EFFECT OF SURFACE ROUGHNESS FOR WORKPIECE AND TAPER DIE ON FULL ELASTO HYDRODYNAMIC LUBRICATION (FEHL) IN ALUMINUM COLD DIRECT EXTRUSION WITH MAXIMUM REDUCTION

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Abstract

To reduce friction effects in extrusion process, the contact surfaces must be separated by lubricant film .One of the technique is FEHL, in which the oil film produces from plastic and elastic deformation for workpiece and die respectively along working zone, and this process happens if the extrusion speed equals or greater than critical speed. The surface roughness for workpiece and die in extrusion process represent significant parameters on this technique. So that it must be limited a range in which FEHL is commences. In present work the range of surface roughness degrees are estimated in direct extrusion of 1060.1 aluminum alloy by using taper die made from alloy steel with maximum extrusion ratio (Ao /Ai) equals to 2.77. Calculations of plastic deformation in billet of aluminum at each point along working zone are done by using a numerical modeling of hydrodynamic lubrication. This modeling is based on finite difference method, and that leads to find out the distribution of pressure along forming zone distance, and new variation of film thickness.

Keywords:

Elasto-hydrodynamic lubrication, cold extrusion, numerical analysis**.**

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Introduction

The behavior of friction after the onset of hydrodynamic lubrication is the combined results of several counteracting factors. First, with increasing speed the increase in film thickness of the lubricant dampens the rise in shear strain rate within the liquid. Also, the temperature of the liquid rises causing a reduction in the viscosity of the lubricant. Altogether, these effects moderate the rise in film thickness and in shear stress within the liquid. Second, friction itself is the sum of friction value caused by internal shear in the film of the lubricant and by the residue of metal to metal contact of the asperity tips on the workpiece and the die. With increase in speed, shear in the liquid rises moderately while fewer and fewer contacts are made between the workpiece and the die to cause lowering of their contribution to friction value. Thus, the effect of increasing speed is a moderate increase in film thickness.

Critical Speed

When the ram speed equal to or greater than critical speed, full elasto-hydrodynamic lubrication occurs, so that it is limited for different degrees of average surface roughness for die and workpiece .In full elasto-hydrodynamic lubrication, oil film thickness (h) must be greater than summation of average surface roughness for workpiece and die at each section along working zone (i.e. h > (Ra for die +Ra for w.p.)). In present work the critical speed is estimated for three degrees of surface roughness for die and workpiece and it is written in

table. 1:

Table 1: Average surface roughness for workpiece and extrusion die (micron).

Ra for die (Ra_d)	Ra for billet (Ra_b)	$\sum(Ra_d+Ra_b)$	RT tot.	Case No.
0.3	0.75	1.05	4.2	1
0.4	0.8	1.2	4.8	2
0.5	0.85	1.35	5.4	3

Analysis of Plastic Deformation

At the beginning of the die, the workpiece is under elastic deformation and the lubricant film has a thickness equal to the workpiece die clearance. Near to the entry of the work zone the pressure in the lubricant film is built up and the film thickness equals to (hs) and it is estimated by iteration from equation (1)[1]:

$$hs = \frac{\left(1-e^{-\alpha\sigma o}\right)e^{-\alpha q}hs^3}{3\eta_o \alpha xs U1\left[1-\left(\frac{xs^2}{xi^2}\right)\right]} + \frac{2hs}{\left(1+\frac{xs}{xi}\right)} \quad (1)$$

The initial value of the pressure q is determined with equation (2), considering only the work represented by the uniform deformation. [1]

$$q = 2\sigma_o \ln\left(D1/D2\right) \qquad (2)$$

Then the workpiece is plastically deformed in along working zone from the diameter D_1 to D_2, and the film thickness (h) is successively reduced in its convergent flow to the die apex o. The film thickness at the exit of working zone will define the lubrication regime in the work zone. To calculate the pressure and the film thickness in the working zone, some considerations are assumed and it's found in ref. [2] to get the following equation:

$$\frac{dp}{dD} = \frac{-2kA}{D}\left(\varepsilon_1 + 2\ln\frac{D1}{D}\right)^{k-1} + \frac{2}{D}\left[\frac{A\begin{pmatrix}\varepsilon_1 + \\ 2\ln\frac{D1}{D}\end{pmatrix}^k + \frac{\eta_o\left(\alpha p - b\Delta\theta\right)}{h}}{U1\left(\frac{D1}{D}\right)^2 \frac{\cos^2\beta}{\sin\beta}}\right] \qquad (3)$$

Where:

ε_1=True strain in the entry of region II,[2]→ $\varepsilon_1 = \frac{1}{2}\left(\frac{\beta}{\sin\beta^2} - \cot\beta\right)$

$\Delta\theta$ =Increment of the lubricant temp.

Equation (3) is a first order ordinary differential equation that can be solved with the fourth order Runge-Kutta method; hence the variation of pressure with respect to the variation of diameter is a function of pressure and diameter only.

The initial boundary condition to iteration is defined by the pressure in the lubricant at the entry of working zone:

$$p = q + A\varepsilon_1^k - \left(\frac{A\varepsilon_1^{k+1}}{k+1}\right) \qquad (4)$$

The programming of equation (3) for taper is solved with the following parameters in table.2:

Table 2.Parameters for workpiece, dies, and oil used

workpiece Aluminum 1060.1	Dies	5050 Circulating. oil
σo=30 Mpa $\sigma y = A\varepsilon^k$ A=88.95Mpa K=0.234	tool steel alloy(x32crMoCov 333)	(N.s/m^2)$\eta_{o=}$ 1.09
D1=24.7 mm; axial length of billet=40mm	D_1=25 (mm) D_2=15 (mm)	α=18e-9 (pa^{-1})
C=896 (J/kg. c°) ρ =2707 (kg/m^3) Kw=204 (w/m c°)	β =21.037 *(pi/180) (rad) Nd=0.3 Kd=51.9 (w/m c°)	b=0.015 (°C^{-1}) kl=0.17 (w/m c°)

Note: The variables c, kW, kd, and kl are used to find the increment of lubricant temperature ($\Delta\theta$) when the average temperature of the film (θ_m) at any position x can be calculated considering the adiabatic heating of the workpiece and the heat transfer by conduction to the die and to the lubricant. [2]

Analysis of Elastic Deformation

ANSYS program is used to find the elastic deformation for die when o pressure of oil acts on working zone profile. This process requires determination of some basic information, like the type of elements used, geometrical and material properties, and the analysis options used to obtain the solution.

After applying the ANSYS solution procedure to find the values of elastic deformation that occurs in die due to pressure supply, these values are added to values of film thickness of lubricant which are produced by plastic deformation of workpiece (solve equation (3) numerically), and that leads to new values of film thickness and then new pressure values are estimated from equation (3) again , so that the ANSYS program is repeated to calculate new values of elastic deformation according to these new pressure distribution to find new film thickness distribution in working zone , then new pressure values and this case continues until the results of film thickness reach steady state condition (with accepted error). Figure 2, shows the distribution of deformation in y direction (elastic deformation) for taper die after the above iteration.

The Variables

First: This study is done for four types of initial extrusion speed 1.5mm/s,2mm/s,7.5mm/s and 10mm/s respectively.

Second:

Change of RT for surface of billet and die (4.2, 4.8, 5.2 micron).

The Solution:

1- Finding out the values of elastic deformation for die due to oil pressure that calculated from analysis of plastic deformation (as written above),this process is repeated with each value of initial extrusion speed and these values are represented in the following equation:

$$\delta 1= -2132.4X^5 +135.124X^4-3.45681X^3 +0.0255411X^2-4.20202E-5X+4.99793E-6$$

$\delta2=-2117.1179X^5+136.473X^4-3.40425\,X^3+0.027518\,X^2-4.00826E\text{-}5X+5.2899E\text{-}6$

$\delta3=-2046.118X^5+137.083\,X^4-3.26805\,X^3+0.03176X^2-3.770209E\text{-}5X+5.7326E\text{-}6$

$\delta4=-1546.534X^5+166.0411X^4-2.32611X^3+0.04198X^2-2.37785E\text{-}5X+9.0686E\text{-}6$

Note: δ1 for 1.5 mm/s: δ2 for 2 mm/s: δ3 for 7.5 mm/s: δ4 for 10 mm/s.

2- The plastic deformation in billet of aluminum at each point along working zone is calculated as discussed in item of analysis of plastic deformation above ($h_{p)}$.

3-The values of RT is subtracted from summation of film thickness for workpiece (plastic deformation (h_p)) and die (elastic deformation (δ)) to calculate net of oil film thickness h_{net}.

4- We are found from distribution of h_{net} along working zone and for all initial extrusion speed that the minimum values of h_{net} are happened at end of the die as illustrated in figures(3), and it increases with speed increase within average smaller than average of film thickness at beginning of the die. That means the activity of hydrodynamic lubrication action is increased with increase of extrusion speed. So that critical speed is estimated according to h_{net} at end of the die for all initial extrusion speed.

From figure (3) too, the effectiveness of elastic deformation on net film thickness behavior along working zone will decrease by increasing of extrusion speed, because the increments of plastic deformation will be greater than of it in elastic deformation.

5- To limit effect of initial extrusion speed on film thickness values at the end of the die (he), the values of h_{net} at the end of the die for each four curves are used as illustrate in fig.(4).

The values of he is increased with initial speed increased according to third order equation ,and the value of critical speed on which the value of he equals to zero is estimated .(Ucr=0.66 mm/s).

The above procedure for different values of RT (4.8, and 5.2 micron) is repeated to find out the critical speeds values for each values of surface roughness (Ucr=0.94 mm/s and 1 mm/s for RT=4.8 and RT=5.2 micron respectively). The values of RT versus Ucr are drawn to find equation of critical speed as a function of RT as shown in fig. (5).

The Conclusion

Net oil film thickness along working zone separates between workpiece and die surfaces due to elasto-hydrodynamic lubrication action and it dependents on magnitudes of average surface roughness for each surface (RT total). The significant of magnitude of RT total on critical speed changes with non uniform behavior, (i.e. when RT is small, any change of it will cause high increment in required of critical speed, but when RT is large the average of this increment will decrease).

References

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Nomenclature

Symbol	Meaning	Units
A	Mechanical strength coefficient	MPa
b	Temperature constant	1/c°
D	Local workpiece diameter	mm
D1,D2	Diameter of the workpiece at entry and exit respectevely	mm
h	Lubricant film thickness	micron
hs	Film thickness at entry to plastic zone.	micron
he or e	Film thickness at exit of the forming zone	micron
K	Strain hardening coefficient	Dim.less
c	Specific heat	J/kgc°
L	Length of dies profile	mm
p	Oil pressure	MPa
q	Pressure in the extrusion champer	MPa
U1	Initial speed	mm/sec
Ucr	Critical speed	mm/sec
X	Die axial distance	mm
Xs	Axial distance in which plastic flow begins	mm
α	Pressure constant	m^2/N
β	Semi die angle	Rad.
ηo	Viscosity with pressure equal to 0.1 Mpa	Pa.s
Nw	Poisson’s ratio for workpiece material	Dim.less
Nd	Poisson’s ratio for die material	Dim.less
ρ	Density of the workpiece material	Kg/m^3
σo	Yield stress of the workpiece material in uniaxial tension test	MPa
ε_1	True strain in the entry of region II	Dim.less
Kw	Thermal conductivity of workpiece	w/mc°
kd	Thermal conductivity of extrusion die	w/mc°
kl	Thermal conductivity of lubricant used	w/mc°
σy	Flow stress	Mpa
η	Viscosity of lubricant	Pa.s

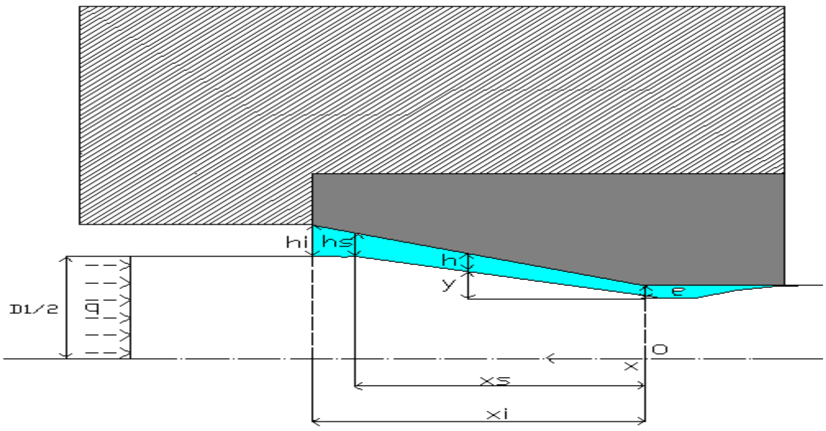

Fig. 1. Details of oil film shape for taper die[1]

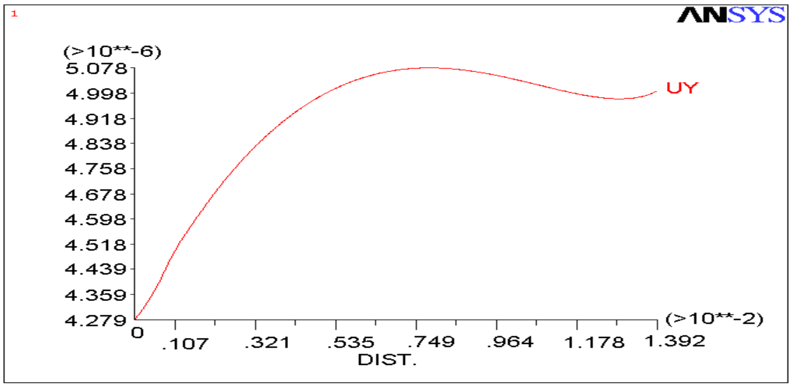

Fig.2.a.Elastic deformation along path of working zone .

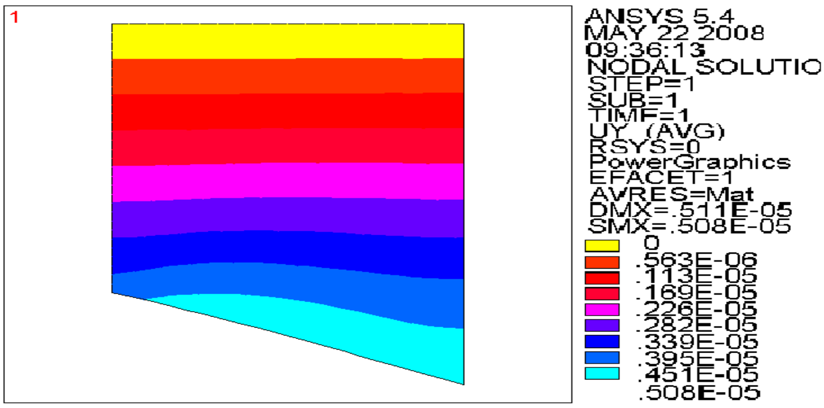

Fig. 2.b.Elastic deformation of extrusion taper die

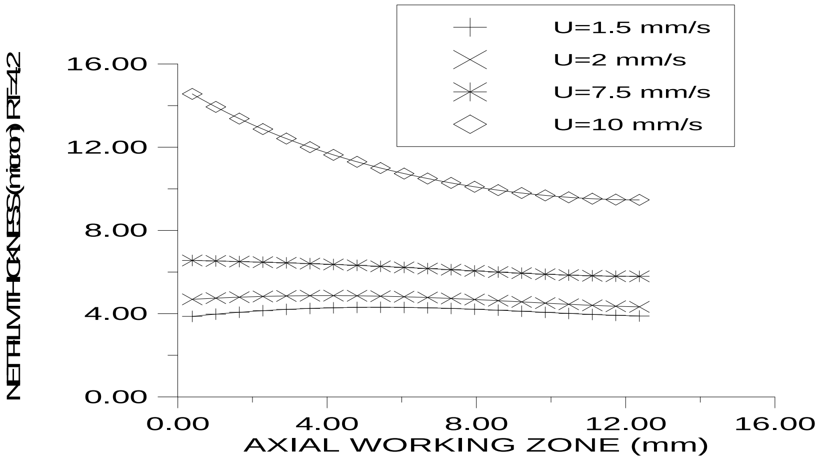

Fig.3.Net film thickness along working zone

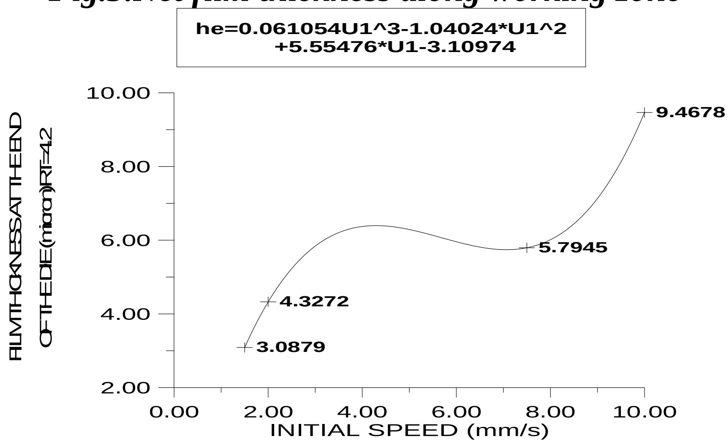

Fig.4.End film thickness versus initial extrusion speed

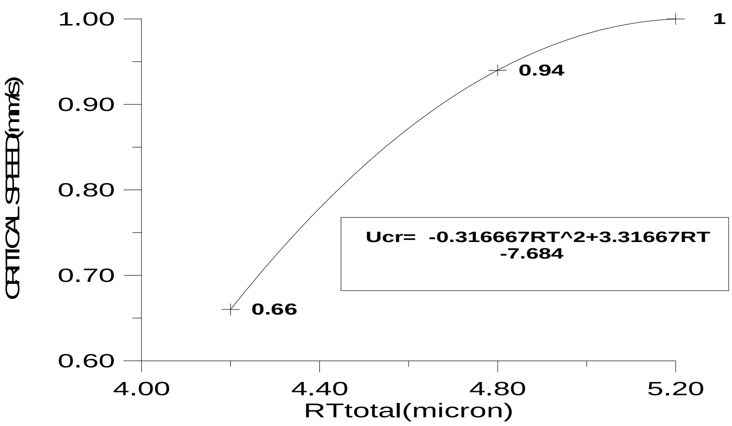

Fig.4.Critical speed as a function of RT

تأثير الخشونة السطحية للشغلة والقالب على التزييت الهيدروداينميكي المرن في عملية البثق على البارد للالمنيوم تحت اعلى نسبة تخفيض

لتقليل تأثير الاحتكاك في عملية البثق ،الاسطح المتلامسة يجب ان تفصلها طبقة من الـ يت ويلجأ التقنيات التي تحقق ذلك هي تحقيق التـ ييت الهيـ روداينميكي المرن حيث ان طبقة الـ يت تنشأ فيه من التشـ ه اللـ ن والمرن لكل من الشـ لة والقالب على التـ الي وعلى طـ ل ممر التشكيل وهذة العملية تحـ ث اذا كانت سرعة البثق تساوي او اكبر من قيمة السرعة الحرجة. الخشـ نة السطحية لكل من الشـ لة والقالب في عملية البثق تعتبر من العـ امل المهمة على هذه التقنية لذا يجب تحـ يـ مـ ى الخشـ نة السطحية التي يتحقق فيها التـ ييت الهيـ روداينميكي المرن. هذا البحث مـ ى الخشـ نة السطحية حسبت لعملية بثق سبيكة الالمنيـ م ٦٠٠ باستخـ قالب مائل مصنـ ع من الفـ لاذ السبائكي يحقق اعلى نسبة تخفيض (Ao /Ai=2.77) حسبت. التشـ ة اللـ ن لعينة الالمنيـ م المبثـ ق في كل نقطة على طـ ل ممر التشكيل تنجـ باستخـ ام عرض عـ دي للتـ ييت الهيـ روداينميكي وهذا العرض مستند على طريقة الفروقات المحـ دة التي تلاكتشداف تـ زيع ضـ ط الـ يت على طـ ل ممر التشكيل وبالتالي معرفة التوزيع الجـ يـ لسمك طبقة الـ يت.