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Short communication

An upper bound solution to extrusion of circular billet to circular shape through cosine dies

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Abstract

Metal forming by extrusion is one of the widely used metal forming processes. Conventionally the extrusion is carried out using the shear faced dies. In these dies the metal is forced to go through abrupt change in cross-section. Hence, they suffer from the practical problems such as formation of dead metal zone, non-uniform flow of metal, more redundant work and designed based on empirical methods. Modifications have been done in the extrusion dies to incorporate gradual reduction in the area of cross-section in order to ensure smooth flow of metal and to dispense with the problems faced by the conventional dies. Such modified dies are known as streamlined extrusion dies. The profile of the streamlined extrusion dies is the crucial parameter to optimize the extrusion process. Many profiles such as third order polynomial equation, fifth order polynomial equation, Bezier curve, etc., have been suggested for the design of streamlined extrusion dies with the view to reduce the extrusion load for the given reduction ratio. In this work the extrusion die is assumed to have the cosine profile to extrude circular billet to circular shape. The plastic deformation work required to extrude circular billet to circular cross-section through cosine profile based is determined using upper bound solution. It has been proved that the die designed based on cosine profile is superior to the conventional shear dies and the straightly converging dies. It is also proposed to validate the results by the experiments.

Keywords: Extrusion; Upper bound; Cosine die

1. Introduction

Extrusion is the process by which a block of metal is reduced in cross-section by forcing it to flow through a die orifice under high pressure. Extrusion dies are used in the industries for high production rate and accuracy in the metal forming process. There are many factors that affect the extrusion process like die profile, friction factor, extrusion pressure and temperature. The extrusion process is carried out conventionally by shear faced die, as shown in Fig. 1. But shear faced dies have many practical problems such as dead metal zone, breaking of whiskers, more redundant work and above all the design of shear die is done based on experience and made by trial and error methods. But these methods are approximate and time-consuming methods. The profile of the extrusion dies is the important parameter to optimize the extrusion pressure.

In earlier work, Nagpal and Altan [1] used the dual stream functions to obtain upper bound solutions for the extrusion of an ellipse from cylindrical billets. Yang and Han [2] proposed an analytic method for estimating extrusion pressure for arbitrarily curved dies using upper bound solution. The three-dimensional approach

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Nomenclature

R	radius of the billet
r	radius of the extruded component
$f(z)$	function of variable z
x, y, z	Cartesian coordinate system
c_1, c_2, c_3, c_4	constants
$g(z)$	function determined by the determinant
J^*	total power consumption
W_I	plastic deformation,
W_S	die surface friction
V_x, V_y, V_z	velocity components
V_0	velocity of billet
α, ϕ, ψ	angles
J	Jacobian
L	length of the die
P_{ave}	average pressure
R_s	the relative stress
σ_0	yield stress of the material
$\dot{\varepsilon}_{ij}$	strain rate components

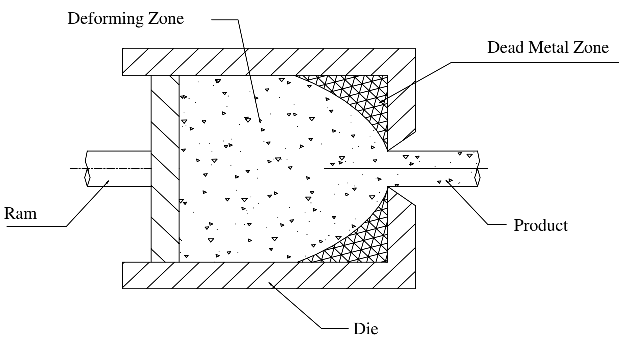

Fig. 1. Shear die.

for obtaining optimal die shape which produce minimal stress in the extrusion is explained elsewhere [3]. Yang et al. [4] analyzed the forward extrusion of composite rods through curved dies using flow function concept. An upper bound analysis for the extrusion of square sections from square billets through various curved dies is shown in [5]. Narayanasamy, et al. [6] proposed an analytical method for designing the streamlined extrusion dies. In this paper, the extrusion die is assumed to have the cosine profile and an upper bound analysis is proposed for the extrusion of circular section from circular billets. The material flow in the extrusion die does not remain on the same radial plane which contains the longitudinal axis, so that a three-dimensional approach is proposed in this paper.

2. Velocity functions

The velocity field that has been derived from incompressibility conditions, and which satisfies the velocity boundary conditions, is a generalized kinematically admissible velocity field. The following assumptions are required to construct the kinematically admissible velocity field for the extrusion of circular sections from circular billets. The circular billet passing through the points OAB at the die entry goes through points $O'A'B'$ at the die exit as shown in Fig. 2.

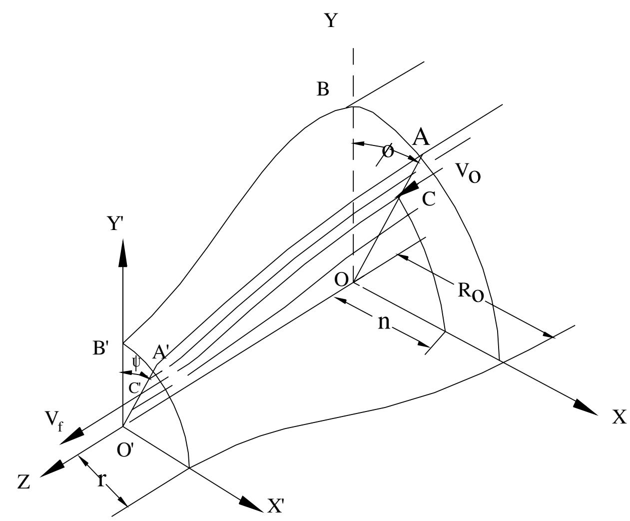

Fig. 2. A general deformation zone for cosine die.

Any coordinate along line AA′ as in Fig. 2 is formulated in a Cartesian coordinate system as follows:

$$x = c_1 \cos\frac{\pi z}{2L} + c_2,\quad y = c_3 \cos\frac{\pi z}{2L} + c_4,\quad z = z, \tag{1}$$

where the constants c_1, c_2, c_3 and c_4 are determined by the following boundary conditions. Consider that the line does not produce any abrupt change of flow direction along the extrusion axis at the entry and the exit of die, the boundary conditions being given for Eq. (1) as

$$\left.\begin{aligned} x = n\sin\phi\,\tfrac{\partial y}{\partial z} = 0 \\ y = n\cos\phi\,\tfrac{\partial y}{\partial z} = 0 \end{aligned}\right\} \text{ at } z = 0, \tag{2a}$$

$$\left.\begin{aligned} x = n\cos\psi\,\tfrac{\partial y}{\partial z} = 0 \\ y = n\cos\psi\,\tfrac{\partial y}{\partial z} = 0 \end{aligned}\right\} \text{ at } z = L, \tag{2b}$$