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ANLYSIS OF HYDRODYNAMIC FLUID LUBRICATION IN STRIP DRAWING PROCESS

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ABSTRACT

The main theme of this paper is a study of the theoretical film thickness which could be developed under representative practical drawing condition this quantity gives a good indication of the potential of the system for hydrodynamic lubrication action when compared with the surface quality of die and strip. We also include the effect of changing the work material, lubricant viscosity, and pressure coefficient of viscosity on the pressure, shear stress and temperature of die, lubricant film and strip. The process consists of strip passing through die of conical shape. The lubricant film introduced during the process completely separates the die from work piece material. The film can be divided into three regions, inlet zone, working zone and outlet zone in which consideration is taken for working zone as well as outlet zone for effect of viscosity on fluid in case of lubrication thickness.

KEYWORDS: working zone ,viscosity, film thickness.

INTRODUCTION

An Analysis of Work Zone

In this chapter we discusses mathematically various parameter such as pressure shear stress, film thickness and temperature of lubricant, die and strip. Finally give the suitable formula for different parameter on the basis of this formula author determines the variation of different parameter in work zone and outlet zone.

The following assumptions are used.

a) The lubricant flow is a two-dimensional and steady laminar flow.

b) Lubricant is an in compressible Newtonian liquid having viscosity η that depends upon the local pressure P and temperature θ as

$\eta = \eta_i \exp(\alpha P - \delta \theta)$ (i)

η_i - Viscosity at $P = 0$ $\theta = 0^o$ C

α- Pressure coefficient of viscosity

α- Pressure coefficient of viscosity

δ- Temperature coefficient of viscosity

No slipping of lubricant takes place on the die and work piece surfaces. The change of P and η across the film thickness are disregarded and the average values are used.

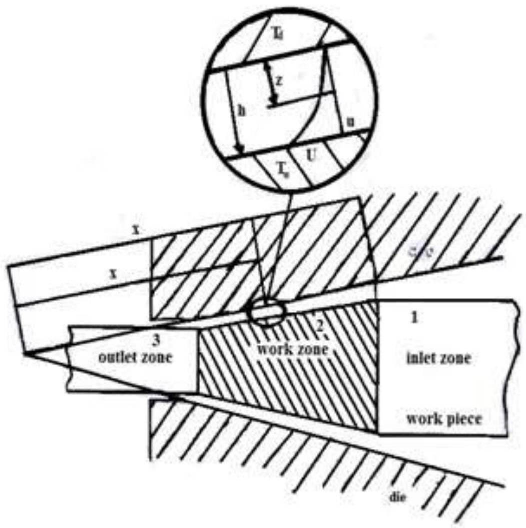

Fig. 1 Strip Drawing Process

At the initial point of work zone means
$h = h_m$

$$\frac{dP}{dx} = 0$$

P= σ' y

The surface temperature θ_d and θ_s of die and work piece in the inlet zone equal the room temperature.

The heat conduction is one dimensional along the direction in the die and lubricant film and in the work zone that the die temperature at a distances much larger than h from die surface equals θ_i.

In this region the strip is reduced as it passes through the die and it will be assumed that a thin but coherent film of lubricant separates the solids. The lubricant is subjected to high pressures and shear rates and hence it is necessary to pay some attention to the thermal situation.

If it is assumed that the heat produced by plastic deformation of the metal is retained within the strip, the surface temperature at any point where the strip given as:

$$\bar{\theta}_s = \frac{\theta_s}{\theta_i} = 1 + \frac{\sigma_y{}'}{pc\theta_i} In\left(\frac{t_i}{t}\right) \ldots\ldots\ldots (ii)$$

Where σ'y(t_i / t) represents the work done per unit volume during the plastic deformation at constant flow stress σ' y. If convection and adiabatic compression terms are neglected and conduction across the film is assumed to be the dominant mode of heat transfer in the lubricant, the energy equation reduces to:

$$\theta_m = \frac{1}{h}\int_0^h \theta \; dz = \frac{\theta_s + \theta_d}{2} + \frac{\eta u^2}{12k_1} \ldots\ldots.. (iii)$$

and

$$\overline{\theta_m} = \left(\frac{\overline{\theta_s} + \overline{\theta_d}}{2}\right) = \frac{\eta U^2}{12k_1\theta_i} \ldots\ldots\ldots\ldots (iv)$$

A simple linear heat flow analysis will be employed to estimate the die surface temperature. It will be assumed that the die temperature returns to the inlet temperature at some distance Z from the oil-die interface. The condition to be satisfied at the interface is that

$$k_1\left(\frac{d\theta}{dz}\right)_{z=h} = k_d\left(\frac{d\theta}{dz}\right)_{z=h} = \frac{-k_d(\theta_d-\theta_i)}{Z}$$

…….(v)

When equation (xi) is differentiated and the result introduced into equation (v) it is found that

$$\theta_d = \frac{1+\frac{Z}{h}\left(\frac{k_1}{k_d}\right)\overline{\theta_s}+\frac{\eta U^2}{2k_1\theta_i}\left(\frac{k_1}{k_d}\right)\frac{Z}{h}}{1+\frac{Z}{h}\left(\frac{k_1}{k_d}\right)} \text{ ………(vi)}$$

In the expressions (xi), (iv) and (vi) for lubricant and die surface temperatures U represents the strip surface velocity and conservation of matter requires that this velocity should be related to the strip velocity at inlet (drawing speed) by the simple relationship

$$U = \left(\frac{t_i}{t}\right)U_i \text{……..(vii)}$$

It has been argued that Couette action is the dominant flow mechanism in the lubricant film in region 2 and since the surface velocity increases as the strip gets thinner the film thickness also reduces according to the equation

$$h_2 = \left(\frac{t}{t_i}\right)h_{m1} \text{………(A)}$$

Hence

$$\frac{dp}{dx} = \frac{1}{t}\left[\frac{\eta_i U_i {t_i}^2}{h_i}\left(\frac{\bar{\eta}}{{t_2}^2}\right) + \sigma'_y \tan\beta\right] \text{….(viii)}$$

Equation (A) enables the film thickness variation in the region of plastic deformation to be determined and step-by-step numerical integration of equation (viii) allows the pressure distribution to be calculated. The initial pressure at entry to region 2 is, of course, the yield value σ'_y but evaluation of the pressure gradient form equation (viii) must be based upon an iterative procedure since the mean lubricant viscosity at any station is a function of temperature as well as pressure.

Once the hydrodynamic pressure profile has been established the normal stress in the strip can be calculated form equation (xiii) and the surface tractions are given by equation (xvi). The strip, lubricant and die temperatures are calculated form equations (ii), (xi) and (vi).

The final pressure distribution can be integrated to provide force components parallel and perpendicular to the drawing direction and the tangential surface stress can be integrated to give the viscous force in work zone.

$$k_1 = \frac{d^2\theta}{dz^2} = -\eta\left(\frac{du}{dz}\right)^2 \text{……… (ix)}$$

The thermal conductivity of the lubricant may be a function of process but it will be assumed to be constant in the present analysis. The lubricant viscosity is a function of pressure and temperature and the simple isothermal expression employed in region 1 is abandoned in flavor of

$$\eta = \eta_i \exp(\alpha P - \delta\theta)$$

Since the pressure and viscosity in region 2 is very high and the pressure gradients relatively small the Poiseuille flow term is not expected to cause an appreciable perturbation to the linear velocity distribution across the film.

Hence

$$\frac{du}{dz} \approx \frac{U}{h} \ldots\ldots\ldots(x)$$

When this approximation is introduced into equation (ix) and the following boundary conditions are introduced:

$\theta = \theta_s$, z=0

$\theta = \theta_s$, z=h

A double integration enables the temperature distribution across the film to be written as

$$\theta = \theta_s + \frac{\eta U^2}{2k_1}\bar{z}(1-\bar{z}) - \bar{z}(\theta_s - \theta_d) \ldots(xi)$$

where the variation of viscosity across the film is neglected and the effective η is calculated at the mean film temperature θ_m.

Equilibrium of an element of the strip in the region of plastic deformation requires that

$$\frac{d}{dx}(t\sigma_x) + \rho \tan\beta + \tau = 0 \ldots\ldots\ldots(xii)$$

The normal stress σ_x and the hydrodynamic pressure P are related by the following yield criterion

$$\sigma_x + P = \sigma'_y \quad \ldots\ldots\ldots(xiii)$$

where

$$\sigma'_y = \frac{2}{\sqrt{3}}\sigma_y \ldots(xiv)$$

Now dt/dx = tan β and hence when the yield criterion (xiii) is introduced into equation (xii) it is clear that

$$\frac{dp}{dx} = \frac{1}{t}\left(\tau + \sigma'_y \tan\beta\right) \ldots\ldots\ldots(xv)$$

If the pressure gradient in region 2 is small the high viscosity of the lubricant permits

the viscous shear stress acting on the strip to be written in the following simple form.

$$\tau = \frac{\eta U_2}{h} = \frac{\eta_i U_i}{h}\left(\frac{t_i}{t_2}\right)\bar{\eta} = \frac{\eta_i U_i}{h_i}\left(\frac{t_i}{t_2}\right)^2 \bar{\eta} \ldots(xvi)$$

where $\bar{\eta} = \eta/\eta_i$.

AN ANALYSIS OF OUTLET ZONE

In this region the strip remains plastic but almost constant thickness with a uniform oil film separating it from the die. The strip surface temperature as given by equation (ii) is constant and the mean lubricant and die surface temperatures calculated from equation (xi) and (vi) are almost constant.

The pressure in the lubricant is calculated from the simplified form of equation (viii) which results when tan β is equated to zero.

To understand the implications of the theoretical analysis of the previous section a number of sample calculations have been made. These have been aimed at showing the dependence of the lubricant film generation, pressure, shear stress and temperature on yield stress of different work materials.

Table 1: Different work piece materials which we have taken from ASM Hand book on Metal forming is given below:
The situations considered in these calculations are presented in Tabular form.

Quantity	**Value**
β degree	5
α m^2/NT	1.7 x 10^{-8}
x_i m	5.08 x 10^{-8}
U m/sec	25.4
η_iP	0.47
2t_i m	3.175 x 10^{-3}
ρ Kg/m^3	7861.12
k_l (Joule/ m.sec. ^{o}C)	0.14
k_d(Joule/ m.sec. ^{o}C)	24.998
Z m	1.27 x 10^{-2}
θ_i^{o}C	40
L m	3.175 x 10^{-3}
C (Joule/ kg. ^{o}C)	272.389

η_2 =0.145 Pascal – Sec.
η_3=0.27 Pascal – Sec.
η_4=0.47 Pascal – Sec.

The dependence of the lubricant film, pressure, shear stress and temperature on the pressure coefficient of viscosities of different lubricants which have been taken is given below:

α_1 = 1.45 x 10^{-8}/Pascal
α_2 = 1.7 x 10^{-8}/Pascal
α_3 = 2.2 x 10^{-8}/Pascal
α_4 = 1.595 x 10^{-8}/Pascal
α_5 = 1.9 x 10^{-8}/Pascal

Flow diagrams which help us to define a procedure one step at a time, and arrange it in logical sequence are given in Fig.4.1 and Fig.

SAE No.	C %	Mn %	Yield Stress (N/m^2)	Types of Processing
1040	0.37 – 0.44	0.6 – 0.9	4.895 x 10^8	Cold drawn
1041	0.36 – 0.44	0.9 – 1.2	5.998 x 10^8	Cold drawn
1046	0.43 – 1.0	0.7 – 1.0	5.446 x 10^8	Cold drawn
1049	0.46 – 0.53	0.6 – 0.9	5.619 x 10^8	Cold drawn
1050	0.48 – 0.55	0.6 – 0.9	5.792 x 10^8	Cold drawn

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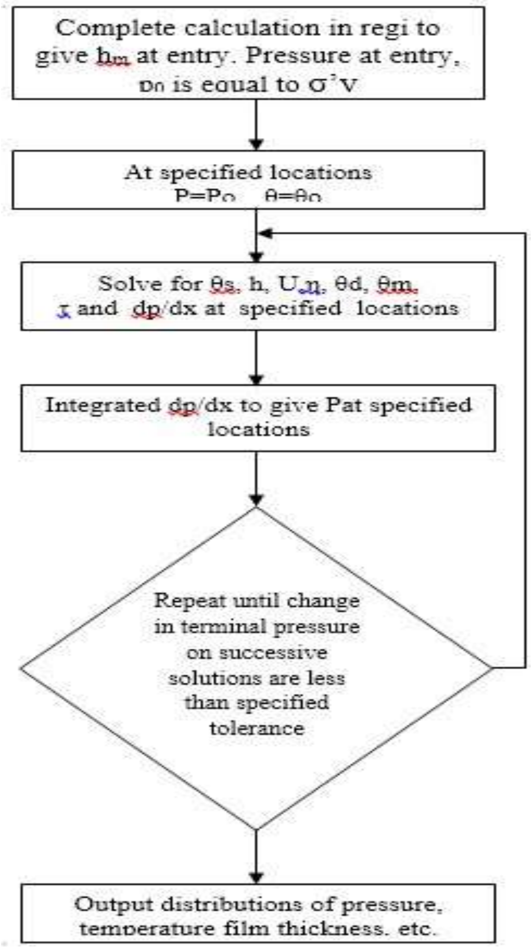

Fig. Flow diagram for work zone (Region 2)

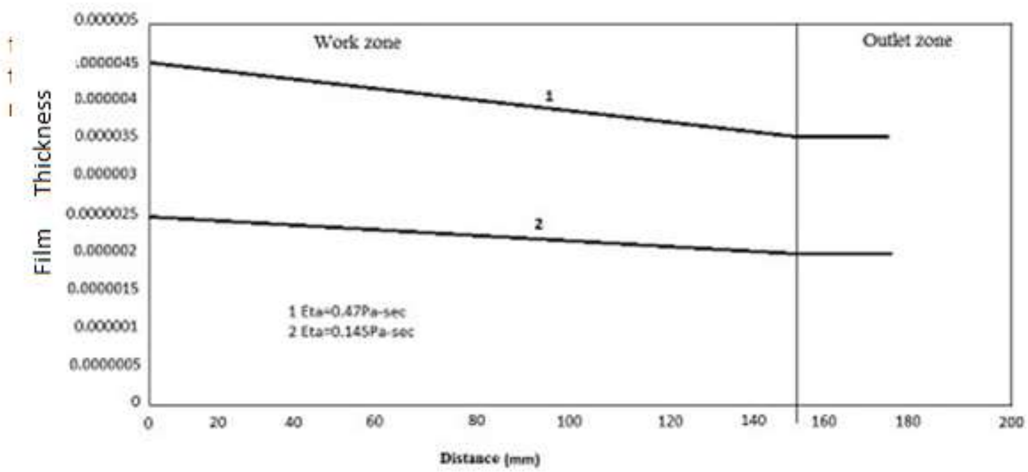

Fig 1 Variation of film thickness vs Distance

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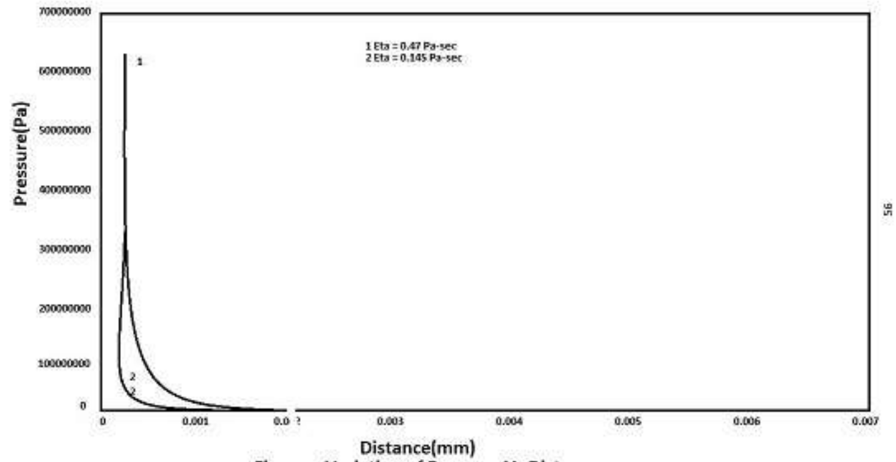

Fig. 2 Variation of Pressure Vs Distance

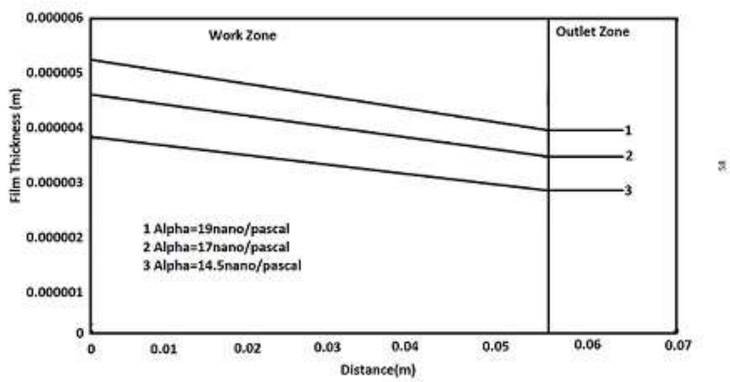

Fig. 4 Variation of film thickness vs distance

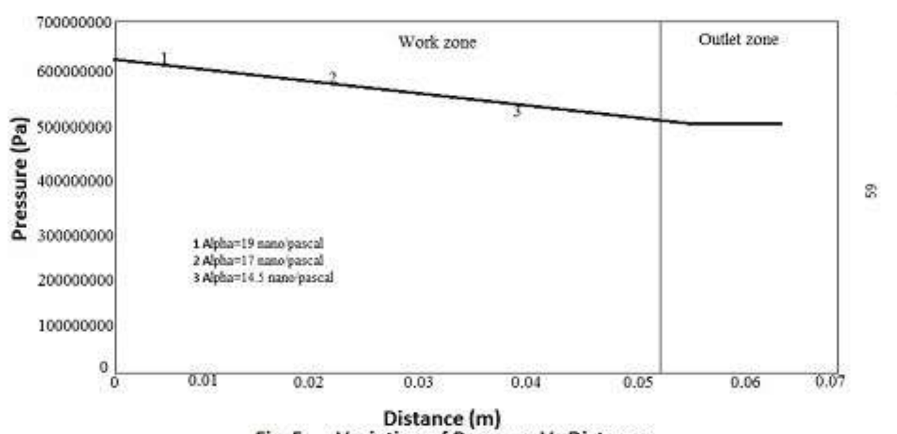

Fig. 5 Variation of Pressure Vs Distance

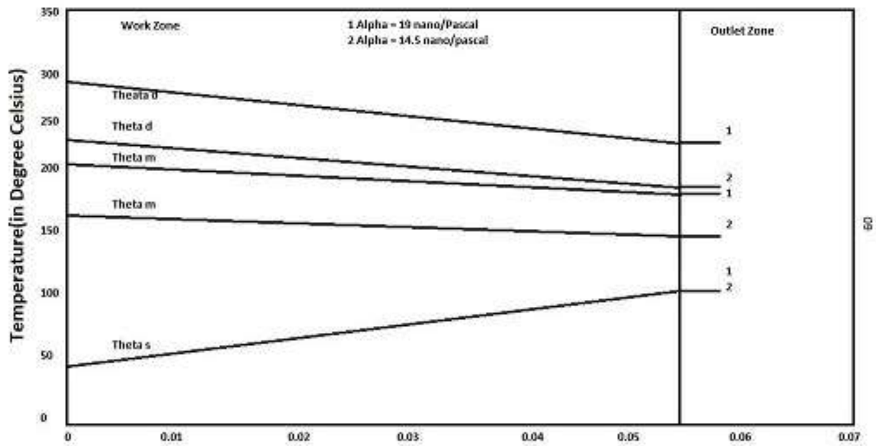

Fig. 6 Variation of Temperature Vs Distance

RESULTS AND DISCUSSION

Results obtained for strip drawing of steel (yield stress $\sigma_y = 5.516 \times 10^8$ N/m^2, density $\rho = 7861.12$ Kg/m^3 and specific heat C = 272.389 Jule/Kg ºC) are summarized in table 5.1 and other results obtained are shown graphically.

For different value of coefficient of viscosity the variation of film thickness is shown in Fig.1 from graph, it shows that for higher value of coefficient of viscosity, film thickness becomes more. Pressure variation with different coefficient of viscosity is shown in Fig. 2. Temperature variation with different coefficient of viscosity is shown in Fig.3, from graph, it shows that temperature of die and lubricant film for low coefficient of viscosity is minimum.

Different value of pressure coefficient of viscosity, film thickness variation shown in Fig. 4 for higher value pressure coefficient of viscosity (α) film thickness higher. Pressure variation with different value of α is shown in Fig. 5. It shows that pressure does not depend on value of α. For work zone and outlet zone pressure variation is shown in Fig. 4.

Temperature variation with different value of α is shown in Fig. 5. This shows that strip temperature does not depend on α. It depends only on work material due to same work material for different value of α graph coincides.

CONCLUSIONS

From this present work following conclusions are drawn:
1. Effective hydrodynamic pressure generation is restricted to a very small portion of the inlet region.
2. In the zone of plastic deformation the film thickness decreases steadily in proportion to the reduction in strip thickness.
3. Predicted film thickness suggests that hydrodynamic action might be important under many modern drawing conditions.
4. Film thickness is more for low yield stress work material in comparison to high yield stress work material.
5. Film thickness comes out to be more highly viscous lubricant in comparison to low viscous lubricant.
6. Viscous heating effect is more than heating due to strip deformation in case of highly viscous oil.
7. Film pressure decays relatively slowly through the plastic zones.

NOTATION

A_0-A_7 Viscosity equation constant

C Specific heat of strip

E Modules of elasticity

h	lubricant film thickness
h_m	Constant in integrated Reynolds equation
h^*	Film thickness at entry to plastic zone based upon rigid-plastic analysis
k_d	Thermal conductivity of die material
k_1	Thermal conductivity of lubricant
L	Length of land
P	Pressure
Q	Volume rate of flow of lubricant per unit width
q	Reduced pressure
2t	Strip thickness at entry to die
U	Strip velocity
u	Velocity of lubricant film

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