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Theoretical analysis of extrusion through rotating container: Torque and twist angle

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ABSTRACT

In order to evaluate the deformation behavior of billet, calculation models of twist angle along the circumferential direction are obtained on account of theory derivation. And the process of extrusion through rotating container is in-depth analysis by using of numerical simulation. The research results show, with the increasing of container angular velocity, the axial twist angle on the outer space of billet presents an increasing tendency under the effect of a constant friction factor. But the increasing magnitude becomes small and tends to be a certain value. The curving degree of intersecting lines tends to be decreased instead of increasing. With the comparison, the curving degree is directly proportional to extruding temperature, angular velocity of container and friction factor. But the extruding speed presents an inverse relationship with the curving degree. The torque model of extrusion is obtained and it can provide theoretical bases for process formulation and device design.

1. Introduction

Recently, the field of metal plastic forming gradually concentrates on finite element simulation, but the certain value and change rule of key physics quantity can be obtained intuitively by using of slab method [1,2] and upper bound method [3,4] in the process of extrusion and forging. Therefore, theoretical methods are still widely used in the field of plastic forming.

In the process of theoretical analysis carried out by Faraji [5], an upper-bound approach was used to analyze the tubular channel angular pressing (TCAP) process. Deformation of the material during TCAP process was analyzed by upper-bound analysis to determine the maximum required load. The effects of TCAP parameters such as channel and curvature angles, deformation ratio (R1/R2) and tube material on the process pressure were investigated. The results showed that an increase in the second channel angle and a decrease in the ratio R1/R2 led to lower process loads. In the first and third curvature angles ranging from 25° to 65°, and the required load remained almost constant. The apparent punch load decreased when hardening exponent (n) increased. Good agreement was observed between predicted pressure obtained from upper-bound analysis and FE results.

In the research of Rout and Maity [6], an analysis using three-dimensional upper bound method with curved surface die had been carried out for extrusion of square billet. The extrusion pressure and optimum die length had been computed by multivariable optimization technique. The results obtained would help the design of optimum die and the investigation of its performance.

Sahoo et al. [7] tried to remodel and apply the spatial elementary rigid region technique to analyze extrusion of angle section bars from round billets through the linearly converging die. Optimized values of the non-dimensional average extrusion pressure at various area reductions had been computed and compared with experimental results. It was observed that the proposed technique could be used effectively with adequate accuracy to predict the optimal die geometry which required a minimal forming stress at different reduction of areas and friction conditions.

The research carried out by Kar [8] was devoted to the upper bound analysis of extrusion of T-section bars from square billets through square dies using the modified SERR (Spatial Elementary Rigid Region) technique. Optimized values of the non-dimensional average extrusion pressure at various area reductions had been computed and compared with experimental results which were available in literature. The experiments agreed well with the theoretical analysis.

A modified slab method for the investigation of the axisymmetric forming of compressible materials was introduced by Axmann and Mannl [9]. It was based on the elementary slab method, the

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main difference being the additional variable relative density, describing the porosity. The material itself was modeled as rigid-plastic, with a yield condition given by. Reasonable assumptions were conducted to a model used for the forward extrusion and axial compression of powder metals. The results achieved with appropriate material parameters for copper powder corresponded with experimental experience. No matter what kind of the theoretical methods was used by the theoretical analysis, the demonstration needed to be done for confirming the correctness of the result. Moreover, the finite element method became a widely used means on account of its conformity with experiment condition, abundant results and the low-spending.

Nowadays, as computational power improved, manufacturing process can be considered in terms of material flow, temperature and profile speed distribution, load–stroke history and so on by means of finite element (FE) simulation. 3D finite element method was used to study the deformation behavior of pure aluminum during Cross-ECAP. Plastic strain and strain rate distribution during this processing technique was calculated and compared with conventional ECAP process [10].

Three deformation routes for the recently invented severe plastic deformation (SPD) method named tube channel pressing (TCP) have been introduced. The effects of routes, back pressure and friction have been investigated on deformation behavior of commercially pure (CP) aluminum tubes. Utilizing finite element analysis provides a broader understanding of these effects through different deformation routes [11].

Finite element method (FEM) and artificial neural network (ANN) were used to simulate ECAP deformation of AA2024 aluminum alloy. The results showed that the area is over where friction acted and hence the total accumulated friction force was reduced when the billet length was reduced. The FEM and ANN results were in good agreement with experimental measurements [12].

Extrusion through rotating container is a new plastic forming method that has been proposed by author [13], and there are many processing parameters influencing the flow behavior of material. However, in order to realize the container rotation, the torque applied on container needs to be quantified with different conditions. Firstly, torque model of container should be built, so that the subsequent experiments can be carried out. Meanwhile, the model of twist angle on the outer space of billet can be characterized through theory method. And flow behavior of billet that experienced twisting deformation has been evaluated by finite element simulation.

2. The torque model of container

The schematic illustration of extrusion through rotating container is shown in Fig. 1. The extrusion tooling includes punch, stationary container, rotating container and die. The rotating container is driven by a servo motor.

The device which applied torsion on the container is one of preconditions to realize the rotating container extrusion. Therefore, theoretical calculation can provide a theoretical basis for the design and check of driving device. From theoretical analysis, the torque that required in process can be divided into two parts: one is the starting torque, which can provide acceleration for container speeding up to the rated speed. The other one is operating torque. It is the one that provided uniform rotation when container reached the rated speed. The expression of torques can be given as,

$$\text{Starting Torque } M_1 = \text{Starting Inertia Moment } M' + \text{Friction Moment } M'' \quad (1)$$

$$\text{Operating Torque } M_2 = \text{Friction Moment } M'' \quad (2)$$

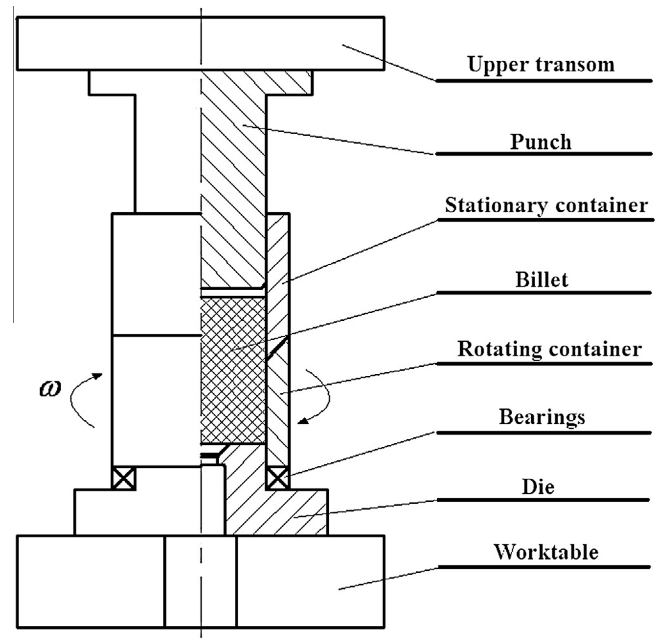

Fig. 1. Schematic illustration of principle.

It can be seen from the expression (1) and (2) that the starting torque M_1 is significantly greater than operating torque M_2. Therefore, in the torque calculation, the starting torque M_1 should be the basis for designing and checking. The theoretical derivation has been shown in the following.

2.1. Friction Moment

Extrusion is a complicated severe deformation processing, and the friction at the workpiece/tooling interface is a highly complex phenomenon [14,15]. The contact condition is characterized by a constant shear friction model. In this condition, the friction shear stress on the contact surface is proportional to shear yield strength K, namely the expression (3),

$$\tau = mK \quad (3)$$

where m is the Friction factor, $0 \leqslant m \leqslant 1$ and K is the Shear yield strength of material.

The friction between billet and rotating container is shown below:

$$f = \tau_0 \cdot S \quad (4a)$$

where τ_0 is the Friction stress.

Inserting the expression (3) into expression (4a) gives,

$$f = \tau_0 \cdot S = mK \cdot \sin\ \gamma \cdot 2\pi R_0 l_0 \quad (4b)$$

where γ is the angle between resultant velocity and axial velocity on the billet surface in the rotating container; R_0 the radius of billet in the rotating container; and l_0 is the length of rotating container.

The angle γ is shown in Fig. 2,

Considering a point P outside the material contacting with the inside surface of rotating container, the resultant velocity of P can be divided into axial component Δv_y and circumferential component Δv_φ.

The angle γ can be defined as follows,

$$\sin\gamma = \frac{\Delta v_y}{\Delta v} = \frac{v_0}{\sqrt{v_0^2 + \left(\beta_1 \omega_d R\left(\frac{y}{l+l_0}\right)^2\right)^2}} \quad (5)$$