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A Combined Effect of Elasto-Plasto Hydrodynamic Lubrication in Cold Strip Rolling

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GJRE-A Classification :

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Nomenclature

p= pressure	N/m²
x= Dimension along arc of contact	m
μ= Viscosity of lubricant.	N.m/sec
μo= Base viscosity of lubricant at ambient temperature	N.m/sec
γ= Lubricant pressure coefficient of viscosity	
h= Film thickness	m
u1= Rolling speed	m/sec
u2= Strip velocity	m/sec
σ1= Back tension	N/mm²
σo= Front tension	N/mm²
σy= Yield stress of strip material	N/mm²
R= Roll radius	m
r= Reduction	
y1= Initial strip thickness	mm
τ= Shear stress at the surface	N/mm²
η= Coefficient of friction between roll surface and material	
k= Yield stress with initial speed	N/mm²
k1,ko= Yield stress with inhibited speed at inlet and outlet side	N/mm²
yo= Thickness of strip at exit	mm
yi= Thickness of strip at inlet	mm
α= Angular coordinates radius	

I. Introduction

In the lubrication of cold metal forming such as rolling drawing, and extrusion, lubricant films are entrained by wedge action in nominally steady processes. The pressure of the film thickness can vary from atmospheric to the order of yield stress of the work piece.

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In cold rolling as strip is reduced and elongated it changes speed relative to roll speed and must slide against the roll surfaces .The resultant friction produces forces ,which tend to retain the strip in the roll bite ,roll force and torque increasing with increase in friction. A decreases in (μ), the coefficient of friction, is thus desirable to reduce power consumption and roll loads and to obtain increased strip reduction. The latter is of particular importance in the rolling of thin plate where the high loads required because considerable roll flattening. This increases frictional forces until a point is reached at which no further reduction of the strip can occur. Further increase in load merely cause further roll flattening. If (μ) could be reduced by improved lubrication, the value of this limiting reduction would be increased enabling thinner strip to be rolled.

consequently the roll gap will increase during the rolling, as well as being increased slightly by the elastic roll-flattening already exist under very high loading and the mill "spring back", which is the deformation will be elastic-plastic of the mill, it is an important factor which must be taken into account when setting the roll gap for a given pass .Some reheological model was used by (Grubin and Vinogradova, [9] and Dowson and Higginson, [6] such as the ones used in elastohydrodynamic lubrication (Cheng, [4], (Wilson and Walowit, [13] in their plasto- hydrodynamic analysis of the strip rolling,(Aggarwal and Wilson,[1],[2] solved numerically the equations which includes the permissible velocity profiles against various relevant flow.Their results can provide neither the local variation of flow properties nor the global behavior in any real metal forming lubrication since the continuity equation has not been incorporated in their analysis. (Yuan and Chern, [14] developed a theoretical hydrodynamic lubrication analysis which takes account of temperature dependent viscosity variation along as well as across the film thickness. (Kuniaki and zhrgaug,[8] carried out a series of experiments using a rolling type tirbo meter to investigate the frictional dependence on the average velocity of the lubricant V at the contact zone inlet and the relative sliding velocity ΔV between the roll and the work piece during deformation .

In this research undertake to gain further knowledge of the mechanism of lubrication in the roll gap by taking a model of lubricant entrainment under very high pressure using E.H.L. theory with the effect of elasto-plastic behavior of metal rolling strip which

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prompted to develop an improved model. The theoretical results give good agreement when compared with an experimental one done by the previous workers.

II. Analysis

1. The Reynolds equation, which take into consideration, the isoviscous properties of the lubricant and the boundary conditions at the surfaces as derived by (Wilson and Aggarwal,1987):-

From equilibrium considerations the local velocity (u) is given by:-

$$u = \frac{1}{\mu}\left(\frac{z^2}{2}\frac{\partial p}{\partial x} - c_1 z + c_2\right) \text{..........(1)}$$

The values of c_1 and c_2 could be obtained by taking (z=0),(u=u_1) and(z=h),(u=u_2). Then eq. (1) becomes:-

$$u = u_1 + \frac{(u_2 - u_1)z}{h} + \frac{\partial p/\partial x}{2\mu}(z^2 - h^2)$$

............(2)

The volume flow rate per unit width (Q) is given by :-

$$Q = \int_0^h u\partial z \text{ ....(3)}$$

Substituting eq.(2) into (3) gives :-

$$\frac{h^3}{12}\mu\frac{dp}{dx} = \bar{u}.h - Q \text{ ....(4)}$$

Where:

$$\bar{u} = (u_1 + u_2)/2$$

$$\mu = \mu_0 e^{\gamma p}$$

2. The film thickness of the lubricant in eq.(4) can be represented as :

h total = h (elastic of the roller) + h (elastic-plastic deformation of the strip) ....(5)

h (elastic of the roller) could be delivered from E.H.L. theory :-

$$h_{elastic} = \frac{x^2}{2R} - \frac{1}{\pi E}\int p(s)\ln(x-s)^2.ds$$

.................(6)

note that in eq.(6) we have just the elastic deformation of one surface roller.

h (elastic-plastic deformation) could be obtained as :-

$$d\in ij = (d\in ij)_e + (d\in ij)_p \text{ ....(7)}$$

where

$$(d\in ij)_e = \frac{d\sigma_{ij}'}{2G} + \frac{(1-2\nu)}{E}\delta_{ij}d\sigma_{kk} \text{ ....(8)}$$

σij'=deviatric stress

G= modulus of rigidity

E= young modulus

ν =poisons ratio

δij dσkk= the component of mean stresses

Also the plastic strain is:-

$$(d\in ij)_p = d\lambda\frac{dQ}{d\sigma_{ij}} \text{ ....(9)}$$

Where

dλ=proportionality constant termed the plastic multiplier.

$\frac{\partial Q}{\partial\sigma_{ij}}$ = Plastic potential flow rate after yielding =σij\`

$$\therefore (d\in ij)_p = d\lambda\sigma_{ij}` \text{ ....(10)}$$

So that it can be seen that the total elastic-plastic strain for the strip is:

$$d\in ij = \frac{d\sigma_{ij}}{2G} + \frac{(1-2\nu)}{E}\delta_{ij}d\sigma_{kk} + d\lambda\sigma_{ij}'$$

..........(11)

Where

dεij = $\frac{\Delta h(i)}{hi}$ for the deformation of the strip.

Knowing that the value of dλ are variable for each element which is dependent on the strip flow rate Q and can be obtained as in the numerical method.

III. Theoretical Solution

1. assume the pressure distribution in the work zone as in (Bland and Ford,1948)

$$p^+ = \frac{k.y}{y_o}\left[1 - \frac{\sigma_o}{k_o}\right]e^{\eta.H} \text{ ....(12)}$$

$$P^- = \frac{k.y}{y_o}\left[1 - \frac{\sigma_i}{k_o}\right]e^{\eta.H} \text{ ....(13)}$$

Where η= the coefficient of friction between roll surface and Material.

2. Substitute the pressure distribution in the total film thickness equation h(total)
3. The values of h(i) and p(i) that obtained from steps(1) and (2) are substituted in eq.(4) and new values of u(i) and new position of (αn) .
4. The new values of h(i) are substituted in Reynolds equation to Finding a new pressure distribution p(i) in the work zone.
5. These new pressure values compared with the old

one so that the convergence criterion must be less than (.005).

$$\sum\left|p_{new}-p_{old}\right|/\sum p_{new}\le 0.005 \quad \text{..........(14)}$$

6. If the convergence criterion > 0.005 the new values of p(i) are Obtained from:

pnew(i) = wp(pnew(i) – pold(i)) + pold (i) ....(15)

Where WP: Relaxation factor.

7. These new values of p(i) are substituted in step (2) to find new values of film thickness.
8. Then we check the new value of p(i) at the edge of work zone with The yield stress of the material, if they are not equal then we take the new value of p(i) as :

p(i) = (p(i) – σy) /2 – pnew ....(16)

and then we return to step (2) to find new h(i).

IV. Numerical Method

The multilevel technique which have been used by (Lubrecht, Tennapel and Bosma, [10], (Conry and Cusano, [5], (Venner and Tennapel, [12] is used in solving this problem by dividing the work zone into 120 nodes with equal mesh size (Δ) where (Δ) = α(i+1) – αi .This mesh size is used in discretization of Reynolds equation.

The elastic film thickness is discredited as :

$$(hi)\ \text{elastic} = \left(\frac{xi^2}{2}\right)+\left(\frac{1}{\pi}\sum_{j=1}^{n}k_{ij}\cdot p_j\right) \quad \text{............(17)}$$

where:

k(i,j) = (i – j + 1/2)Δ(ln| i – j + ½ Δ) – 1 – (i – j – ½)Δ(ln|i – j – 1/2|.Δ) – 1)

Mixed hardening

To cope with the directional change of friction at the neutral point (or region), the relative velocity Δ v of the roll to the strip (see Fig.1) is approximated by:

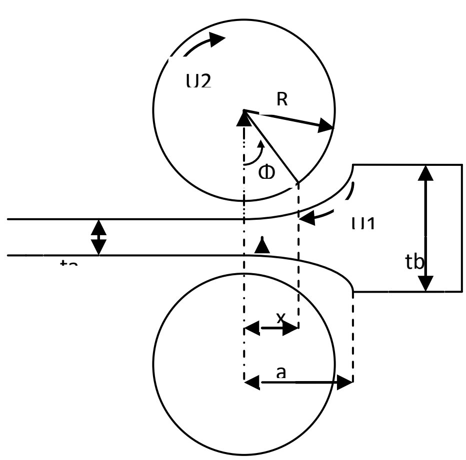

fig (1) : shows the strip rolling with lubrication

$$\Delta v=\sqrt{\left(\frac{1}{2}[(U_h)^2+(V_h)^2+(U_{h+1})^2+(V_{h+1})^2]\right)}$$

$$U_h = u_h + R\omega\sin\alpha_h$$

$$V_h = v_h - R\omega\cos\alpha_h$$

$$U_{h+1} = u_{h+1} + R\omega\sin\alpha_{h+1}$$

$$V_{h+1} = v_{h+1} - R\omega\cos\alpha_{h+1}$$

so that the direction of the frictional shear stress need not prescribed , because the relative velocity Δv is always positive over the roll surface and the position of the neutral point (or region) is determined as a result of minimization of the functional.

The hardening behavior of most materials seems to be a combination of both isotropic and kinematics type of hardening .Sanda c.t,[11] used in his paper the effect of mixed hardening results in a modification of the yield surface which is written as :

$$f(\sigma_{ij}-\sigma_{ij}^{b})-\sigma_y(\kappa)=0 \quad \text{..........(18)}$$

The terms and dk are respectively obtained by assuming a kinematics hardening law.

For eq(11) it can be immediately written as :

$$d\in=[D]^{-1}.d\sigma+d\lambda\frac{df}{d\sigma} \quad \text{...............(19)}$$

where D is the usual matrix of elastic constants

$$d\lambda=\frac{1}{[A+a^T D_a]}a^T dD.d\in \quad \text{.....................(20)}$$

$$a^T=\frac{df}{d\sigma_{ij}}=\left[\frac{\partial f}{\partial\sigma_x}\ \frac{\partial f}{\partial\sigma_y}\ \frac{\partial f}{\partial\sigma_z}\ \frac{\partial f}{\partial\tau_{yz}}\ \frac{\partial f}{\partial\tau_{zx}}\ \frac{\partial f}{\partial\tau_{xy}}\right]$$

,A=H which is the hardness function of the strip material.

V. Results and Discussion

In Fig.(3-a) shows the distribution of the pressure along the contact zone for (14%) percent reduction of steel strip using oil H (see table 1), v = 1.64 m/s , h = 5.75 mm, R = 0.14 m, t/σ1 = 0.024.In this figure there will be a comparison between theoretical and experimental result (done by Dow ,Kannel , and Bupava, 1975) which show some agreement between them . The elastic strain of the elasto-plastic material causes in the entering a decrease in the pressure and the stresses can be felt downstream a distance related to the relaxation time of the material and the velocity Δv while in the next region in the work zone before reaching the neutral point the value of Δv will be decreased and the plastic deformation begin causes very high pressure and the elastic deformation of the roller which introduced in the E.H.L. equations gives the fluctuating of the pressure in this zone . After the neutral point to the exit region the pressure will be dropped to some value and then returned to increase and this is because Δv will be increased also causes the elastic part of the metal strip decreases the pressure roll.

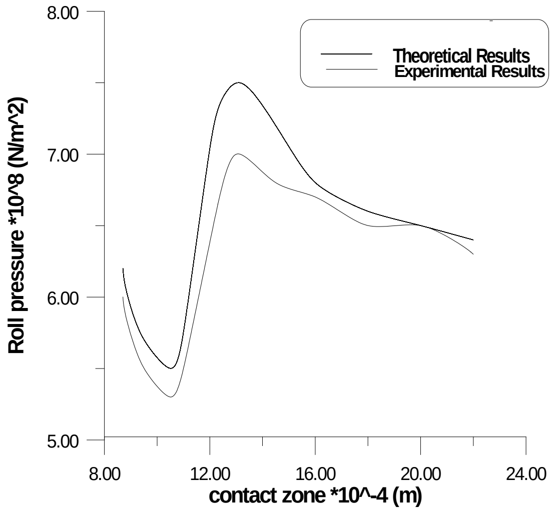

Fig.(3-a) Theoretical and experimental pressure distribution for 14 percent reduction of steel strip using oil H , V=1.64 m/s, R=.14m

In Fig (3-b) shows the variation of film thickness along the contact zone. In the region between(8-11)* m the film thickness increased with decreasing in the pressure then it full very rabidly with increasing the pressure and then increased after the neutral point and then decreases.

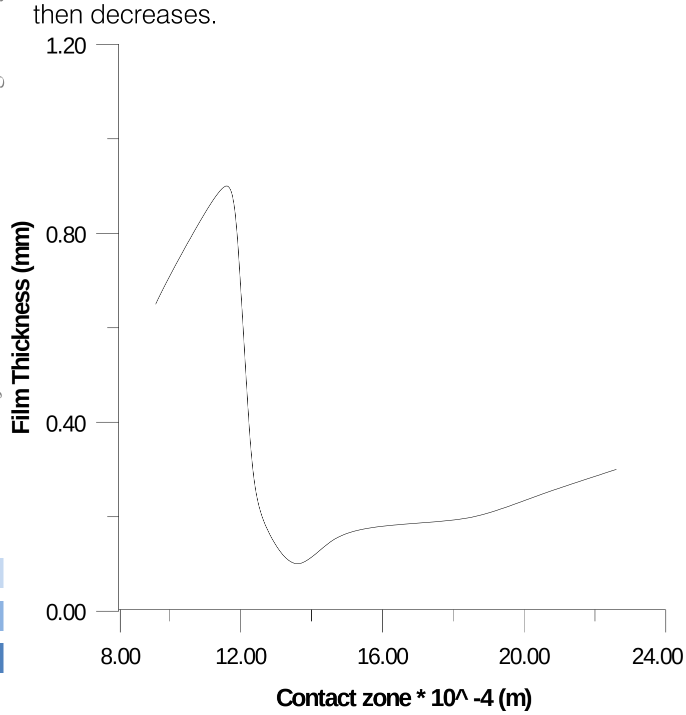

Fig. (3-b) Variation of film thickness with contact zone

The agreement between the practical and theoretical results is more pronounced in Fig .(4-a) which could be shown that at high reduction (30 percent) of steel strip by using oil c give a decrease in the pressure at point (30* m) and a sudden increases in the film thickness as shown in Fig (4-b) . This mean that at high reduction the using of elasto-plastic model with E.H.L. condition affect the pressure distribution and give more accurate results.

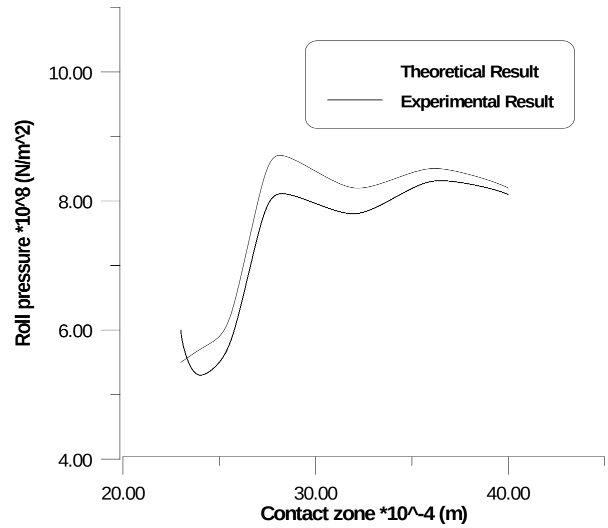

Fig.(4-a) Theoretical and experimental pressure distribution for 30 percent reduction of steel strip using oil C , V=1.65 m/s, R=.3m

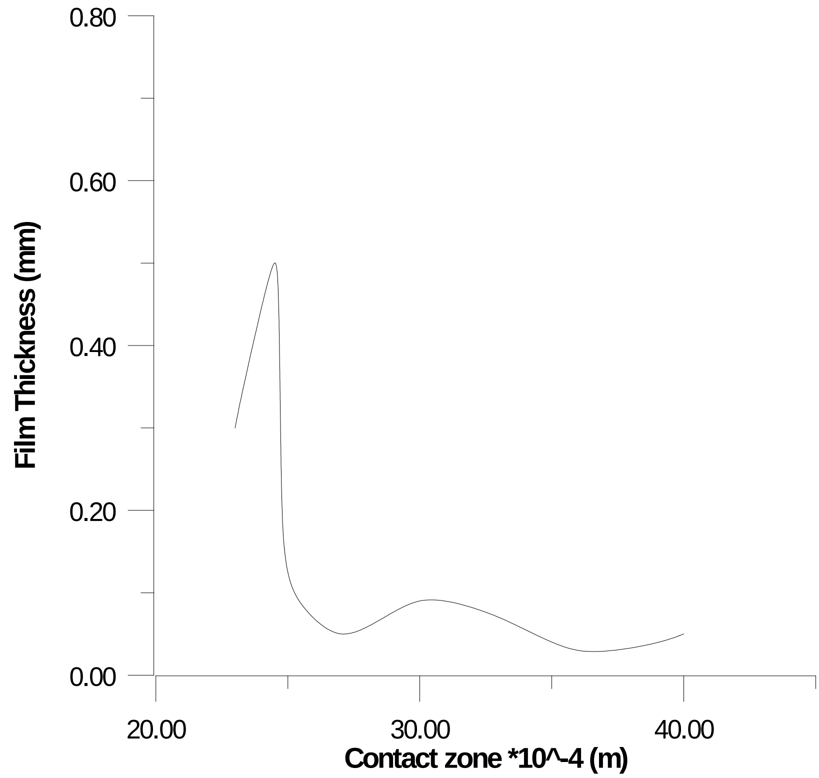

Fig (4-b) Variation of film thickness with contact zone.

In Fig.(5) it shows the relationship between the coefficient of friction and the speed of rolling at high reduction (30 percent) by using oil H and C. The coefficient of friction decreases with increasing the roll speed for values between 17-19 m/min and then will increased. This is because the effect of the relative speed on the pressure distribution and then on the viscosity of the lubricant in the contact zone.

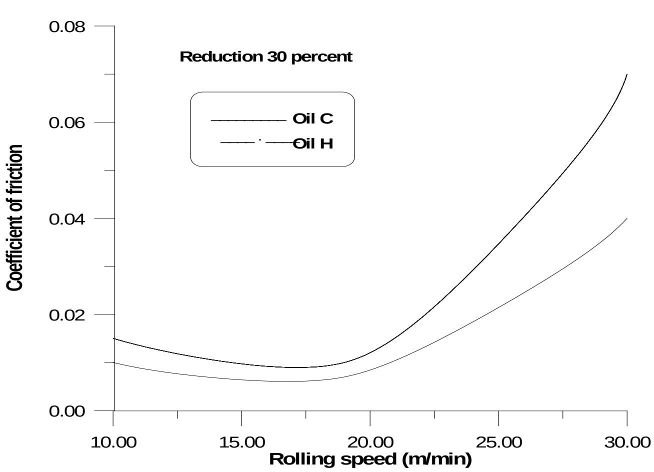

Fig (5) relationship between coefficient of friction and the Rolling speed.

VI. Conclusions

1. The aim of this research is to used the E.H.D lubrication with plastohydrodynamic of cold sheet rolling for determining the effect of lubrication on the pressure distribution and film thickness along the contacts zone .
2. The varaiation of the relative velocity Δv that have been calculated along the contact region give the position of the neutral point which variuas with the percent reduction of the strip and the viscosity of the oil .
3. The results shows that for heavy viscosity and low percent reduction of strip , the pressure distribution and film thickness along the contact region will be agreement with an experimental one for plasto-hydrodynamic lubrication while for high reduction and low viscosity the mixed theory of E.H.L and plasto-hydrodynamic lubrication be more accurate .
4. The effect of speed of the roller with lubricant on the coefficient of friction and then on the critical shear stress under plastic deformation of the strip have been investigated .

References Références Referencias

1. Aggarwal, B.B and Wilson, W.R.D.,(1980) “Improved thermal Reynolds equations” Proc. Leeds- Lyon symp. On Tribology , inst.Mech.Engrs. pp.152-161
2. Aggarwal, B.B and Wilson, W.R.D, (1987) “ Thermal effects in hydro-dynamically lubricated strip rolling” Proc. .Leeds-lyon symp. On Tribology , Inst.Mech.Engr.pp.351-359
3. Bland, D.R. and Hug Ford, (1948) “ The calculation of Roll force and torque in cold strip rolling with tensions” Proc.Inst.Mech.engrs.159.
4. Cheng .H.s.,(1966) “ Plastohy-drodynamic

lubrication " , friction and lubrication in processing , ASME, NEWYORK.

5. Conry and Cusano, (1992) "Numerical method in the effect of an E.H.L. line contact " J. of Tribology , vol.114, pp.616.
6. Dowson and Higginson , (1976) "Elastohydrodynamic Lubrication ", Pergamon, Oxford.
7. Dow.T.A. Kannel, J.W. and Bupara.S.S., (1975) "A hydrodynamic lubrication theory for strip rolling including thermal effect" ASME journal of lubrication Technology, Vol.97 , pp.4-13
8. Dohda kuniaki , Wang zhrgang (1998) " Effects of average lubricant velocity and sliding velocity on friction behavior in mild steel sheet forming" , Journal of Tribology , Vol .120,pp724.
9. Grubin ,A.N. and Vinogradova ,I.E., (1949)"Investigation of the contact of machine components" TSNITMASH (Moscow), 30 (DSIR, London,Transl.337)
10. Lubrecht, Tennaple and Bosma, (1991) "Numerical simulation of the overall rolling of a surface feature in an E.H.L., line contact".J. of Tribology, Vol.113,pp777.
11. Sanda cleja-Tigoiu , (2002) "Small elastic strains in finite elasto-plastic materials with continuously distributed dislocations ", J.of.Theoretical and applied mechanics , vol. 28-29, pp.93-112.Belgrade.
12. 12- Venner and tennapel, (1990) " Advanced multilevel solution of the E.H.L. line contact problem " J of Tribology , Vol.112 , PP.426
13. Wilson, W.R.D. and Walwit, J.A, (1971) "An isothermal hydrodynamic lubrication theory for strip rolling with front and back tension " , In Tribology convection , I.Mech.E.London, pp.169-172.
14. Yuan. k and Chern.B.c (1990) " A thermal hydrodynamic lubrication analysis for entrained film thickness in cold strip rolling "Journal of tribology vol 112.pp.128.

Fig (2) table (1) properties of lubricants

Lubricant	Type of lubrication	Base viscosity (C.P.)	Temperature (1/K)	Coefficient of viscosity
C	Anaphthenic industrial oil fully formulated	93	0.0625	2.9
B	Heavy viscosity Anaphthenic industrial oil fully formulated	3738	0.107	2.5