Mechanics Research Communications 61 (2014) 27–35

Contents lists available at ScienceDirect

Mechanics Research Communications

journal homepage: www.elsevier.com/locate/mechrescom

An analytical model on twisting deformation of rod extrusion through conical die with rotating container

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ARTICLE INFO

Article history:
Received 5 March 2014
Received in revised form 24 May 2014
Accepted 16 July 2014
Available online 24 July 2014

Keywords:
Rotating container
Twisting deformation
Theoretical analysis
Upper-bound method

ABSTRACT

Reducing energy consumption and improving material properties of the extrusion processing are important problems to be solved. The application of torque on the container can transform the friction distribution on the outside surface of billet during the extrusion, and a component of friction force need to be overcame. Due to the large contact area between container and billet, the effect and significance of this method for load reducing appears. In this paper, on the basis of a reasonable assumption to velocity field in the process of rotating container, the twisting length of the billet inside the stationary container was derived by the use of the upper-bound method. The comparison result indicates, when the rotating speed of container lies in a specific range (0–1 rad/s), the average extrusion pressure applied by the punch decreases apparently with the friction increasing. Unlike the traditional extrusion which usually decreases the friction factor in order to improve the properties of the material. Although the relative slippage inevitably occurred between the billet and the container, the optimum results could be obtained by optimization of the slippage parameters.

1. Introduction

Extrusion is not only easy to realize large amount of plastic deformation, but also in favor of the improvement of production quality and performance. And numerous researches were carried out by employed upper bound analysis (Xu et al., 2010; Dozio, 2010; Pastor et al., 2011). Therefore, extrusion was commonly used in the processing of the materials with high deformation resistance and low plasticity (Sheppard et al., 2013). But the high consumption of energy and the poor uniformity of products performance always restrict the development of extrusion process.

A large numbers of investigations show that, imposing a torque on the container has some influences on the billet deformation, stress characteristics and structure properties etc. (Gronostajski et al., 2000; Beygelzimer et al., 2003; Kong et al., 2001; Lin and Huang, 2002) in the plastic volume deformation. Scholars have begun to impose a torque on the mold used for extrusion. Sergeev (1991) had studied an extrusion processing in which torques in opposite direction were respectively being applied on the punch and die simultaneously, and a number of small shallow holes were distributed uniformly at the end of the punch. These holes increased the friction coefficient. The distribution of contact stress between billet and mold could be changed, and the axial load of the punch could be reduced. Ma et al. (2004, 46, 449–464) and Ma et al. (2004, 46, 465–489) deeply analyzed the forming process of the extrusion through rotating dies, and deduced the theoretical expression of the twist angle on the outside surface of the billet inside the die and the container. The expression of extrusion load was also studied. The studied results show that not all the rotary work was delivered to material. When the rotating speed of the die reached a certain level, an energy loss would be appeared because of the relative slippage between the billet and the die. Comparing the theoretical results with the experimental results, a reasonable agreement verified the correctness of the theoretical results. It provided a powerful basis for predicting the billet deformation during the forward extrusion through rotating dies. Meanwhile, through the reasonable assumptions of the die velocity and the boundary restraint conditions, the theoretical expression was simplified. Ma et al. (2003) carried the twisting-compressing experiments through a rotating die. The results show that there would be an obvious decrease appearing with the rotating speed increasing. The deformation of the billet becomes more uniform. They also analyzed the twisting-compressing with a rotating die by the use of upper-bound method. Jahedi and Paydar (2010) carried out the microstructure analysis of the commercially pure aluminum powder that was consolidated at 350 °C through torsion extrusion. Research results show, imposing

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http://dx.doi.org/10.1016/j.mechrescom.2014.07.004
0093-6413/

torque on the die can significantly increase the shear strain of billet during the extrusion, so as to improve the mechanical properties and obtain the dense micro-structure. Maciejewski and Mróz (2008) studied the influence of the axisymmetric extrusion assisted by the cyclic torsion. The extrusion load and torque were characterized by the use of the upper-bound analysis. The results show that, extrusion load would be reduced to a certain value, but it depends on the process parameters. Chino et al. (2008) and Chino et al. (2010) researched the forward extrusion through rotating dies by experiments. The experiments results show, imposing a torque on the die can not only effectively reduce the extrusion load, but also improve the microstructure and properties of the products.

In a word, imposing a torque on the mold to change the metal flow behavior is one of the important approaches to improve the quality and the properties of the products. But many of the related studies focus on the extrusion which imposes a torque on the punch or the die, the investigations of rotating container are rarely reported. On the basis of proposing the forward extrusion through rotating container, characteristic regions and the twisting deformation of the forward extrusion through rotating container are researched.

2. Process principle

From the above analysis, the method of extrusion through rotating die is only appropriate for billets with a circular cross-section. For the forming of the billets with a rectangular section, a criss-cross section and an I-section, the crack of the axial streamline was inevitably caused along the cross section. Due to the change of the die friction condition, the stress distribution become more complex, the uniform metal flow velocity and the distortion defect are easy to appear. Due to the characteristic of the extrusion, the contact area between billet and die is limited. And this method cannot satisfy the actual requirements of production and application.

If a torque is applied to the container, the problem will be solved. Due to the large contact area between the billet and container, the effect of energy reducing will be more significant. Therefore, the method of extrusion through rotating container had been put forward (Li et al., 2011). According to the different ways of imposing torque, they can be divided into full-container rotation and semi-container rotation. The process principles are shown in Fig. 1.

Fig. 1 shows that, as a locating constraint tool before the billet is extruded from the die, the container requires auxiliary location device and structure to realize global rotation, at the same time, the stability and reliability of the structure were considered. Semi-container rotation can simplify the structure. In the semi-container, half of the container is stationary during the extrusion, and a torque is imposed on the other half. From the processing characteristic, plastic deforming zone is mainly located at the inlet of die during the extrusion process. However, the same effect can be achieved through semi-container rotation.

3. Deformation analysis

3.1. Basic assumption

During the extrusion, due to the combined effect of torque and friction, significant twisting deformation occurred. According to the deformation characteristics of billet, it can be divided into *I, II* and *III* three zones. And the interfaces between the three zones are assumed as *bc*, de and *fg*. In order to use the upper-bound method in the subsequent study, a similar distribution of circumferential angular velocity on the outer space of billet has been assumed on the basis of the analytical results that obtained by Timoshenko and Goodier (1969) and synthesizing the deformation characteristic zones, as shown in the Fig. 2. The billet was assumed to be rigid-perfectly plastic material (Dozio et al., 2010). Twisting deformation of billet occurs in the stationary container, die and rotating container during the rotation of the container. A cylindrical billet with a radius of R_0 was extruded through a die angle of 2α and radius of die exit was R_f. The extrusion velocity of punch was v_0. The extrudate emerges with a velocity of v_f as a rigid body. Due to the effect of the friction in the stationary container, the billet in it cannot be twisted overall. Assuming the length of billet which torsion occurred in the stationary container is l. β_1 was the circumferential slippage parameter (rotating speed ratio of billet at the exit of rotating container to rotating container); $\beta_2 = \beta_1\delta^2$ was also the circumferential slippage parameter (rotating speed ratio of billet at the entrance of the rotating container to the rotating container); ω_d was the rotating speed of the rotating container.

It can be seen from Fig. 2, zone *I* in which a reasonable distribution of billet twisted has been assumed, was the distribution of

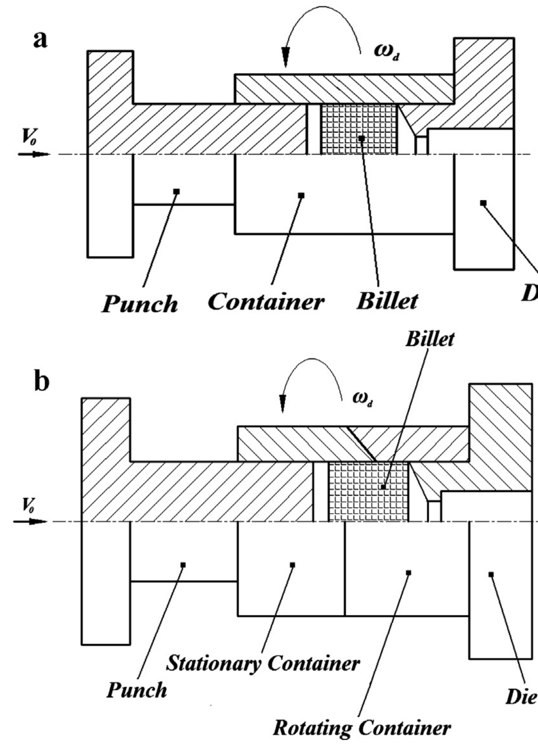

Fig. 1. (a) Process principle of full-container rotation; (b) Process principle of semi-container rotation.

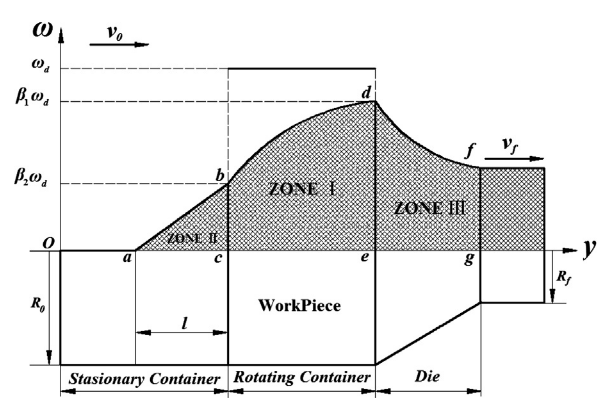

Fig. 2. The distribution of circumferential rotating speed of billet at the outside surface during extrusion through a rotating container.