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Friction in Metal Forming Processes

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ABSTRACT

Friction is a guessing game in spite of advances in the science of tribology. Still it is an important factor to be controlled to get good surface finish, reduce forces and increase formability. Friction factor 'm' is more convenient in metal forming rather than friction coefficient 'μ'. Latter decreases inversely with interface pressure and can lead to misinterpretation of forces. The former is independent of normal stress. More over it is easily measurable and leads to simplification of analysis of forces for metal working processes. It varies from zero for perfect sliding to one for sticking.

Key words: Friction, sliding sticking, coefficient, factor, force, forming, process

1. Introduction

Friction plays an important role in metal working process. It influences the surface finish of product, formability of work piece, forces required etc. There are two extreme situations namely perfect sliding and sticking. Normally the situation will be somewhere in between in metal working. Friction may be desirable or undesirable depending on the process. For example friction may be desirable in rolling but undesirable in extrusion.

2. Definition

Friction contributes to forces in forming. To estimate them one must quantify friction. It can be done as follows with coefficient of friction.

$$\mu = (\tau / \sigma) \ldots. \quad (1)$$

Where τ is shear stress at the interface and σ is normal stress at the interface. This is valid when there is sliding. When there is sticking

$$\mu = (\tau_y / \sigma_y) \ldots (2)$$

where τ_y and σ_y are yield stresses in shear and normal case. When there is perfect sliding $\mu = 0$. When there is perfect sticking it is equal to 0.5 if Tresca criteria is adopted and 0.577 when von Misces criteria is use. To avoid such inconvenience, instead of friction coefficient, friction factor 'm' is used. It is defined as

$$m = (\tau/\tau_y) \ldots (3)$$

where τ is interfacial shear strength and τ_y is yield stress in shear. When there is perfect sliding m = 0 and when there is perfect sticking m = 1 in both Tresca and von Misces criteria. 'm' is independent of normal stress at the interface while μ depends on it. μ is inversely related to normal stress at the interface which is contrary to reality. More over m is easy to measure by a simple ring compression test and also easy to handle in mathematical equations

3. Ring Compression Test

A ring of OD : ID : H_o = 6 : 3 : 2 (24mm,12mm,8mm) is taken and deformed between two dies as shown in fig. 1

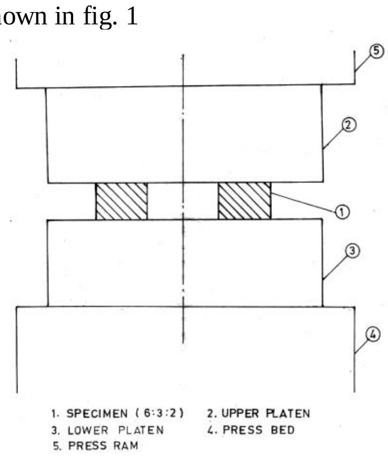

Fig 1 Schematic set up of ring compression test

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The percentage decrease in height and the percentage change in inner diameter is measured. Friction factor is read off from calibration chart as shown in fig. 2.

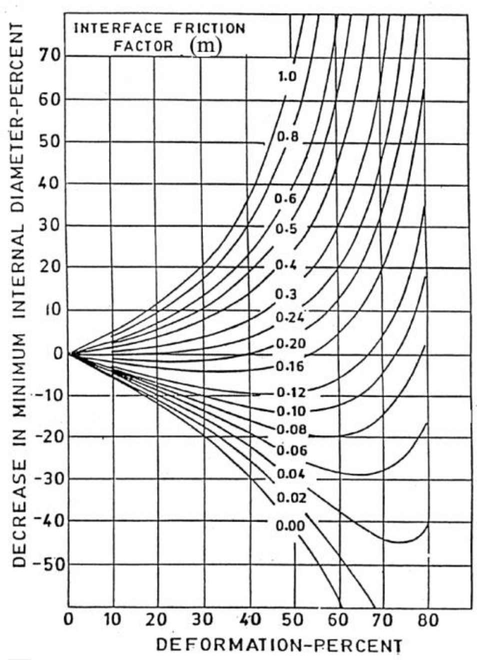
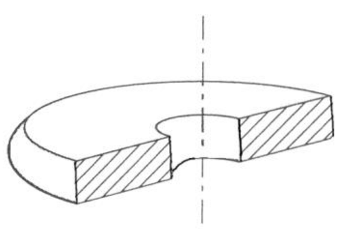
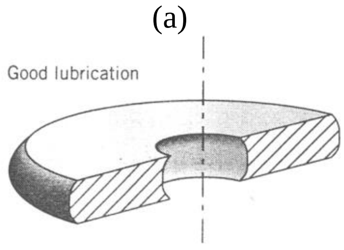


Fig 2 Calibration chart for finding friction factor.

Various possibilities of ring deformation as shown in figs.3 and 4.



(a)



(b)

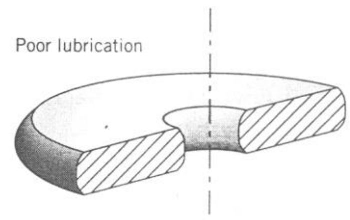


Fig 3 Ring specimen (a) before compression, (b) after compression with low friction and (c) after compression with high friction.

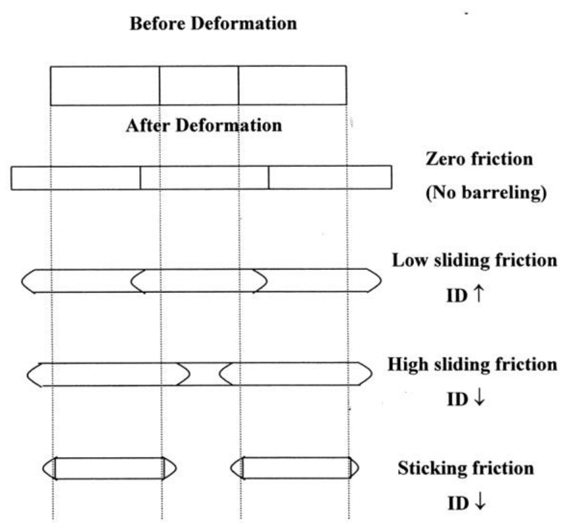


Fig 4 Types of ring deformation after compression

4. Forming Process & Friction

There are several forming processes. Here forging rolling, extrusion, and drawing are considered

4.1 Forging

There are 2 types of forging namely axysymmetric and plane strain forging.

4.1.1 Axy symmetric Forging

Consider a cylinder of height to diameter ratio 1.5 compressed between two dies as shown in Fig.5.

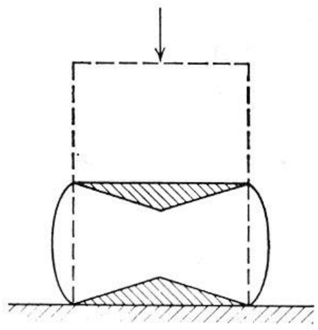


Fig 5 Compression of a cylinder

Friction exists at top and bottom faces of the cylinder. This causes stresses which are zero at the edges and maximum at the center. There exists a friction hill as shown in Fig.6.

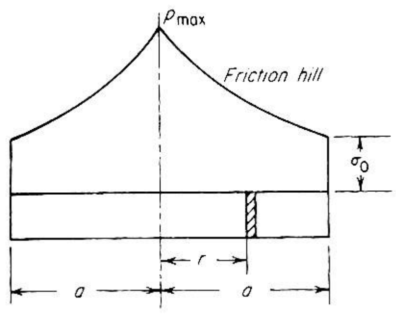


Fig 6 Friction hill in axysymmetric forging

Axial Stress is given by the following equation

$$p = \sigma_y EXP[(2\mu / h)(a - r)] \ldots\ldots(4)$$

4.1.2 Plane strain forging

Considered a cuboidal block of metal of length a, breath b, and height h, compressed between two dies as shown in Fig.7.

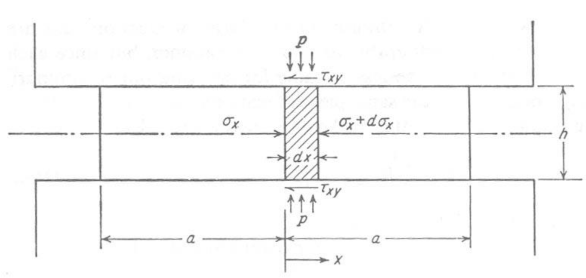


Fig 7 Compression of a cuboidal block

Assume that b >>> a>h. Lateral flow of metal causes stress which is maximum at central plane of the block and zero at the edge plane as shown in fig.8.

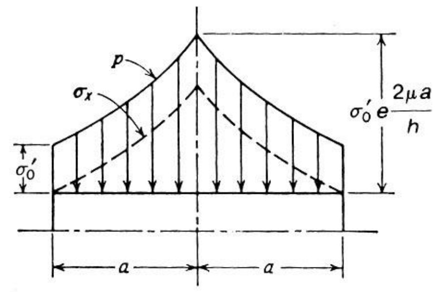


Fig 8 Friction hill in plane strain forging

Axial Stress is given by the following equation

$$p = \sigma_y^{'} EXP[(2\mu / h)(a - x)] \ldots\ldots.(5)$$

Where $\sigma_y^{'} = (2/\sqrt{3})\sigma_y$ if one considers von Misces criterion

4.2 Plane Strain rolling

A simple plane Strain rolling process is shown in Fig. 9

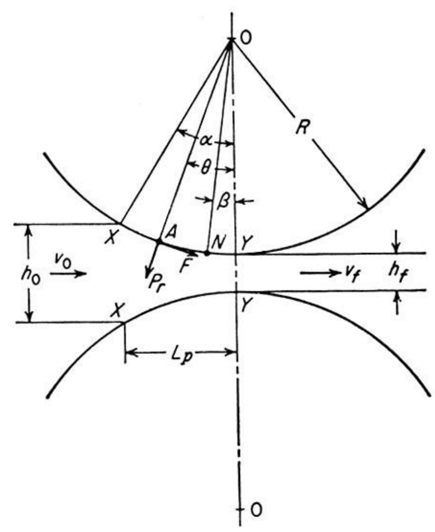


Fig 9 Plane strain rolling process

The effect of friction on roll pressure along the arc of contact is shown in Fig.10.

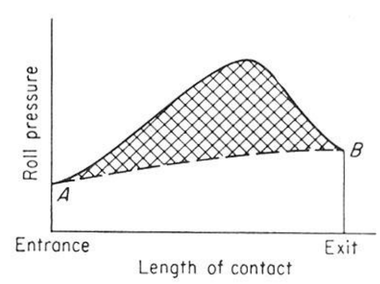


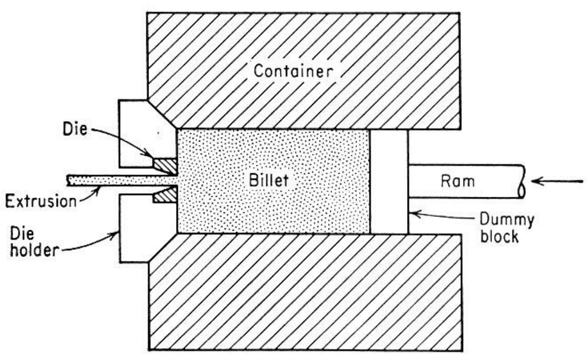
Fig 10 Friction hill in rolling

The hatched area shows the forces required to overcome frictional forces between roll and sheet. Even though the load increases friction is desirable in rolling. If $\mu = 0$ rolling will not occur. As μ increases thicker and thicker slabs can be fed and rolled. The condition for rolling is given by $\mu \geq \tan \alpha$. The draft in rolling is h_o - h_f and maximum draft $(\Delta h)_{max} = \mu^2$ R. Rolling load is given by the following equation.

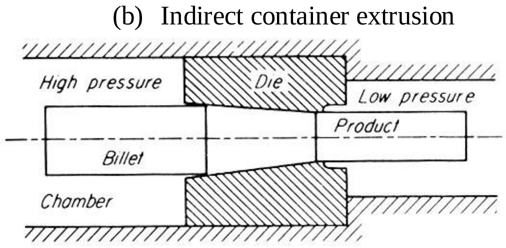
$$P = \left[\left(2/\sqrt{3}\right)\sigma_y \left\{\left(1/Q\right)\left(e^Q - 1\right)\right\} b\sqrt{R\Delta h}\right] ....(6)$$

4.3 Extrusion

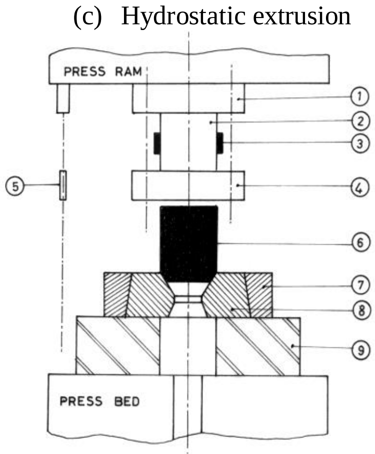
All 3 principal stresses are compressive in extrusion. The 4 types of extrusion process are shown in Fig.11 (a), (b), (c) (d)& (e).



(a) Direct container extrusion
(b) Indirect container extrusion



(c) Hydrostatic extrusion



(d) Containerless extrusion

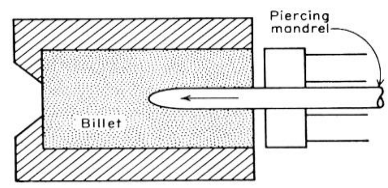


Fig 11 Types of extrusion processes

Force- stock diagrams are shown in Fig.12

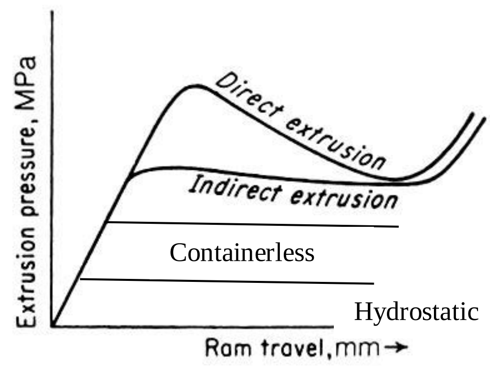


Fig 12 Force-stroke diagram

The forces required for rod extrusion are given by following equations

$F_{tot} = F_{Id} + F_{Sh} + F_{DFr} + F_{CWFr}$…(7)(container direct extrusion)

$F_{tot} = F_{Id} + F_{Sh} + F_{DFr} + F_{CWFr}$…(8)(container indirect extrusion)

$F_{tot} = F_{Id} + F_{Sh} + F_{DFr}$ …(9)(container less direct extrusion)

$F_{tot} = F_{Id} + F_{Sh}$ …(10)(hydro static direct extrusion)

Container wall friction decreases in direct extrusion from maximum at the beginning to a minimum at the end while it remains constant in indirect extrusion and is absent in container less extrusion and hydrostatic extrusion. Die friction is also absent in hydrostatic extrusion. For tube extrusion with mandrel an additional term of mandrel friction will come in as shown below.

$F_{tot} = F_{Id} + F_{Sh} + F_{DFr} + F_{CWFr} + F_{MFr}$…(11)(container direct tube extrusion)

4.4 Drawing

One principal stress is tensile an other 2 are compressive in drawing.

4.4.1 Wire drawing

A simple wire drawing setup is shown in Fig.13.

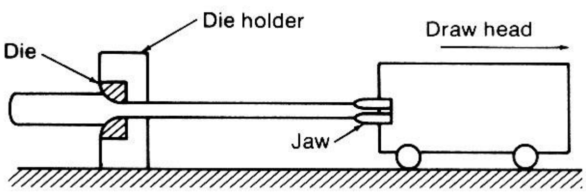


Fig 13 Wire drawing set up

Frictional force in wire drawing is given by the following equation

$F_{DFr} = \sigma_y(\mu / \mathrm{Sin}2\alpha)\varepsilon$ ……(12)

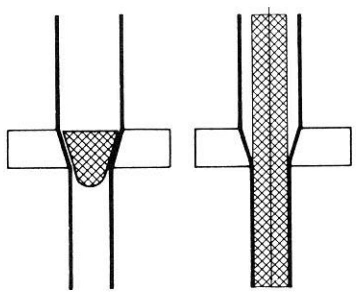
Total force in wire drawing in is given by

$F_{tot} = F_{Id} + F_{Sh} + F_{DFr}$ …(13)

The maximum reduction in a single pass in ideal wire drawing without friction, without redundant deformation and without strain hardening is 63%.

4.4.2 Tube drawing

A simple set up for tube drawing with plug is shown in Fig.14(a)



(a) (b)

Fig. 14 Tube drawing (a) floating plug (b) moving mandrel

In tube drawing the axial stress is given by the following equation

$\sigma_{xa} = \sigma_y[(1+B')/(B')][1-(h_a/h_b)^{B'}]$…(14)

Where $B' = [(\mu_1 + \mu_2)/(tan\alpha - tan\beta)]$…..(15)

Where $\mu_1$is friction coefficient tube and die wall and μ_2 between tube and plug

A simple set up for tube drawing with a moving mandrel is shown in Fig.14(b). Here

$B' = [(\mu_1 - \mu_2)/(tan\alpha - tan\beta)]$ …..(16)

at tube mandrel interface since friction force is directed towards the exist of the die

4.5 Deep drawing

A simple set up in shown in Fig.15.

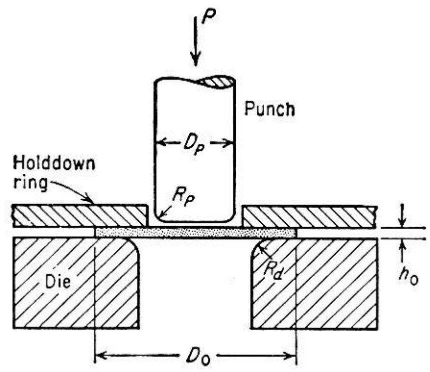


Fig 15 Deep drawing set up

Force stroke diagram is shown in Fig.16.

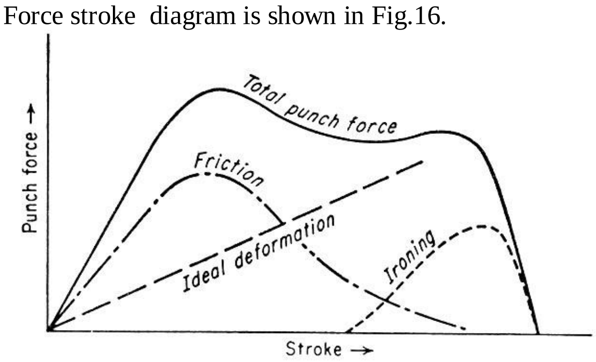


Fig 16 Friction in deep drawing

Roughening the punch or with holding the lubrication to the punch will help in shifting the failure site up the cup wall. So lubrication ids done on the die side only to reduce friction. The force for deep drawing of a cup is given by the following equation

$F_{tot} = F_{Id} + F_{Ir} + F_{Fr}$…(17)

5. Conclusion

Thus friction plays an important role in metal forming processes. Forces, ductility, fracture, surface finish are affected and influenced by friction. It should be properly understood and controlled. It is still an unknown entity in most of the situations and approximate estimations only can be done in spite of advances in the field.

6. Nomenclature

Greek symbols

δ	Semi cone angle of die
β	Semi cone angle of plug

ε	Strain
μ	Friction coefficient
σ_y, σ_0	Normal yield stress
τ_y	Shear yield stress

English symbols

b	Breadth of work piece
h	Height of work piece
Δh	h_0 - h_f
$\bar{h}$	$(h_0 + h_f)/2$
l	Length of work piece
L_p	Length of arc of contact
P	Rolling load
p	Normal pressure
Q	$\mu L_p / \bar{h}$
F_{tot}	Total force
F_{Id}	Ideal force
F_{Sh}	Shear force
F_{DFr}	Die frictional force
F_{CWFr}	Container wall frictional force
F_{MFr}	Mandrel frictional force
F_{Ir}	Ironing force
OD	Outer diameter of the ring
ID	Inner diameter of the ring
H_0	Height of ring

6. References

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