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"Analysis of Sintered Metal Powder Preform During Extrusion through an Equilibrium Approach"

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ANALYSIS OF SINTERED METAL POWDER PREFORM DURING EXTRUSION THROUGH AN EQUILIBRIUMAPPROACH

Strictly as per the compliance and regulations of :

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Arun Ku. Sharma [α], Abhay Ku. Sharma [σ], R.K.Ranjan [ρ] & Maneesh Choubey [ω]

Abstract - The extrusion of metal powders at room temperature with subsequent sintering allows manufacturing of final products with unique microstructures and therefore with unique mechanical properties. In this study, the experimental results of extrusion of both aluminium and copper powders under laboratory conditions are presented and analysed. The main objective of the work is to demonstrate the various aspects of extrusion of powder preforms, which have been compacted and sintered from atomized powder. An attempt has been made for the determination of the die pressures developed during the extrusion of powder preform by using an Equilibrium approach. The interfacial friction law considered and dealt with in great detail, and also the yield criterion. The results so obtained are discussed critically to illustrate the interaction of various process parameters involved and are presented graphically.

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I. Introduction

Sintered powder metallurgical (P/M) preforms are often subjected to secondary processing with an objective to enhance the final density and to obtain components with superior mechanical properties. Amongst the secondary processes, extrusion is a widely accepted process to densify P/M preforms since all the three principal stresses in the deformation zone are compressive in nature [1]. However, the success of the extrusion is mainly dependent on the effective control of the process parameters viz., extrusion strain, temperature, coefficient of friction, relative density, adhesion friction factor. On the contrary to wrought materials, in P/M materials volumetric changes occur throughout deformation due to persistent densification [2]. This further complicates the process mechanism. Hence estimating the achievable density prior to the experimentation is very difficult. Although a considerable amount of work has been reported recently as the various technological aspects of the industrial processing of metal-powder preforms [3], no systematic attempt has been made so far to study the processing load and deformation characteristics during flow through conical converging dies.

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II. Interfacial Friction Law

In an investigation of the plastic deformation of metal-powder preforms, it is evident that with the application of compressive hydrostatic stress the pores will close and the relative density will increase, whereas the application of tensile hydrostatic stress the pores will grow and the relative density will decrease. The density distribution also does not seem to be uniform throughout, being high in the central region and low at the edges. The density distribution will be more uniform for smaller coefficient of friction μ and for a greater initial density. [4]

In plastic deformation of the metal, the surface of the work-piece is distorted and takes on an impression of the tool surface. Therefore, actual contact area, as far as the specific cohesion of the contact surface is concerned, is not negligible as in the case of elastic deformation. Hence friction in plastic deformation is essentially different from sliding friction in machine parts. However, high relative velocity between the work-piece material and tool surface combined with high interface pressure and deformation modes will cause breakdown of the surface film and will allow new surface to come into contact with the tool surface and hence facilitate the intimate contact essential for adhesion .For such a case, the metal being deformed does not necessarily slip along the tool surface. At the same time, it would also be erroneous to deny completely the existence of slip between the work-piece and tool. For this B.V.Deryagin(1952)suggested that frictional stress is a function of both sliding and adhesion and hence the shear equation becomes

$$\tau = \mu[P + \rho_0\varphi_0]$$

The pattern of metal flow during the compression of a metal powder preform is such that there exists two zones, an inner one where no relative movement between work piece and die occurs (the sticking zone), and an outer zone where sliding occurs. Therefore, the appropriate interfacial friction laws for the conditions are:

Axisymmetric condition

$$\tau = \mu\left[p + \rho_o\varphi_o\left\{1 - \left(\frac{r}{nR}\right)\right\}\right] \qquad (1)$$

Where r denote the sticking zone radius for axisymmetric condition, which may be approximated by the relation given by Rooks, and $n >> 1$

III. Yield Criterion

In an investigation of the plastic deformation of metal powder preforms it is evident that change in volume occurs due to porosity. A preform with high relative density (pores of small size) yields with relatively high stress whereas low relative density preforms (pore of large size) yields with relatively small stress. With the application of compressive hydrostatic stress, the pores will close and relative density will increase whereas with the application of tensile hydrostatic stress the pores will grow and relative density will decrease. Even hydrostatic stress can cause the metal powder preform to yield, as the yield surface is closed on the hydrostatic stress axis. The density distribution also does not seem to be uniform throughout. It is high in the central region and low at the edges. [5] The density distribution will be more uniform for a smaller coefficient of friction and for a higher initial relative density of the preform.

In consideration of the characteristics described above, yield criteria for porous metal powder preforms were developed by Kuhn et al,Green and Oyane et al.,Oyane et al simplified their criterion and derived the slip line field theory and the upper bound theory for porous metal powder preforms. Tabata and Masaki [6]proposed the following yield criterion for porous metal powder preforms:

$$\rho^k\sigma_0 = \sqrt{3J_2} \pm 3\eta\sigma_m \qquad (2)$$

The upper sign (negative) in equation (2) is taken for $\sigma_m \leq 0$ and the upper sign (positive) for. $\sigma_m \geq 0$ Figure 1 shows the yield surface for a porous metal powder preform given by equation, which consists of two cones. The height of cone increases with increasingλ. When λ=1, i.e. a pore-free metal, the cone becomes a cylinder and equation (2) reduces to the Von Mises yield criterionand k in equation (2) are experimentally determine from compression and tension test of sintered copper powder preforms are as

$$\eta = 0.54(1-\rho)^{1.2} \quad \text{for} \quad \sigma_m \leq 0 \qquad (3)$$

$$\eta = 0.55(1-\rho)^{0.83} \quad \text{for} \quad \sigma_m > 0 \qquad (4)$$

However, these values can be used for other porous metals because there is little difference in the plastic behaviour in axisymmetric compression tests for and powder preforms. [7]

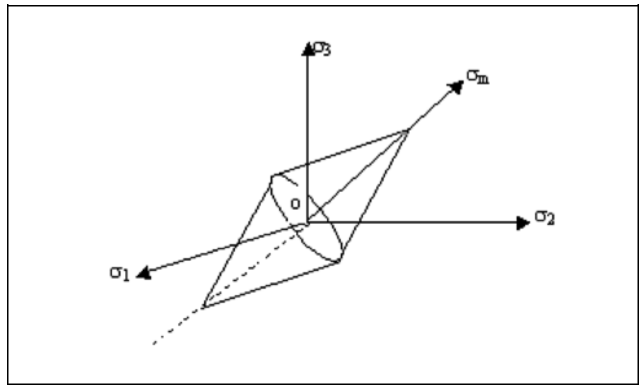

Figure 1: Yield Criterion

IV. Frictional Power Losses in Conical Portion

A wire or a rod of initial diameter D_b is extruded through a conical portion of the die. While passing through the die, the wire deforms plastically and decreases in diameter, the frictional force will be act between the wire metal and die. Cylindrical symmetry assumed to prevail .A slug of metal bounded by the conical surface of the die and by two transverse surfaces normal to the axis of symmetry. One surface is at a distance x from the apex O of the die, and other is at another incremental distance dx. The stress σ_x over the transverse surface is assumed to be uniformly distributed tensile stress. It is normal to the surface with no shear component. For the incremental distance dx the stress varies by the amount $d\sigma_x$ over the surface in contact with conical die. A pressure p is assumed normal to the surface and a frictional drag τ parallel to the surface. (Fig 2)

a) The σ_x stresses on the two transverse planes yield the resultant as (neglecting all incremental terms to power greater than one)

$$\int_0^{2\pi}\left(p\frac{dx}{cos\alpha}\right)\left(\frac{D}{2}\,d\theta\right)sin\alpha = p\pi D\ tan\alpha\ dx = \frac{p\pi DdD}{2} \qquad (5)$$

b) The component of the normal pressure of the die in the x-directions determined and as follows

$$\int_0^{2\pi}\left(p\frac{dx}{cos\alpha}\right)\left(\frac{D}{2}\,d\theta\right)sin\alpha = p\pi D\ tan\alpha\ dx = \frac{p\pi DdD}{2} \qquad (6)$$

c) The component of the frictional stress τ in the x-direction is

$$\int_0^{2\pi}\left(\tau\frac{dx}{cos\alpha}\right)\left(\frac{D}{2}\,d\theta\right)cos\alpha = \tau\pi Ddx = \frac{\tau\pi DdD}{2tan\alpha} \qquad (7)$$

Summing all the parts of forces in the x-direction leads to

$$\frac{\pi D}{4}(Dd\sigma_x + 2\sigma_x dD) + \frac{p\pi DdD}{2} + \frac{\tau\pi DdD}{2\,tan\alpha} \qquad (8)$$

On simplification

$$Dd\sigma_x + 2\sigma_x dD + 2dD\left(p + \frac{\tau}{tan\alpha}\right) = 0 \qquad (9)$$

Now,considering the friction law

$$\tau = \mu\left[p + \rho_o\varphi_o\left\{1 - \left(\frac{r}{r_{xb}}\right)\frac{1}{n}\right\}\right]$$

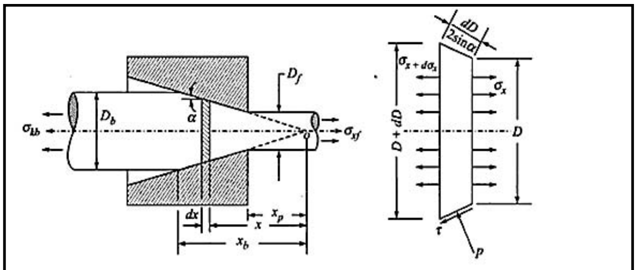

Fig 2 Free Body Equilibrium approach for conical portion

$$Dd\sigma x + 2\,\sigma x d\,D + 2dD\left\{p + \left(\frac{\mu}{tan\alpha}\right)\left[p + \rho_o\varphi_o\left\{1 - \left(\frac{r}{r_{xb}}\right)\frac{1}{n}\right\}\right]\right\} \qquad (10)$$

After simplifying of the equation, we get,

$$Dd\sigma x + 2\,d\,D\left\{(\sigma x + p) + B\left[p + \rho_o\varphi_o\left\{1 - \left(\frac{D}{D_b}\right)\frac{1}{n}\right\}\right]\right\} = 0 \qquad (11)$$

Eq. (11) reduces to,

$$Dd\sigma x + 2\,d\,D\left\{\lambda(1 + B) - B\left[\sigma_x - \rho_o\varphi_o\left\{1 - \left(\frac{D}{D_b}\right)\frac{1}{n}\right\}\right]\right\} = 0 \qquad (12)$$

Integrating and simplifying the eq. (12)

$$\sigma_x = \frac{2B\rho_o\varphi_o}{n\left(\frac{D}{Db}\right)}\cdot\frac{1}{(1-2B)} + \frac{1}{2B}\left[2\lambda(1 + B) + 2B\rho_o\varphi_o\right] + CD^{2B} \qquad (13)$$

Now,

$$C = D_b^{2B}.\left[\sigma_{xb} - \frac{1}{B}\{\lambda(1 + B) + B\rho o\varphi o\} - \frac{2B\rho o\varphi o}{(1-2B)n}\right] \qquad (14)$$

Putting the value of C in eq. (13) and solving it

$$\frac{\sigma_x}{\lambda} = \left[1 - \left(\frac{D}{Db}\right)^{2B}\right]\frac{1+B}{B} + \frac{\sigma xb}{\lambda}\left(\frac{D}{Db}\right)^{2B} + \frac{\rho o\varphi o}{\lambda}\left[1 - \left(\frac{Df}{Db}\right)^{2B}\left\{1 + \frac{2B}{n(1-2B)}\right\} + \frac{2B}{(1-2B}\left(\frac{D}{Db}\right)\frac{1}{n}\right] \qquad (15)$$

Draw stress is the value of σ_x(say σ_{xf}) at the exit when we have $D=D_f$,$\sigma_x=F_b/A$; i.e .σ_{xb} therefore,

$$\frac{\sigma xf}{\lambda} = \left[1 - \left(\frac{Df}{Db}\right)^{2B}\right]\frac{1+B}{B} + \frac{\sigma xb}{\lambda}\left(\frac{Df}{Db}\right)^{2B} + \frac{\rho o\varphi o}{\lambda}\left[1 - \left(\frac{Df}{Db}\right)^{2B}\left\{1 + \frac{2B}{n(1-2B)}\right\} + \frac{2B}{(1-2B}\left(\frac{Df}{Db}\right)\frac{1}{n}\right] \qquad (16)$$

V. Results and Discussion

The deformation pattern of metal powder perform is quite different from solid metal deformation. In the powder metal forming operation, there are 2 processes that happen simultaneously, i.e. compaction and deformation.

Figure 3 shows the effect of semi cone angle (α) of the die. It is found that with the increase of semi cone angle (α) of the die, the relative extrusion stress decreases and after attaining minimum value the power consumption again increases as the cone angle increases. Here such the value obtain within the range of semi cone angle 8° to 10°,thus this values are the optimum value of cone angle with certain set of variables for minimum power consumption. It can be vary with varying the set of variables.

Figure 4 shows therelative extrusion stress increases with increasing the coefficient of friction between preform and die wall. It is due to the fact that friction always opposes the motion and hence we need higher amount of relative extrusion stress for higher value of coefficient of friction.

Figure 5 shows, for lower value of percentage reduction in diameter, relative extrusion stress varies linearly. As relative density increases relative extrusion stress decreases. It is due to the fact that an initially large amount of load is consumed in compaction and then, after gaining sufficient relative density, it is deformed and gives a uniform proportionate curve.

Figure 6 shows for lower value of percentage reduction in diameter, relative extrusion stress varies linearly. It is due to the fact that with too small a cone angle, the contact area between the preform and the die is high, causing significantly high frictional losses. With too large a cone angle, the distortion becomes a predominant factor.

Figure 7 shows the effect of coefficient of friction μ on the extrusion stress for the case of deformation through conical converging dies. With the increase of coefficient of friction, the relative extrusion stress increases

Figure 8 shows the effect of back pull pressure on the extrusion stress for the case of deformation through conical converging dies.

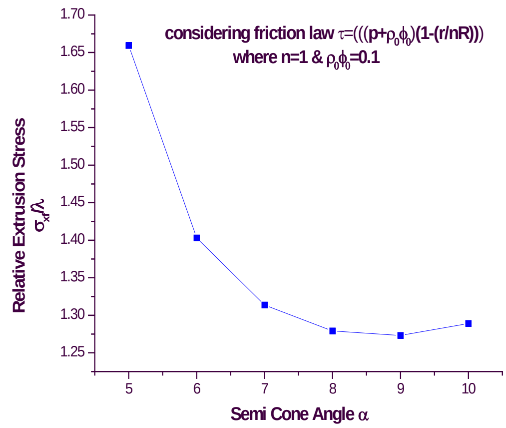

Figure 3 : Variation of relative extrusion stress with semi cone angle.

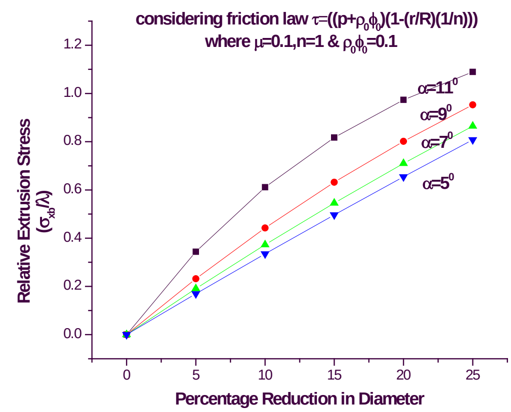

Figure 6 : Effect of semi cone angle and reduction ratio on relative extrusion stress.

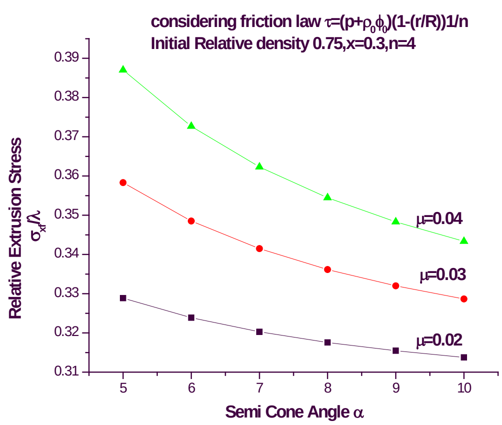

Figure 4 : Effect of coefficient of friction and semi cone angle on relative extrusion stress.

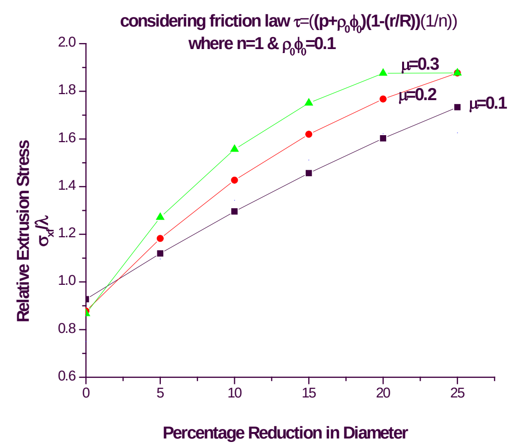

Figure 7 : Effect of coefficient of friction and reduction ratio on relative extrusion stress.

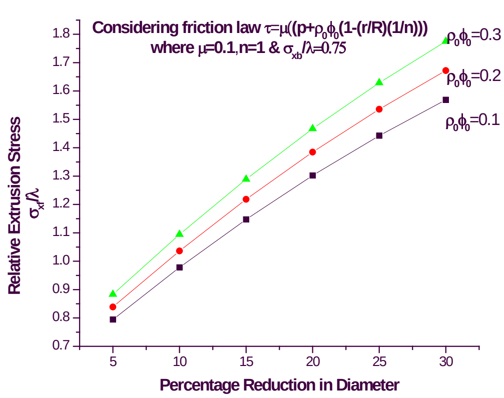

Figure 5 : Effect of adhesion friction factor and reduction ratio on relative extrusion stress.

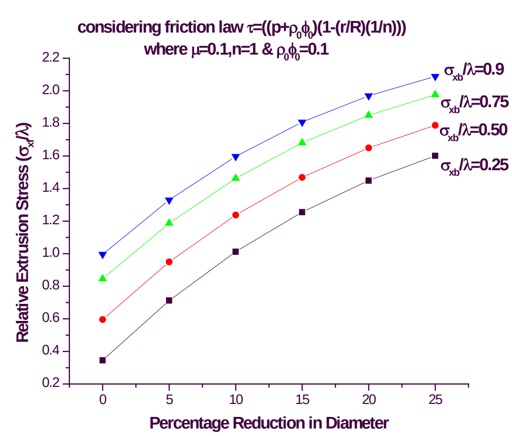

Figure 8 : Effect of back pull and reduction ratio on relative extrusion stress.

VI. Conclusion

Relative extrusion stress shows minima at a particular semi cone angle of the die, so it can be used criteria for the forming through conical dies. Lower value of coefficient of friction requires low value of relative extrusion stress, i.e. it favours the forming operation. Higher initial relative density of the preform needs lower value of relative extrusion stress. For small semi cone angle, the geometry of the preform doesn't affect too much on the relative extrusion stress.So all the above conclusions certainly would be helpful for the forming operation through conical converging dies

List of Symbols

τ = Shear stress

η = Constant and a function of ρ only

μ = Coefficient of friction

p = ram pressure

r = Radius of the sticking zone

J'_2 = Second invariant of deviatoric stress

R_0 = Initial radius of the rod

R_f = Final radius of the rod

α = semi cone angle of the die

σ_{xb} = Back pull stress

k = Constant equal to 2 in yield criterion

n = A constant quantity much greater than

λ = Flow stress of metal powder perform

ρ = Relative density of the perform

σ_{xf} = Extrusion stress

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