International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 04 | Apr 2020 www.irjet.net p-ISSN: 2395-0072

Emulsion Effect on Energy Consumption of Cold Strip Rolling Lubricated in Mixed Regime

Ali Mousavi[1]

[1]Mechanical Engineering Department, Kashan University, Kashan, Isfahan, Iran.

---***---

Abstract

Emulsions are popular lubricants in cold strip rolling. Application od emulsion which are mostly consist of oil and water, makes the products with higher quality, meanwhile keeps the friction low and reduces the unwanted heat generation due to friction. High production of steel companies makes the efficiency of production a prominent issue. In the present study, a model based on mixed film lubrication is used to find the effect of oil content of emulsion on the energy consumption of cold strip rolling process.

1. Introduction

Steel manufacturing is one of the most pollutant industries in the world by producing enormous amount of greenhouse gases [1]. The optimized design of the lubrication system can effectively reduce both the cost of production and energy usage in rolling section in steel manufacturing process and consequently reduce the contaminations from the steel manufacturing industry [2, 3]. Strip rolling with emulsion is widely used in the steel production companies. Oil/water emulsions has this capability to reduce the friction and keep the heat low due to the high specific heat parameter of water and lubricity of oil. In other hand, using O/W emulsion is cost effective in a term because it needs to use lower amounts of oil which is the main expense of lubrication. Fig. 1 shows the cold strip rolling which is lubricated with oil. [4]

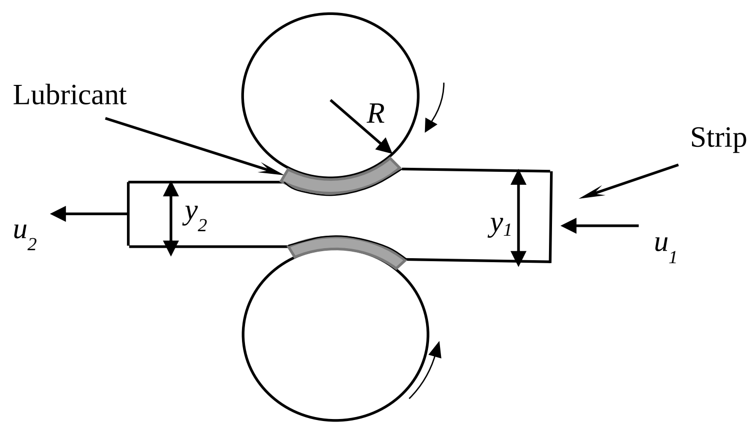

Figure 1. Lubrication of cold rolling

Lubrication with emulsion has been investigated by Yan and Kuroda [5]. In their model, emulsion is considered as a two-phase fluid with continuous phase (water) and disperse phase (oil). Kosasih *et. al.*[6] applied this model to cold strip rolling.

Emulsion as lubricant behavior is mainly dependent on the velocity of the sliding surfaces where emulsion is lubricating. Fig. 2 shows this behavior.

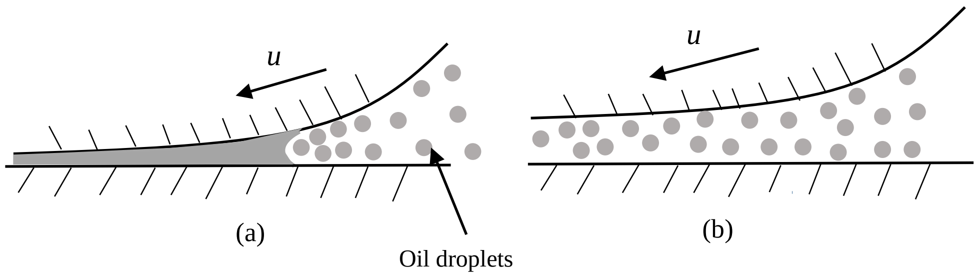

Figure 2. Lubrication with emulsion in (a) low and (b) high speed region.

In low speed region, the oil particles have sufficient time to stick to the surfaces and form an oil pool. In this case, most of the lubrication region is occupied by oil. As the sliding speed increases, them more water is strained between the surfaces. When speed is high enough, most of the lubrication is carried out by the continues phase (water). This behavior makes emulsion unique in its behavior when it is used for lubrication. [7, 8].

In other terms, lubrication is generally divided into different regimes. According to fig. 3, when the load on the two lubrication surfaces is not high, the two surfaces are separated by a thick film of lubricant[9, 10]. This regime is called full-film regime. On the other side, if load increases, the two sliding faces get into direct contact and the lubricant continuity is interrupted by direct contact of asperities of the surfaces.

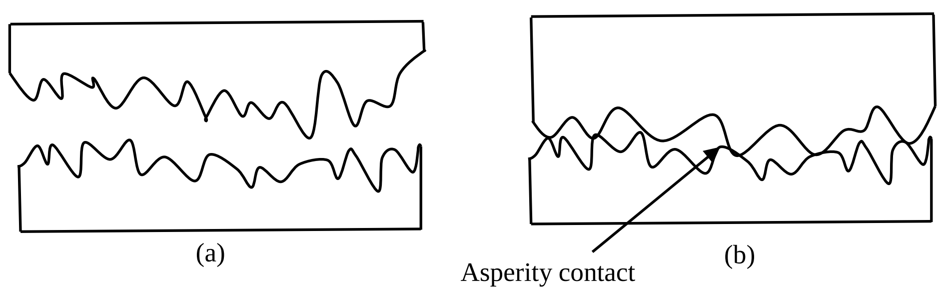

Figure 3. Lubrication of sliding surfaces in (a) full-film and (b) mixed film regime

This regime of lubrication is more serious in Journal bearings [11].

2. Model description
2.1. Slab method

Fig. 4 shows the slab method used for cold strip plastic behavior. The plastic stress on the element of the strip is shown on the two faces of the element. Using the force equilibrium in x and y direction and considering the small plastic region under the rolls, Eq. 1 is found.

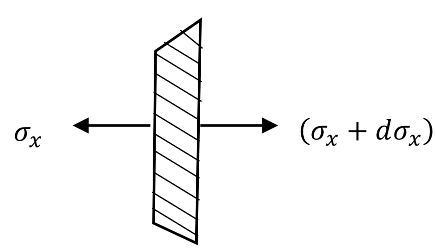

Figure. 4. Strip element in the work zone.

$$\sigma_y \frac{dy}{dx} + y\frac{d\sigma_y}{dx} - y\frac{dp}{dx} - 2\tau = 0 \quad (1)$$

in this equation, σ_y, y, τ and p are the yield stress, thickness of the strip, shear stress on the friction surface of element and pressure from the rolls on the surface of strip[12]

2.2. Mixed film regime

The flow in micro scale is attracting researchers' interest from many different fields due to its extended applications including heat transfer, multiphase flows, Nano particles movement, etc [13-17]. One of the main applications of the micro fluidic equations is in mixed film regime. Cold strip rolling mostly evolves high pressure from the rolls on the plates. This means that lubrication regime is mixed regime. In the mixed regime, contacts of asperities are the dominant friction mechanism. It is also important to take the viscous effect of lubricant into account. The relation which is widely used for describing lubrication in mixed regime is the modified Reynold's equation.

$$\frac{d}{dx}\left(\frac{\Phi_x h_t^3}{\xi}\frac{dp_f}{dx}\right) = -\frac{d}{dx}\left((u_w + u_r)h_t\right) \quad (2)$$

p_f is the lubricant pressure. The work piece and roll speed are given by u_w and u_r. h_t represents the average film thickness. This equation is corrected for the effect of emulsion by applying the equivalent viscosity (ξ) concept.

$$\xi = \frac{\eta_c \eta_d}{\lambda_d \eta_d + \lambda_c \eta_c} \quad (3)$$

where λ_c and λ_d are the water and oil content of emulsion ($\lambda_d + \lambda_c = 1$). In Eq. 3, η_d stands for viscosity of oil.

2.3. Plastic deformation of the asperities

Fig. 5 shows the asperity contact of two sliding surfaces. Due to the pressure on the asperities, the deform plastically. This flattening behavior is the contributor to higher friction force due to increasing of the contact ratio $A = \frac{a}{L}$. The parameter a is half of the contact area in half pitch of asperity contact (L).

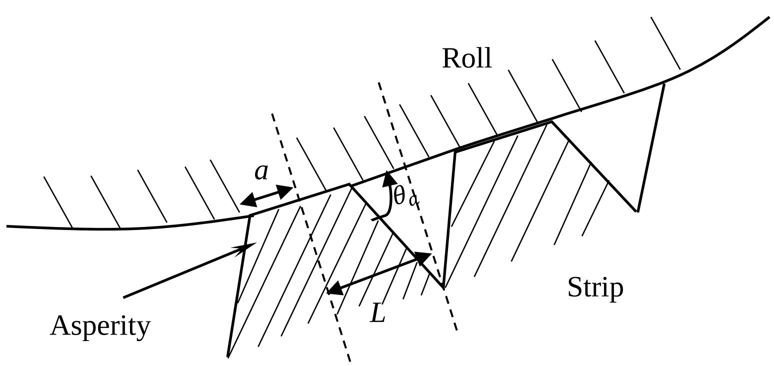

Fig. 4. Asperity contact and the parameters related

Chang and Wilson [18] suggested the following relation for quantifying the flattening effect of asperities.

$$\frac{dA}{dx} = \frac{x}{La\theta_a\left(1 - A + \frac{yE_s}{2L}\right)} \quad (4)$$

θ_a is shown in Fig. 4. E_s is the non-dimensional strain rate which is given by Eq. 5.

$$E_s = \frac{2A - (p - p_f)}{(p - p_f)f_1} \tag{5}$$

$$f_1 = -0.86A^2 + 0.345A + 0.515 \tag{6}$$

$$f_2 = \frac{1}{2.571 - A - A\ln(1 - A)} \tag{7}$$

2.4. Strip speed

The strip thickness changes during the time it is under the rolls and deforms plastically. This decrease of the thickness results in elevation of plate speed. Since the elasticity of strips are small, the plastic condition prevails and the following relation gives the speed based on the thickness of the strip.

$$y_1 u_1 = y_2 u_2 = yu$$

In this relation, y_1 and y_2 are the thickness of the strip in the inlet and outlet of the work zone. u_1 and u_2 corresponds to the speed in inlet and outlet.

2.5. Film and yield condition of boundaries

Lubricant is not under any pressure before it goes under the rolls and after it come out of the rolls in the outlet.

$$x = x_1 \qquad p_f = 0 \tag{8}$$

$$x = 0 \qquad p_f = 0 \tag{9}$$

here, x_1 is the length of plastic work zone.

The plastic yielding of the strip in inlet and outlet is found by von Mises approach.

$$x = x_1 \qquad P = \sigma_y - s_1 \tag{10}$$

$$x = 0 \qquad P = \sigma_y - s_2 \tag{11}$$

s_1 and s_2 are the tensions in inlet and outlet.

3. Solution procedure

In order to find pressure and friction force of strip rolling with emulsion, Eqs. 1, 2 and 4, needs to be solved together. The solution involves an iterative method that consists of two ODE problem of Eq. 1 and Eq. 4 and a second order one dimensional differential equation of Eq. 2. The ODE is solved using Runge Kutta approach and Eq. 4 is solved by a discretization based on central difference derivative replacement. The friction force which is the summation of asperity contact and lubricant friction is found according to the following relations.

$$\tau = Aq_a + (1 - A)q_f \tag{12}$$

where q_a and q_f denote the asperity contact and lubricant friction force.

4. Results and discussion

To validate the results of the present study, the friction stress of the lubricating surfaces are compared with Hajshirmohammadi *et. al.* The comparison is shown in Fig. 5

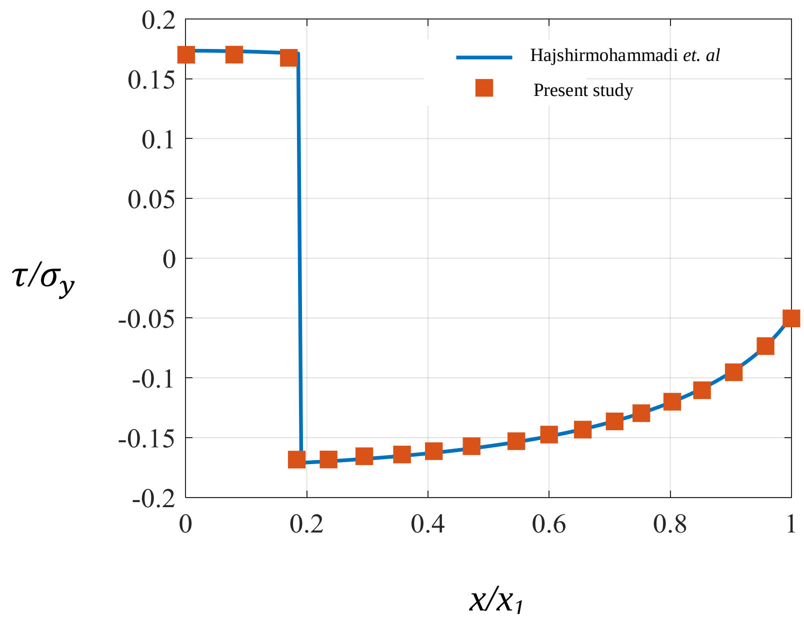

Figure 5. The non-dimensional shears tress on the strip and comparison with the reference [19]

The total friction force between the strip and rolls is calculated according to the following relation

$$F = \int_0^{x_1} \tau dx \tag{13}$$

Energy consumption of the rolling is the torque applied on the rolls time the angular velocity of rolls. The torque is friction force times roll radius ($T = FR$) and the angular velocity of rolls is the linear roll speed divided by its radius $\omega = \frac{u_r}{R}$. The amount of energy consumed to produce one-meter length of strip with unite width is:

$$E = \frac{F\omega}{u_{w1}} \tag{14}$$

To investigate oil content effect on the energy consumption, non-dimensional speed S is defined as follows.

$$S = \frac{r\alpha\eta_0(u_r + u_1)}{\sigma_0 R_q x_1} \tag{15}$$

Fig. 5 shows E value changing with oil content of emulsion in different speeds S.

The oil content varies from 1% to 100% (pure oil) in this figure.

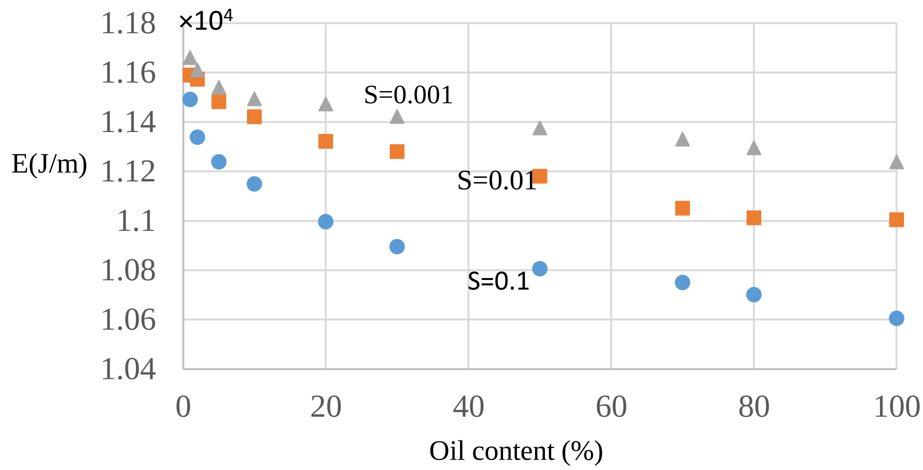

Fig. 6. Energy consumption per unite area of strip for cold rolling as a function of oil percentage for three different non-dimensional speed S=0.1, S=0.01 and S=0.001

It can be inferred from Fig. 5 that as the oil content of emulsion increases, the energy consumption per unite area of strip production reduces. Also production speed makes the manufacturing energy expenditure lower. This is understandable due to this fact that the oil content makes the lubrication easier. However; this reduction of energy consumption is more visible in low percentage of oil content and as the emulsion gets closer to pure oil, E value change is minor.

Table 1. rolling parameters used for simulation of cold rolling

Parameter	η_0 **(mm)**	α**(1/Pa)**	R**(mm)**	σ_y**(MPa)**	y_1**(mm)**	y_2**(mm)**
Value	0.02	6.2e-8	0.126	97.75	1	0.8

Conclusion

A model for cold trip lubrication of strips is used to evaluate the effect of emulsion properties on the energy consumption. This was found that increasing the oil content of emulsion as lubricant can make the production more cost-effective. In other hand, increasing speed can help reducing the energy needed for production.

Nomenclature

σ_y	yield stress	x	coordinate along the rolling direction
τ	Shear stress	x_1	Roll contact length
u_1	Strip speed in the inlet		
u_2	Strip speed in the outlet	y_2	Strip thickness in the outlet
u_w	work-piece inlet speed	y_1	Strip thickness in the inlet
u_r	roll speed	c	adhesion coefficient
p_f	Lubricant Pressure,	R	roll radius
p	interface pressure	η	(dynamic) viscosity of oil
ξ	Equivalent viscosity	s_2	forward tension
ϕ_x	Flow factor		
h	surface separation	S	non-dimensional roll speed

$$S = \frac{r\alpha\eta_0(u_r + u_{w1})}{\sigma_0 R_q x_1}$$

A	Contact ratio		
α	viscosity pressure coefficient	η_0	oil viscosity at ambient temperature.
q_a	Asperity shear stress	E	Elastic modulus
q_f	Lubricant shear stress		

References

[1] Y. Tian, Q. Zhu, and Y. J. E. P. Geng, "An analysis of energy-related greenhouse gas emissions in the Chinese iron and steel industry," vol. 56, pp. 352-361, 2013.

[2] Z. Guo and Z. J. E. Fu, "Current situation of energy consumption and measures taken for energy saving in the iron and steel industry in China," vol. 35, no. 11, pp. 4356-4360, 2010.

[3] S. N. R. Isfahani and A. Sedaghat, "A hybrid micro gas turbine and solid state fuel cell power plant with hydrogen production and CO2 capture," *International journal of Hydrogen Energy,* vol. 41, no. 22, pp. 9490-9499, 2016.

[4] Z.-w. Lu, J.-j. Cai, Q.-b. Yu, and A. J. A. M. S.-C. E.-. Xie, "The influences of materials flows in steel manufacturing process on its energy intensity," vol. 36, no. 4, pp. 370-378, 2000.

[5] S. Yan and S. Kuroda, "Lubrication with emulsion: first report, the extended Reynolds equation," *Wear,* vol. 206, no. 1-2, pp. 230-237, 1997.

[6] P. Kosasih and A. Tieu, "Mixed film lubrication of strip rolling using O/W emulsions," *Tribology International,* vol. 40, no. 5, pp. 709-716, 2007.

[7] T. Wu, D. Wagner, and D. J. I. J. o. F. Kirk, "Analysis of the plastic zone of a circle crack under very high cycle fatigue," vol. 93, pp. 415-421, 2016.

[8] B. Hajshirmohammadi, S. Amir, and E. J. T. T. Arshid, "Effect of Material Porosity on Thermal Analysis of Conical Shell," *Society of Tribologists and Lubrication Engineers,* no. just-accepted, pp. 1-34, 2018.

[9] B. Hajshirmohammadi and A. Ebrahimib, "Investigation on Helical Gears under Mixed-Lubrication Regime."

[10] M. Mehdizadeh, S. Akbarzadeh, K. Shams, and M. Khonsari, "Experimental investigation on the effect of operating conditions on the running-in behavior of lubricated elliptical contacts," *Tribology Letters,* vol. 59, no. 1, p. 6, 2015.

[11] M. Mehdizadeh, B. Hajshirmohammadi, A. Ghobadi, and M. Esfahanian, "Investigation of Foil Journal Bearing Performance by Generalized Differential Quadrature (GDQ) Method."

[12] H. Xie, K.-i. Manabe, T. Furushima, K. Tada, and Z. J. T. I. J. o. A. M. T. Jiang, "Lubrication characterisation analysis of stainless steel foil during micro rolling," vol. 82, no. 1-4, pp. 65-73, 2016.

[13] J. Krizek, P. Delrot, and C. Moser, "Laser-induced liquid micro-jets for needle-free injection into biological tissue (Conference Presentation)," in *Microfluidics, BioMEMS, and Medical Microsystems XVII*, 2019, vol. 10875: International Society for Optics and Photonics, p. 1087512.

[14] I. Tlili *et al.*, "Macroscopic modeling for convection of Hybrid nanofluid with magnetic effects," vol. 534, p. 122136, 2019.

[15] S. N. Roohani Isfahani, M. R. Salimpour, and E. Shirani, "Numerical study and sensitivity analysis on convective heat transfer enhancement in a heat pipe partially filled with porous material using LTE and LTNE methods," *Heat Transfer—Asian Research,* vol. 48, no. 8, pp. 4342-4353, 2019.

[16] A. Akbarzadeh, M. Mehdizadeh, S. Akbarzadeh, and K. Shams, "Effect of nanoparticles on the running-in behavior in lubricated point contact," *STLE, Dallas,* 2015.

[17] M. Mehdizadeh and S. Akbarzadeh, "Experimental investigation and a model to predict the steady-state friction coefficient in the lubricated contact," *STLE Vegas, USA,* 2016.

[18] D.-F. Chang, N. Marsault, and W. R. Wilson, "Lubrication of strip rolling in the low-speed mixed regime," *Tribology transactions,* vol. 39, no. 2, pp. 407-415, 1996.

[19] B. Hajshirmohammadi, M. R. Forouzan, and A. J. T. T. Heidari, "Effect of Interstand Tensions on Lubrication Regime in Cold Strip Rolling with O/W Emulsion," vol. 62, no. 4, pp. 548-556, 2019.