analysis of Cold Rolling of Thin Strip with Friction Variation. *Tribology International*. 37 (2004) 185-191.
2. Z.Y. Jiang, A.K. Tieu, X.M. Zhang, C. Lu and W.H. Sun, Finite Element Simulation of Cold Rolling of Thin Strip. *Journal of Materials Processing Technology*. 140 (2003) 542-547.
3. J. Larkiolda, P. Myllykoski, J. Nylander and A.S. Korhonen, Prediction of Rolling Force in Cold Rolling by using Physical Models and Neural Computing. *Journal of Materials Processing Technology*, 60 (1996) 381-386.
4. H. Keife and C. Sjögren, A Friction Model Applied in the Cold Rolling of Aluminum Strips. *Wear* 179 (1994) 137-142.
5. H. L. Murphy, J.P. Bressanelli and K.E. Pinnow, Method for Rolling Stainless Steel. *U.S. Patent 3496746*, (1974).
6. V.A. Nikolaev et al., Wear on the Surfaces of the Work Rolls of a Reversing Cold Rolling Mill. *Stal in English*. (1969) 196-198.
7. W.L. Roberts, R.J. Bentz and D.C. Litz, *Cold Rolling Carbon Steel Strip to Minimum Gage*. Iron and Steel Engineer Year Book. (1970) 413-420.
8. H. Abdollahi and K. Dehghani, 'A new software (Matroll) to determine the coefficient of friction and to plot the friction hill during the cold rolling of aluminum' Proceedings of the Int. Conf COM 2005, Calgary, Canada, (2005) 319-333.
9. K. Dehghani, Measurement the Coefficient of Friction during the Cold Rolling of Industrial Aluminum Mill, Master Thesis, Tehran University, (1990) 141-157.
10. B. Avitzur, *Metal Forming: Processes and Analysis*, McGraw Hill Book Company, New York, NY, USA, (1979).
11. S. Kondo, Improving Rolling Stability during Cold Rolling of Aluminum, *Light Metal Age*, December, (1974), 5-7.
12. S. Jianlin and Z. Xinming, Evaluation of Lubricants for Cold Rolling Aluminum Strips, *Journal of Central South University of Technology*, 4 (1997), 65-68.
13. P.M. Lugt, A.W. Wemekamp, W.E.T. Napel, P. V. Liempt and J.B. Otten, Lubrication in Cold Rolling, *Wear*, 166 (1993), 203-214.
14. S. Zhang and J. G. Lenard, The Effects of the Reduction, Speed and Lubricant Viscosity on Friction in Cold Rolling, *Journal of Materials Processing Technology*, 30 (1992), 197-209.
15. R. Lazic, R. Dodok and V. Milenkovic, Influence of Front and Back Tensions in Friction in the High Speed Cold Rolling of Aluminum Strip, *Aluminum*, 59 (1983), 381-384.
16. L.B. Sargent, Lubricants for Cold Rolling Aluminum Alloys- a Laboratory Appraisal, *Light Metal Age*, (1975), 15-17.
17. Tselikove, *Stress and Strain in Metal Rolling*, MIR Publishers, Moscow, Russia, (1967) 60-80.