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THE ROLE OF FRICTION IN SINTER FORMING

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ABSTRACT

Friction condition between deforming tool and workpiece in metal forming are of the greatest importance concerning a number of factors such as force and made of deformation, properties of the finished specimen and resulting surface roughness. The relative velocity between the workpiece material and the die surface together with high interfacial pressure and/or deformation modes will create the conditions essential for adhesion in addition to sliding.

INTRODUCTION

During the last few years metal-powder components have assumed an important position in industry, as they are being used successfully in a wide range of applications. Both the mechanical and the metallurgical properties of the metal powder components compare favorably with those of wrought materials[1].

Although a considerable amount of work has been reported recently as the various technological aspects of the industrial processing of metal-powder preforms[2-5], no systematic attempt has been made so far to study the effect of friction and /or different required frictional conditions for particular forming process as a separate chapter. The present investigation has been undertaken with a view to study the effect of friction on deformation characteristics of sintered preform under flow through converging dies, forming considering barreling and without barreling. Different frictional condition has also been undertaken to study the best fit conditions of friction to define the particular forming operation. It is expected that the result of these investigations will be helpful in understanding the deformation pattern under different frictional condition and thus it will be helpful for designing the preform and dies for industrial use.

NOMENCLATURE

2b = Sides of the square
τ = Shear stress
μ = Coefficient of friction
k = Constant equal to 2 in yield criterion
n = A constant quantity much greater than 1
r, θ, z = Cylindrical co-ordinates
ρ = Relative density of the preform
σ_0 = Yield stress of the non-work hardening matrix metal
$\dot{\varepsilon}_r, \dot{\varepsilon}_\theta, \dot{\varepsilon}_z$ = Principal strain increment
η = Constant and a function of ρ only
h = Instantaneous thickness of preform
p = ram pressure
P = Die load
r = Radius of the sticking zone
A = Perpendicular distance from center to side of disc
N = No. of sides in a polygon
B = Bulging constant
J_2' = Second invariant of deviatoric stress

Interfacial friction Law

Friction condition between deforming tool and workpiece in metal forming are of the greatest importance concerning a number of factors such as force and made of deformation, properties of the finished specimen and resulting surface roughness. The relative velocity between the workpiece material and the die surface together with high interfacial pressure and/or deformation modes will create the conditions essential for adhesion in addition to sliding[6].

For such a mechanism of composite friction, which usually occurs in plastic deformation of metal powder preforms, the shear equation becomes t =m [p + r_0 f_0].

Where the first term (m p) on the rigid is the sliding friction and the second term (m $r_0 f_0$] is the friction due to adhesion which is due to change of relative density depends upon the deforming conditions such as speed and surface roughness. During the compression of a metal powder preforms the compressive force gradually increases the relative density, which latter is directly proportional to the real area of contact. The real area of contact grows and approaches the apparent area as the forces increases which in tern increase the relative density as illustrated in fig (1). This approach will probably be asymptotic[7].

The pattern of metal flow during the forging of a metal preform is such that there exist two zones, an inner zones where no relative movement occurs between the workpiece and the die (the striking) and the outer zone where sliding occurs. But in the present investigation all possible frictional conditions have been analyzed critically.

These are:

$\tau = \mu\, p$

$\tau = \mu\, [\, p + \rho_0\ \phi_0\,].$

$\tau = \mu\, [p + \rho_0\ \phi_0\, \{1\text{-}(r_m / n_r).1/n\}].$

$\tau = \mu\, [p + \rho_0\ {}_0\, \{1\text{-}(r_m / n_r)^{1/n}\}].$

(1)

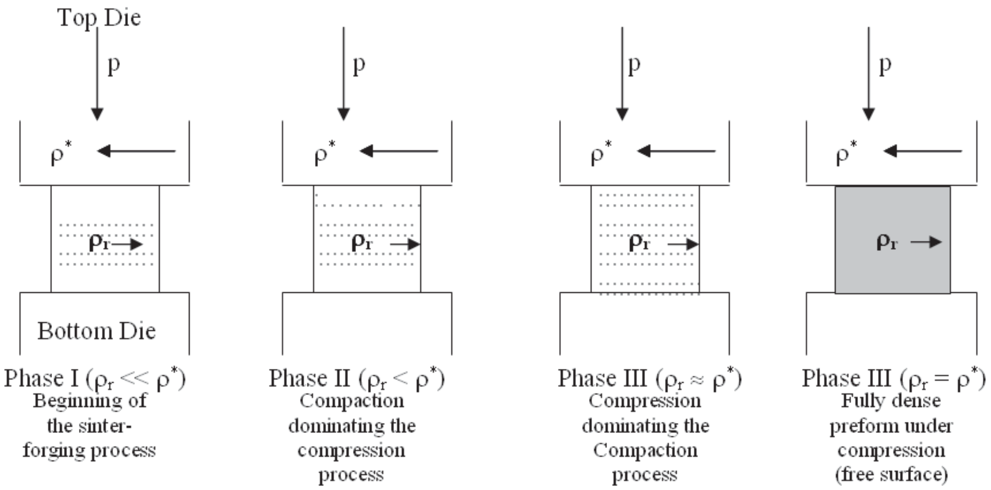

Figure (1). Physical model of a sinter forging process.

Where

ρ = Applied Pressure

ρ_r = Real density of real contact area

ρ^* = Apparent density of the apparent contact area

Analysis for friction

For the study the role of friction in sinter forming process, different forming operation has been considered here. With the reference of author's analysis for converging dies and forging are presented here for discussion of effect of friction and/ or frictional conditions.

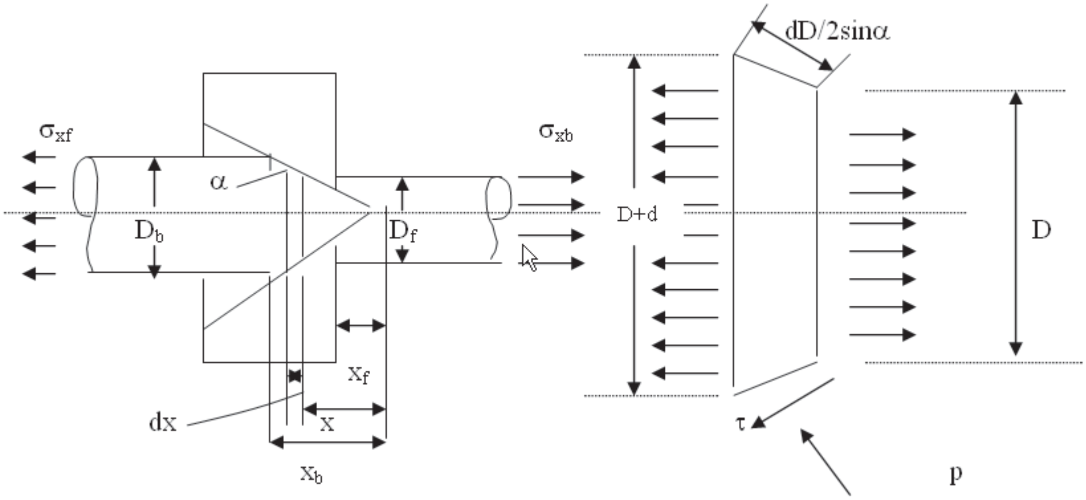

Figure (2). Free body equilibrium of converging die

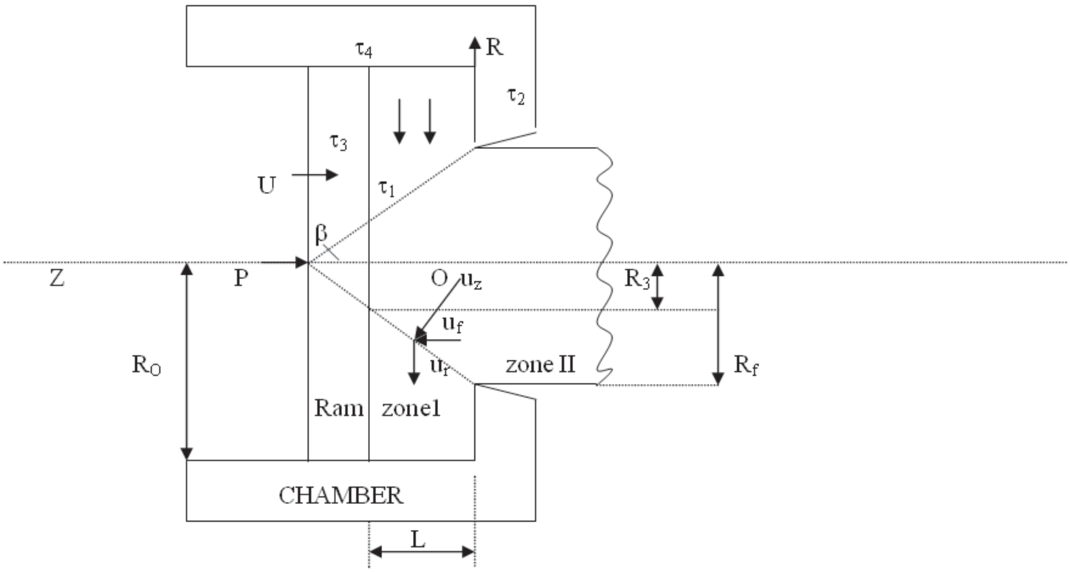

Figure (3). Kinematically admissible velocity field for the end of the stroke.

Flow through converging dies
Relative drawing stress:

Considering $\tau = \mu\ p$

$$\frac{\sigma_{xf}}{\lambda} = \frac{\sigma_{xb}}{\lambda} \cdot \left(\frac{D_f}{D_b}\right)^{2\beta} + \left[1 - \left(\frac{D_f}{D_b}\right)^{2\beta}\right]\left(\frac{1+\beta}{\beta}\right) \qquad (2)$$

Considering $\tau = \mu\,[\,\rho + \rho_0\ \phi_0\,]$.

$$\frac{\sigma_{xf}}{\lambda} = \frac{\sigma_{xb}}{\lambda}\left(\frac{D_f}{D_b}\right)^{2\beta} + \left[1-\left(\frac{D_f}{D_b}\right)^{2\beta}\right]\left(\frac{1+\beta}{\beta}\right) + \frac{\rho_0\phi_0}{\lambda}\left[1-\left(\frac{D_f}{D_b}\right)^{2\beta}\right] \tag{3}$$

Considering $\tau = \mu\,[p + \rho_0\ \phi_0\,\{1-(r_m / n_r).1/n\}]$.

$$\frac{\sigma_{xf}}{\lambda} = \frac{\sigma_{xb}}{\lambda}\left(\frac{D_f}{D_b}\right)^{2\beta} + \left[1-\left(\frac{D_f}{D_b}\right)^{2\beta}\right]\left(\frac{1+\beta}{\beta}\right) + \frac{\rho_0\phi_0}{\lambda}\left[1-\left(\frac{D_f}{D_b}\right)^{2\beta}\left(1+\frac{2\beta}{n(1-2\beta)}\right)+\left(\frac{2\beta}{1-2\beta}\right)\left(\frac{D_f}{D_b}\right)\frac{1}{n}\right] \tag{4}$$

Considering $\tau = \mu\,[p + \rho_0\ \phi_0\,\{1-(r_m / n_r)^{1/n}\}]$.

$$\frac{\sigma_{xf}}{\lambda} = \frac{\sigma_{xb}}{\lambda}\left(\frac{D_f}{D_b}\right)^{2\beta} + \left[1-\left(\frac{D_f}{D_b}\right)^{2\beta}\right]\left(\frac{1+\beta}{\beta}\right) + \frac{\rho_0\phi_0}{\lambda}\left[1-\left(\frac{D_f}{D_b}\right)^{2\beta}\left(1+\frac{2\beta n}{1-2\beta n}\right)+\left(\frac{2\beta n}{1-2\beta n}\right)\left(\frac{D_f}{D_b}\right)\right] \tag{5}$$

Relative extrusion stress

Considering $\tau = \mu\,p$

$$\frac{\sigma_{xb}}{\lambda} = \frac{\sigma_{xf}}{\lambda}\left(\frac{D_b}{D_f}\right)^{2\beta} + \left[1-\left(\frac{D_b}{D_f}\right)^{2\beta}\right]\left(\frac{1+\beta}{\beta}\right) \tag{6}$$

Considering $\tau = \mu\,[\,p + \rho_0\ \phi_0\,]$.

$$\frac{\sigma_{xb}}{\lambda} = \frac{\sigma_{xf}}{\lambda}\left(\frac{D_b}{D_f}\right)^{2\beta} + \left[1-\left(\frac{D_b}{D_f}\right)^{2\beta}\right]\left(\frac{1+\beta}{\beta}\right) + \frac{\rho_0\phi_0}{\lambda}\left[1-\left(\frac{D_b}{D_f}\right)^{2\beta}\right] \tag{7}$$

Considering $\tau = \mu\,[p + \rho_0\ \phi_0\,\{1-(r_m / n_r).1/n\}]$.

$$\frac{\sigma_{xb}}{\lambda} = \frac{\sigma_{xf}}{\lambda}\left(\frac{D_b}{D_f}\right)^{2\beta} + \left[1-\left(\frac{D_b}{D_f}\right)^{2\beta}\right]\left(\frac{1+\beta}{\beta}\right) + \frac{\rho_0\phi_0}{\lambda}\left[1-\left(\frac{D_b}{D_f}\right)^{2\beta}\left(1+\frac{2\beta}{n(1-2\beta)}\right)+\left(\frac{2\beta}{1-2\beta}\right)\left(\frac{D_b}{D_f}\right)\frac{1}{n}\right] \tag{8}$$

Considering $\tau = \mu\,[p + \rho_0\ \phi_0\,\{1-(r_m / n_r)^{1/n}\}]$.

$$\frac{\sigma_{xb}}{\lambda} = \frac{\sigma_{xf}}{\lambda}\left(\frac{D_b}{D_f}\right)^{2\beta} + \left[1-\left(\frac{D_b}{D_f}\right)^{2\beta}\right]\left(\frac{1+\beta}{\beta}\right) + \frac{\rho_0\phi_0}{\lambda}\left[1-\left(\frac{D_b}{D_f}\right)^{2\beta}\left(1+\frac{2\beta n}{1-2\beta n}\right)+\left(\frac{2\beta n}{1-2\beta n}\right)\left(\frac{D_b}{D_f}\right)\right] \tag{9}$$

Where $\beta = \mu / \tan\alpha$, $\rho_0\ \phi_0 = xp$, where x = 0.1, 0.2, 0.3,

Extrusion at the end of the stroke:

$$\frac{p_{ram}}{\sigma_0} = -\sqrt{\frac{3(1+\eta^2)}{2(1+\eta^2)}}\cdot\frac{2\sqrt{2}}{3}\left[\sqrt{1+A} - \sqrt{\left(\frac{R_z}{R_z}\right)^4 + A} - \sqrt{A}\ln\left|\frac{\left(R_z/R_z\right)^2\left\{\sqrt{1+A}-\sqrt{A}\right\}}{\sqrt{\left(R_z/R_0\right)^4 + A} + \sqrt{A}}\right|\right] + \frac{1}{\sqrt{3}}\left[\frac{(1-2\eta)}{3(1=2\eta)}\left(\frac{R_0}{h}\right)\left\{\left(\frac{R_f}{R_0}\right)^3\right.\right.$$

$$\left.\left. -\left(\frac{R_i}{R_0}\right)^3\right\} - \left(\frac{R_f}{R_0} - \frac{R_i}{R_0}\right) - \left(\frac{u_f}{u}\right)^2\left\{\left(\frac{R_f}{R_0}\right)^2 - \left(\frac{R_i}{R_0}\right)^2\right\}\frac{h/R_z}{\left[1-\left(R_0/R_z\right)^2\right]}\right] - \frac{2(1-2\eta)m}{3\sqrt{3}(1+\eta)}\left(\frac{R_0}{h}\right)\left[\left(\frac{R_z}{R_0}\right)\left\{3-\left(\frac{R_z}{R_0}\right)^2\right\} - 2\right] - m\left(\frac{h}{R_0}\right) \quad (10)$$

Where $A = (1-2\eta)^2 / 3(1+\eta^2)$

RESULTS AND DISCUSSION

Consider the case of drawing the values obtained indicate various parameters associated with a typical set of drawing case of a powder preform.

$D_f / D_b = 0.6$; $\rho_0 \phi_0 = 0.3p$; $n=3$; $\sigma_{xb}/\lambda = 0.1/4, 1/2, 3/4$

$\mu = 0.0, 0.1, 0.2, 0.3,$

The values λ varies over the interface entry to exit which has a finite value (where yielding start) and from this finite value it first decreases to a minimum value and then increases suddenly near the exit. This variation of λ is in proportion in changes in σ_o. It requires an accurate determination of the variation of λ and σ_o at the work-die interface. But the consideration of this variation will extend the numerical work considerably.

Four different friction conditions have been applied in this case. But two extreme cases are

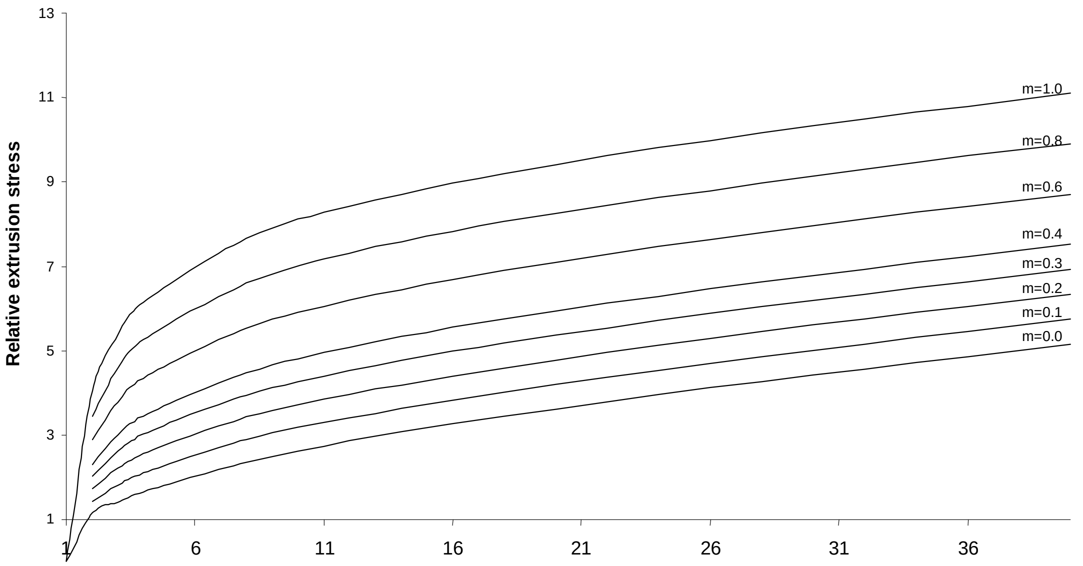

Fig. - 4: Effect of reduction and constant shear friction factor m on extrusion stress at the end of stroke

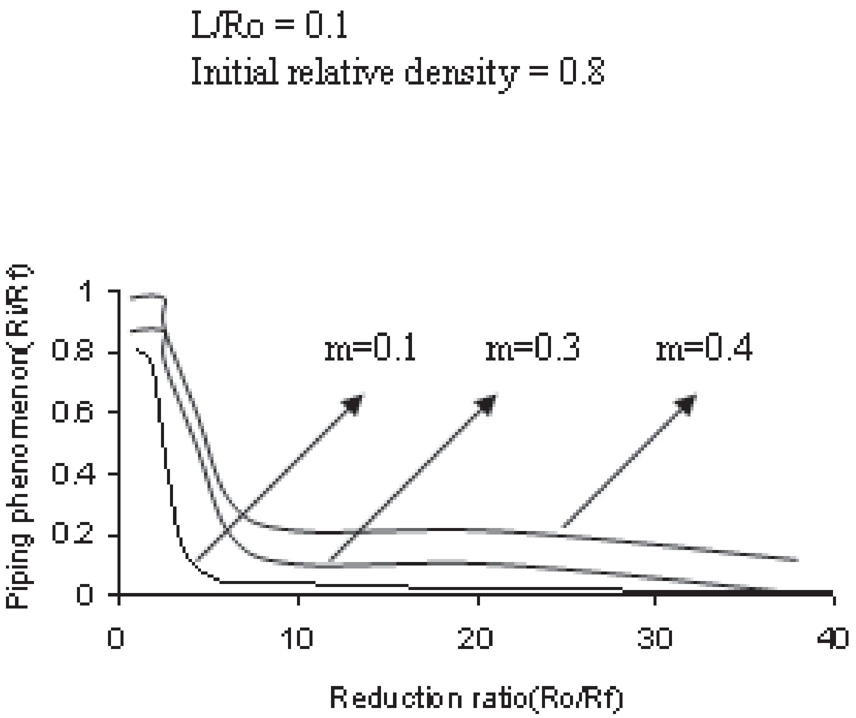

Fig. - 5: Effect of reduction on the piping phenomenon at the end of stroke

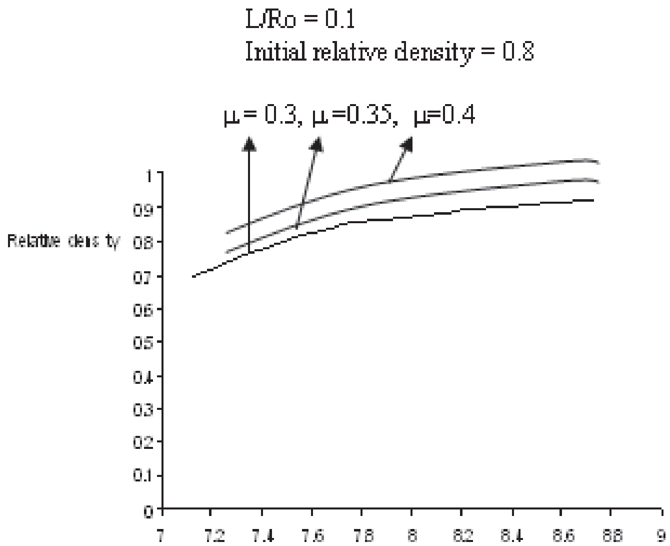

Fig. - 6: Relation between relative extrusion

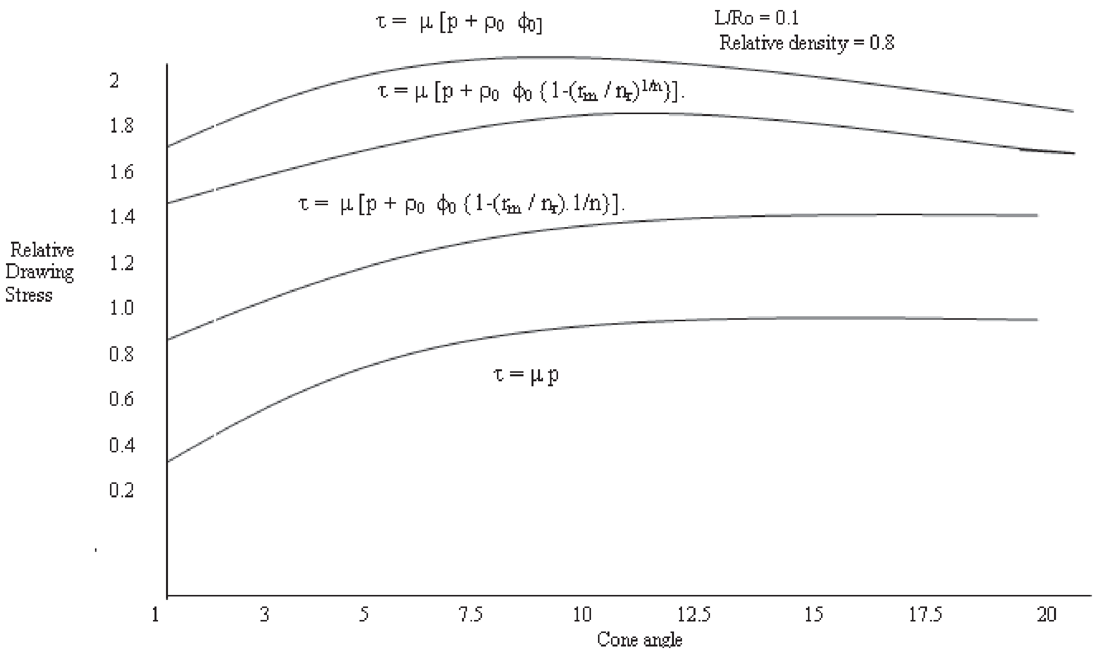

Fig. - 7: Effect of cone angle on relative drawing stress

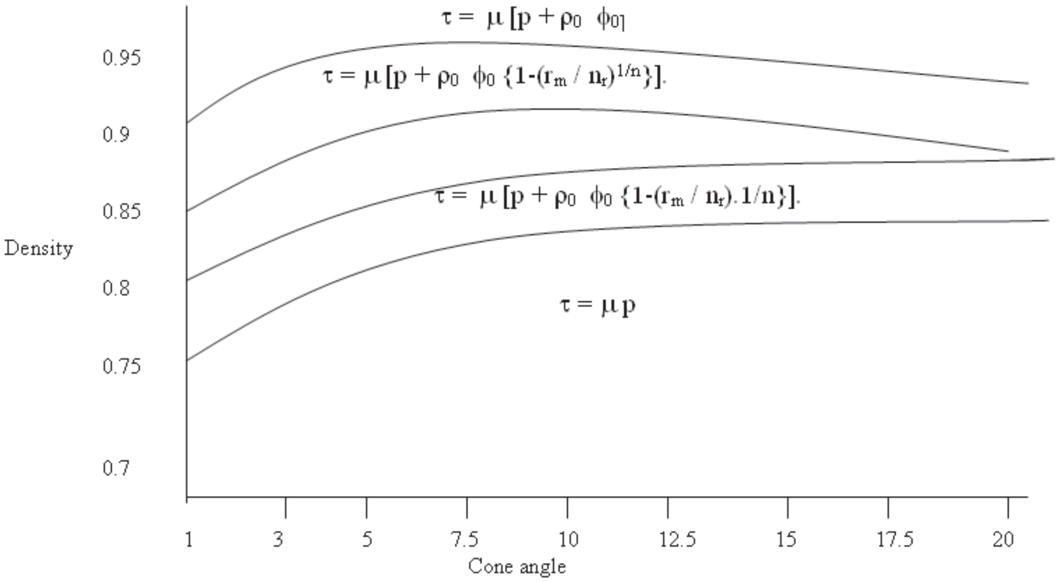

Fig. - 8: Effect of cone angle on relative density

considered; one of them are sliding friction condition and sticking friction condition. Rest two lies between these two; less relative drawing stress is observed in sliding case when comparing with sticking friction case. This is due to fact that the sticking friction offers move resistance to flow the workpiece. [Figure (4)] As coefficient of friction increases, it increases the relative drawing stress. So for higher value of coefficient of friction, it is difficult to draw the workpiece [figure (4)]. As coefficient of friction increases, it increases the relative density of preform increases. It is our required condition. Preform containing higher relative density is comparable to wrought material.

The similar discussion is made for extrusion. Only difference is their nature of pressure applied. In drawing operation, due to tensile nature of pressure applied, pores initially grow resulting with reduced relative density. Then pores collapse and linear variation is observed. In the case of extrusion due to compressive nature of applied pressure, this type of this type of phenomenon is not seen, so variation of relative density follows the linear relative with the applied load/ pressure.

For higher value of coefficient of friction, the possible reduction of preform is limited. Because at higher value of coefficient of friction cracks are observed at little earlier stage than lower value of coefficient of friction. So there should be a compromise among all given set of coefficient of friction and required relative density.

At the end of the stroke, a large variation of frictional losses is observed. The two well-known phenomenon cavity and piping is observed at the end of the stroke. From figure [5], it can be said that as coefficient of friction increases, piping phenomenon increases. From figure [6] it is seen that for a particular extrusion ratio higher coefficient of friction needs, increased value of relative extrusion stress. Again, higher coefficient of friction value gives the higher relative density of the perform figure 6. So after knowing the behavior of friction and frictional conditions, one can design the die workpiece economically.

Conclusion

From result and discussion, now it is clearly seen that the frictional condition $t = m\ [p + r_0\ f_0\ \{1\text{-}(r_m / n_r).1/n\}]$ is the best fit for sintered forming process. It is comparable with the experiment result. The coefficient of friction increases the relative density of the preform. But at the same time, it increases the relative extrusion/drawing pressure. From this observation one can design the die considering different friction/ frictional conditions.

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