Observation of Interface for Tribology During Precise Metal Forming

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Abstract
The interface between surface asperities and lubricant is of prime importance in metal working tribology.The micro contact between tool and work piece helps in understanding the behaviour at the interface especially in precise metal forming. The micro contact mechanism falls into three categories boundary, mixed, hydrodynamic based on film thickness average value. Researchers have found out variation in coefficient of friction with increase in speed during sheet drawing. Sometimes new lubrication regime are developed which depends upon coefficient of friction and deformation speed. In this paper the micro contact behaviour at the tool work piece interface is discussed along with observation apparatus. An attempt has been made in establishing model for micro contact behaviour along with future research potential .

Keywords
MPHL – Micro Plasto Hydrodynamic Lubrication, Tribology, Coefficient of Friction, Hydrodynamic and Micro Contact Behaviour

I. Introduction

Tribology is the science of friction, wear and lubrication and plays a very important role in case of precise metal forming operations .The natural phenomenon out of it are friction and wear whereas lubrication is an old phenomenon which is practiced by human civilisation from quite a long time. Tribololgy is derived from Greek word "tribos" which means rubbing and "logy" which means knowledge. The Knowledge of rubbing is termed as tribology. Here in these paper dependencies of coefficient of friction on speed which was established by researcher is observed and micro contact behaviour as observed by a researcher between tool and the work piece with lubrication is discussed.
Kudo et al (1976) have observed increased coefficient of friction with increased speed in sheet metal drawing on a aluminium specimen .Mizuno (1978) proposed the micro plasto hydrodynamic lubrication mechanism .Azushima (1990) observed the lubricant behaviour at the interface directly between tool and the work piece by a newly developed sheet metal drawing apparatus.

A. Observation of Interface During Sheet Metal Forming

Kudo et al (1976) have observed increase in coefficient of friction with increase in speed in sheet metal drawing operation [3]. The experiment was conducted with aluminium with a expected surface roughness of R_{max} of 2 to 3 μm in a drawing speed range of 10^{-3} m/s

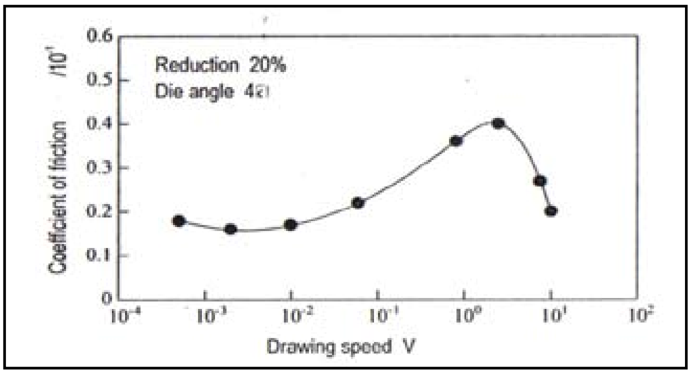

Fig. 1: Effect of Drawing Speed on Coefficient of Friction in Sheet Drawing Experiments of Aluminium With an Etched Rough Surface Using Oil Having Viscosity 1800 Centistokes

In order to prove this they introduced MPHL (micro plasto hydrodynamic lubrication) proposed by mizuno et al (1978) in which lubricant trapped permeates into area of contact and a thin hydrodynamic film of order of 0.1 μm is formed [1].

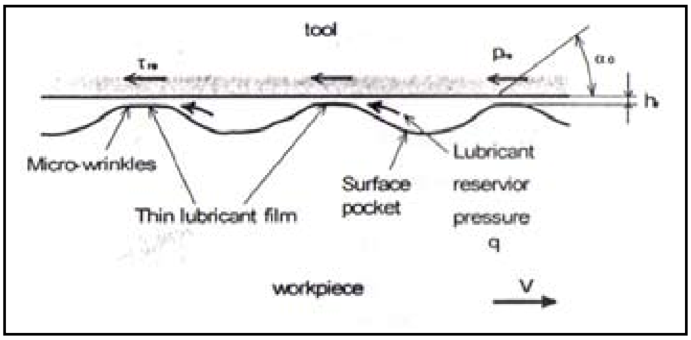

Fig. 2: Model of MPHL Lubrication Mechanism

To establish dynamic model Azushima et al (1990) observed this behaviour in a newly developed sheet metal drawing apparatus [1].

1. Apparatus for Observation

It consists of a pair of die halves one made of tool steel and other made up of quartz .It also have one microscope, CCD camera and a video system. A hydraulic actuator presses the specimen sheet into die halves .Vertical hydraulic actuator develops a load up to 5000 N and horizontal hydraulic actuator develops a load up to 1000 N. It generates maximum drawing speed of 1000 mm/sec over a range of 1000 mm [5].
The die angle is 3o and thickness of quartz die is 20 mm. The strain gauge load cell measures the drawing load for assessment of coefficient of friction. Magnification of image is done by microscope and a lamp is used for illumination. Overall magnification of CCD is x60 [4].

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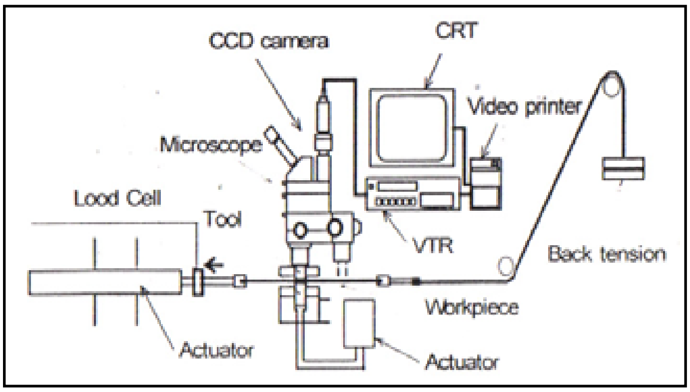

Fig. 3: Schematic Representation of the Apparatus for Sheet Metal Forming

II. Observation of Micro Plastic Hydrodynamic Lubrication

A1100 aluminium work piece is used. It is 2mm thick 10 mm wide 500 mm long with Vickers hardness 24.4. Work piece sheets are provided with uniformly distributed pyramidal indentation .Distance between these indentations is 2mm at an angle of 160o .The length of one side square of indentation is 0.63 mm and depth is about .056 mm.The specimen sheet is drawn at a speed of 0 .8 mm/sec with lubricant of various viscosities [2].

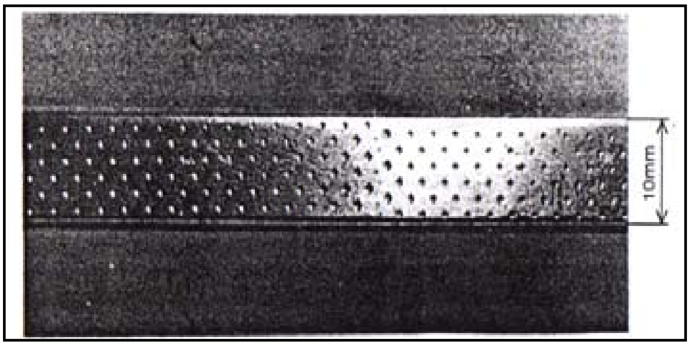

Fig. 4: Surface of Aluminium Sheet With Uniformly Distributed Indentations

The following figure shows the sequential image of working area taken during drawing reduction up to 9.7 % with a lubricant having viscosity 100 centistokes.

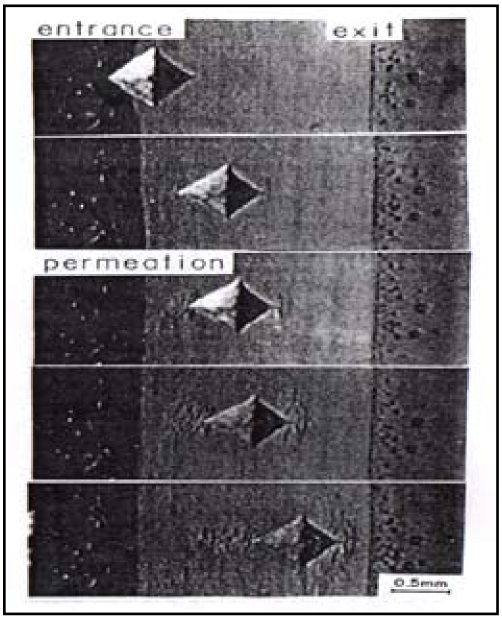

Fig. 5: Permeation Behaviour of the Lubricant

The following figure shows sequential image taken during drawing reduction 9.2% with a lubricant viscosity 1000 centistokes. The figure shows lubricant being squeezed out from oil pockets and permeation of lubricant trapped in surface pocket is evident.

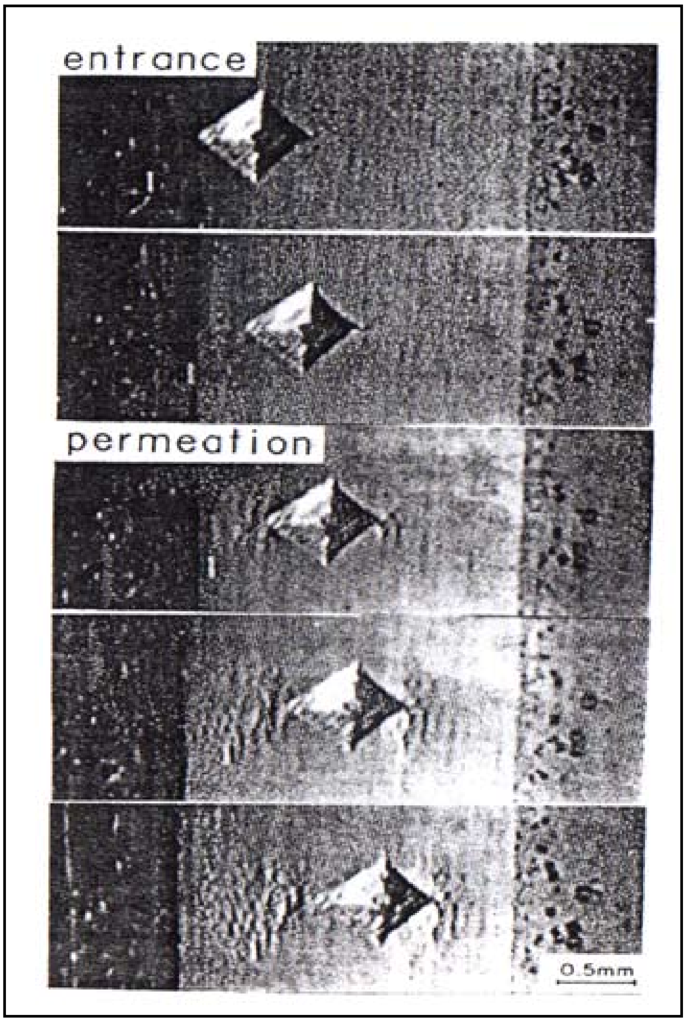

Fig. 6: Permeation Behaviour of the Lubricant for Above Mentioned Case

According to viscosity the lubricant it permeates backward and forward in the figure 1.5 .It is observed that the amount of lubricant permeating forward is greater than amount of lubricant permeating backward. In the figure 1.6 more lubricant is seen to be permeating backwards.

So, direction of permeation depends upon viscosity of lubricant.

III. Mechanism of Micro –PHL

The permeation of lubricant was shown in the enlarged fig. 5 and fig. 6. Now a two dimensional model for the same is shown in the below mentioned figure. The lubricant pressure is q and there is a marked volume reduction of the pyramidal indentation. q becomes close to $p_{re}(x)$ on real contact area when the work piece undergoes bulk deformation. Moreover it is expected that pressure p_d will rise due to hydrodynamic effects depending upon product of lubricant viscosity η and drawing speed V [4].

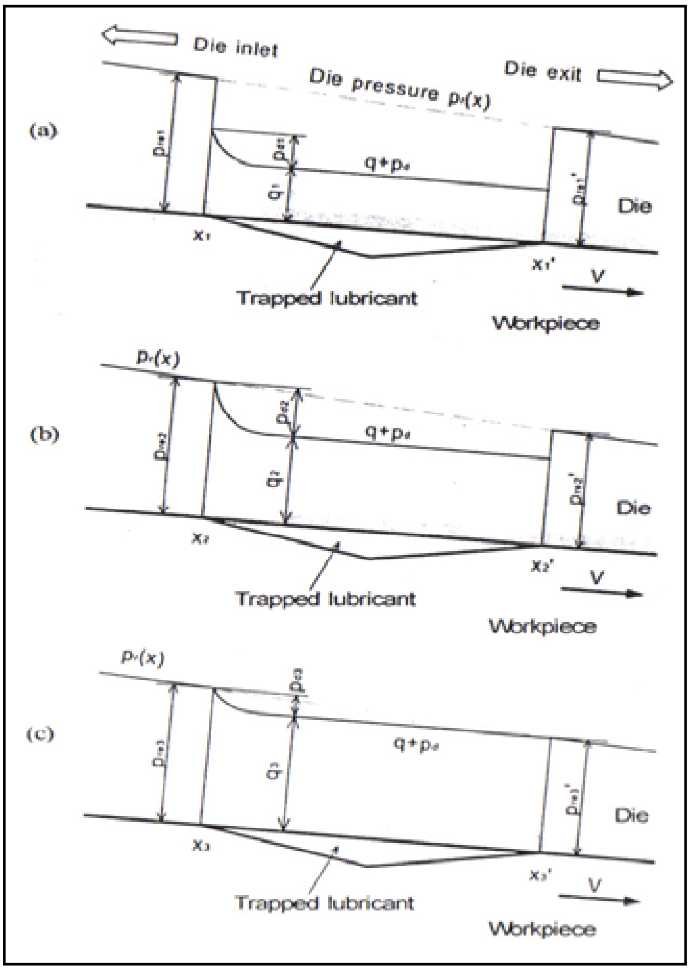

Fig. 7: Models for Lubricant Permeation Into Real Contact Area (a) No Permeation (b) Backward Permeation (c) Backward And Forward Permeation

At the entrance point of the working area general relationship between $p_{re}(x)$, q and p_d is shown. The hydrodynamic pressure is derived p_d is derived by Reynolds's equation. $p_{re}(x)$ decreases towards the die exit but lubricant pressure increases from the die entrance towards die exit. $q_2 + p_{d2}$ will reach p_{r2} at the back edge of the pocket as shown in fig. 7(b) .High ηV results in backward permeation of trapped lubricant. This model confirms with experimental observation and results. In fig. 7(c) q_3 will reach p_{re3} resulting in backward and forward permeation at front edge of pocket.

When drawing speed or lubricant viscosity is low q will reach p're first at the front edge of the pocket resulting in forward permeation. It happens before q $+p_d$ reaches back edge .When pockets moves towards die exit q reaches p_{re} $+p_d$ at back edge of the pocket resulting in forward and backward permeation.

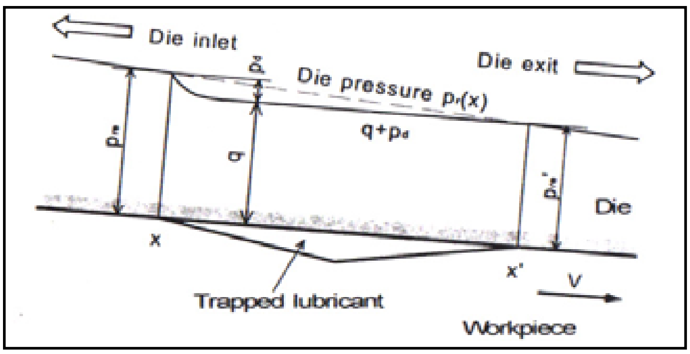

Fig. 8: Model of Forward Permeation of Trapped Lubricant in Pocket

IV. Coefficient of Friction and Process Parameters Under MPHL (Azushima and Uda 1991)

It has been discussed that coefficient of friction increases with increasing Drawing speed [3]. This will be interpreted in terms of lubricant that permeates from surface pocket into real contact area.

In order to measure the current volume of lubricant permeated from surface pocket the sheet metal drawing apparatus from figure 1.3 is used. There was a significant change in volume of pyramidal indentation .The dimension and area of pyramidal indentation was measured in a CRT and a image processor. The volume and geometrical changes of pyramidal indentation was used to predict the amount of lubricant that permeated from the surface pocket .The drawing experiment is carried out at a drawing speed of 0.13, 0.65 and 1.48 mm/s with thickness reduction up to 25 % .The lubricant used is same as in previous case .

To measure the volume of lubricant permeated from the pyramidal indentation area of it under CRT photograph is measured. The fig. 9 shows the open area ratio and thickness reduction of sheet drawing [7].

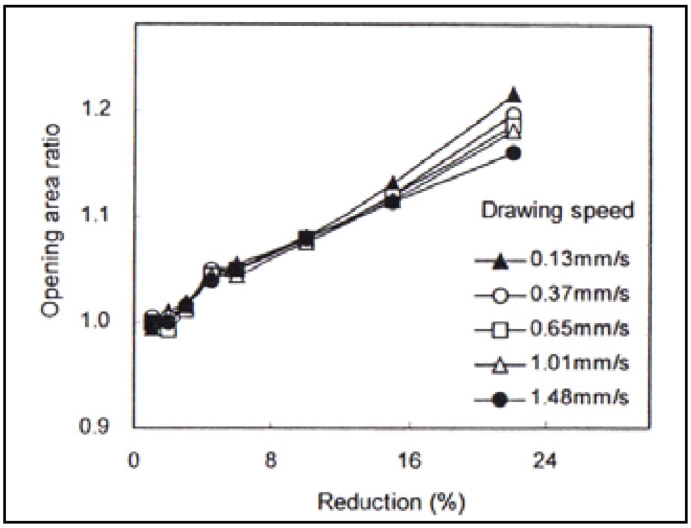

Fig. 9: Relationship Between Open Area Ratio of Pyramidal Indentation and Thickness Reduction Percentage for Various Drawing Speeds

At first the open area ratio decreases with increase in percentage reduction but when percentage reduction increases to 4 % then oper area ratio increases with increase in percent reduction in thickness .With increase in drawing speed the open area ratio of insulator decreases slightly.

To estimate the coefficient of friction between tool and work piece under micro-PHL an attempt was made to calculate the mean oil film thickness over real contact area using estimated value of lubricant that permeate from pyramidal indentation .In order to calculate volume following three factors were taken into account .

- Volume shrinkage and volume indentation of trapped lubricant under hydrostatic pressure and bulk yield of work piece material.
- Volume shrinkage of indentation caused by lubricant permeation.
- Elongation of longitudinal dimension of open area corresponding to % thickness reduction .It takes place without change in geometry.

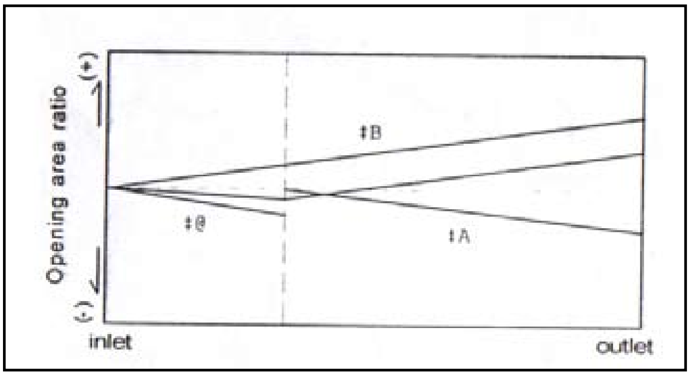

Fig. 10: Change of Opening Area Ratio of Pyramidal Indentation in Working Area

To calculate mean film thickness divide the estimated volume of permeated lubricant to real contact area. From figure 1.9 the volume of lubricant that corresponds to 15% reduction is 0.0006 mm^3 at a drawing speed of 0.13 mm/s and 0.00012 mm3 at 1.4 mm/s resulting in a mean film thickness of 0.14 μm and 0.29 μm respectively .By increasing drawing speed ten folds mean oil film thickness increases only two fold .The value of mean film thickness is obtained by surface roughness experiment .

By applying Navier stokes equation for two dimensional isothermal hydrodynamic lubrication, the mean coefficient of friction for a lubricant with viscosity η at mean sliding speed of V_m is given by

$$\mu_m = \eta \frac{V_m A_r}{h_m p_m A_a} \quad (1)$$

Where p_m is the mean pressure on apparent area of contact. A_r is the mean contact area. A_a is the apparent contact area. h_m the mean film thickness does not increase as much with increase in V_m.

The μ value obtained by this equation is poor in comparison with those obtained by Ruan,kudo,et al (1987) .This suggest that thermal effects have to be considered along with the non Newtonian property of lubricant and sub microscopic lubricant in real contact area and this requires modification in present micro-PHL mechanism.

V. Future Research Potential

The mechanism of micro plasto hydrodynamic lubrication has been investigated by various research workers. In order to have clear understanding of the interface a lot of research work is needed some of the factors which required further investigation includes

- The thermal effects which mean the temperature rise and fall affecting the whole micro plasto hydrodynamic lubrication mechanism.
- The non Newtonian properties of lubricant
- Effect of sub microscopic lubricant in real contact area
- Whether atomic scale friction force is exhibiting periodicity or not.
- Whether maxima in the interatomic forces occur in the normal or lateral direction.
- Usage of AFM atomic force microscope to check the atomic bonding and inter atomic forces at nano level
- Usage of friction force microscope FFM to map chemical variations.
- Apparatus for measuring indentation hardness and modulus of elasticity in micro scale studies.

Thus, these points must be considered when micro plasto hydrodynamic lubrication is considered at nano level in precise metal forming .

V. Conclusion

This paper showed by the means of photographs the permeation behaviour of lubricant in the case of micro plasto hydrodynamic lubrication. This paper also showed that coefficient of friction increased with drawing speed. The micro contact behaviour of the tool and work piece was also shown along with the mechanism, of micro plasto hydrodynamic lubrication.

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