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1/5

A New Extrusion Method for Consolidation of Powders

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Extrusion is used for consolidation of powders, however, small pores are apt to remain in the extruded compacts. A new extrusion method with large shear deformation has been investigated to minimize such residual pores. In this method, powder is compressed into a cylindrical container and extruded through a die with a rectangular exit, with changing flow direction at a right angle to the compression axis once in the single shear process, or twice in the double shear process. It has been shown that a dead zone is formed at the corner with a right angle in the die and large shear deformation occurs in the vicinity of the corner. The density of compacts extruded with this method is higher than 99% of that of the material made of ingot. Compared with conventional extrusion, better mechanical properties — higher tensile strength and elongation — can be achieved by this method.

Key words: extrusion, powder forming, metal powder, consolidation, mechanical properties

1. Introduction

Among the various methods for consolidation of powders, extrusion is widely used for P/M production. Recently, extrusion has been used for fabricating metal matrix composites[1)~3)] and rapidly solidified powders[4), 5)]. However, small pores are apt to remain in the extruded compacts. In the extrusion process, powder is deformed severely at the wall side, but passes through a die without severe deformation near the central portion of a container, as shown in **Fig. 1**.

After the analysis of the powder flow in the process, metal powders were extruded by this new method and the properties of the compacts produced were compared with those of compacts produced by conventional extrusion.

2. Experimental procedure

2. 1 Shear deformation in a die

The material flow in the die for double shear exrusion is illustrated in **Fig. 2.** Powder travels through a die with change of the flow direction at a right angle to the preceding flow direction.

Table 1 shows the process conditions for shear extrusion.

2. 2 Simple analysis of powder flow

Assuming that the velocities of powder flow in the three zones are V_1, V_2 and V_3, and the cross-sectional areas of the three zones are S_1, S_2 and S_3, we have

$$V_1S_1=V_2S_2=V_3S_3 \tag{1}$$

Table 1 Process conditions

Material		A1050
Press		Knuckle joint
Process time/s		2.0
Initial temperature/K	Workpiece	673
	Punch	423
	Die	423

3. Theory

3. 1 Theoretical check of the incremental inverse finite-element procedure

As an illustration of the incremental inverse tech-nique, we consider the relationship between the nodal force $\{R\}$ and the incremental displacement $\{dU\}$.

The nonlinear finite-element equation is expressed as

$$[K(dU)]\{dU\}=\{R\}. \tag{9}$$

The nodal force based on the bending at the die radius is expressed as[4)]

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Sample

$$H_b = \{1+\exp(\pi\mu/2)\}\, t^2 L \sigma_Y / \{4(\rho_d + t/2)\}, \qquad (10)$$

$$d\left[\Sigma \frac{1}{2} m_i \left\{\left(\frac{dx_i}{dt}\right)^2 + \left(\frac{dy_i}{dt}\right)^2 + \left(\frac{dz_i}{dt}\right)^2\right\}\right] = \Sigma (X_i dx_i + Y_i dy_i + Z_i dz_i), \qquad (11)$$

where L and ρ_d denote the circumferential length of the inner boundary and the die radius, respectively.

3. 2 Calculated results and comparison with experimental results

Experiments were performed on testpieces prepared from sheet metals. The experimental data were fitted by an empirical power hardening law of the form

$$\sigma = \sigma_Y (1 + c\varepsilon_p)^n \qquad (16)$$

The coefficients σ_Y, c and n are given in **Table 2**, along with other pertinent data.

Figure 11 shows the experimental and calculated results for the clamping force H vs the deep drawing ratio β. The calculated forming limit lines for H vs β are shown in Fig. 11 as solid lines.

Table 2 Material properties

Material	t /mm	E /GPa	σ_Y /MPa	c	n
Steel	0.30	208	296	2590	0.18
Aluminum	1.07	76	80	172	0.34

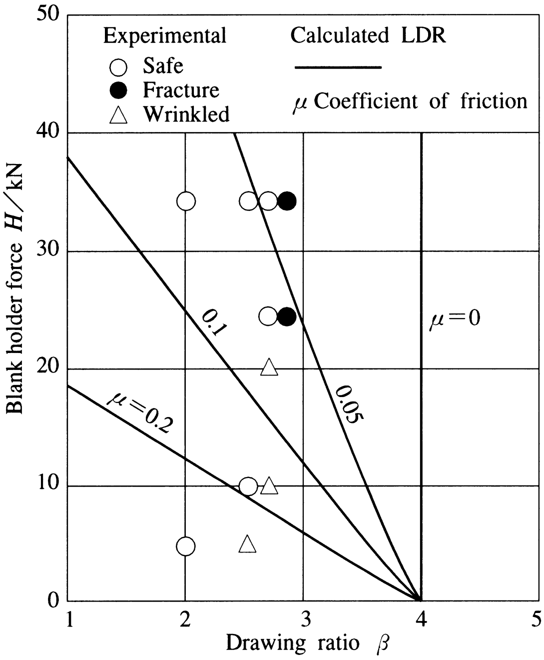

Fig. 11 Comparison of experimental and calculated limiting drawing ratios as a function of blank holder force during the production of square cups from optimum-shaped blanks

4. Conclusion

Some of the results obtained in the present study show a reasonable correspondence with previously published experimental data on the limiting blank size or deep drawing square cups from optimum blank shapes.

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Nomenclature

b	width of a rectangular plate
E	Young's modulus
h	plate thickness
u_i, u, v, w	Cartesian displacement components

Appendix

Expressions for B_1 and B_2 in Eqs. (15) and (16) are

$$B_1 = (a+b)/[\{(a+b)/c\}\{(b+c)/a\}], \qquad (A1)$$

$$B_2 = (a^2+b^2)/[\{(a^2+b^2)/c^2\}\{(b^2+c^2)/a^2\}]. \qquad (A2)$$

Sample

1/11

Reduced scale 100%

Table 1 Process conditions

Material		A1050
Press		Knuckle joint
Process time/s		2.0
Initial temperature/K	Workpiece	673
	Punch	423
	Die	423

M. Johnson

Sample

11/11

Reduced breadth 75 mm (72%)

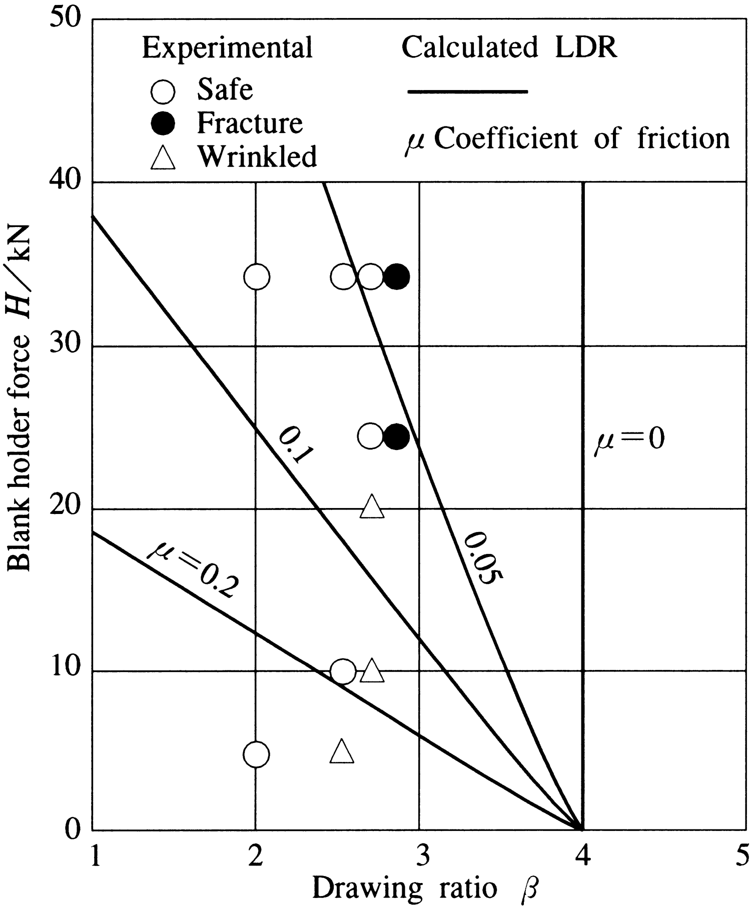

Fig. 11 Comparison of experimental and calculated limiting drawing ratios as a function of blank holder force during the production of square cups from optimum-shaped blanks

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