Mathematical Analyses and Numerical Simulations for Forward Extrusion of Circular, Square, and Rhomboidal Sections From Round Billets Through Streamlined Dies

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In the present investigation, an analysis using three-dimensional upper-bound method based on continuous velocity filed has been carried out for the extrusion of circular, square, and rhomboidal sections from round billets. The die surface representation in the present work could easily be applied to the extrusion of many different shapes just by defining the functions that describe the entry and exit sections and putting them into the general formulation. The die profile was tested for the third- and fifth-order polynomial functions. The extrusion process is also simulated using the finite element code, ANSYS (V 14.0), in order to assist the mathematical solution and to show the stress and strain distributions for the products when the strain hardening effect is taking into the account. Effects of friction, shape complexity, reduction of area, and die length on the extrusion pressure were also investigated. The results obtained in this work were compared with the theoretical results of other workers and found to be in highly compatible. [DOI: 10.1115/1.4035123]

Keywords: upper bound method, finite element, streamlined dies, extrusion process, ANSYS software

1 Introduction

The extrusion of shaped sections through continuous dies has been increasingly used to improve the quality of products and raise the productivity. However, the designing of optimal die shapes depends on the predictions of actual metal flow characteristics within the die under the given conditions [1]. Recently, analytical methods for predicting the metal flow during the three-dimensional extrusion of sections have been proposed by the following main researches that enable us to design extrusion dies, the most other works coming next built on these main researches. Nagpal and Altan [2] proposed dual stream functions to obtain a kinematically admissible velocity field that demonstrated a three-dimensional metal flow. Their model, however, was limited to the extrusion of ellipse bar or rod. Nagpal et al. [3] presented a computer-aided technique for the extrusion of T-section from round billets. The die was designed by dividing the initial and final cross sections into a number of sectors in which the extrusion ratio of these sectors is equal to the overall extrusion ratio. Yang and Lee [4] used conformal transformation techniques for the extrusion of generalized sections from similar billets in which the intermediate sections were transferred into a unit circle. This formulation becomes very complex for the extrusion of complex sections, also includes redundant work relating to the velocity discontinuities at the entrance and the exit sections of the die, respectively. Gunasekara and Hoshino [5] proposed a purely analytical work based on an upper-bound theorem for the extrusion of polygonal sections from round billets through curved dies. The geometry of the die was constructed by an envelope of streamlines between the entry and the exit sections. Kiuchi et al. [6] introduced a new concept in the upper-bound analysis of extrusion and drawing of sections through straight converging dies. They allowed for velocity discontinuities at entrance and exit sections of the die, respectively. Yang and Han [7] proposed their work for the extrusion of a rectangular section from round billet through curved die. The die surface was constructed analytically by using Fourier series expansion. The Fourier series was expanded for many terms until the rectangular shape is generated. A general kinematically velocity field was proposed by Abrinia and Bloobar [8] which becomes automatically admissible whatever the die geometry is used. A formulation was derived based upon the upper bound theorem. The die surface was constructed by the same concept as that used by Nagpal et al. [3] but the entrance and exit sectors were connected using the third degree Bezier curves. The effects of area reductions and friction factors on the extrusion pressure were discussed.

It becomes clear that the streamlined extrusion dies were designed by the following methods: (i) polynomial equation based dies [5,8]; (ii) area and line mapping technique [3,4]; and (iii) analytical method [2,6,7]. The aims of this work is as follows: (1) obtaining a new, easily, and systematic representation of the dies surfaces; (2) obtaining a 3D upper bound solution based on continuous velocity filed modified from Ref. [6] to evaluate the extrusion pressure of circular, rhomboidal, and square sections from round billets; and (3) obtaining 3D elasto-plastic finite element simulations to assist the mathematical models.

2 Kinematically Admissible Velocity and Strain Rate Fields

It is necessary to build the proposed kinematically admissible velocity field using streamlines concept. Figure 1 shows the general die shape in cylindrical co-ordinate systems in which the z- direction is coincident with the extrusion axis. The boundary limits for the die surfaces are given by

$$\begin{aligned} &0 \le r \le R_S(\theta, z) \\ &0 \le \theta \le \theta_{f(z)} \\ &0 \le z \le L \end{aligned} \tag{1}$$

Throughout this analysis, the following assumptions are employed [6,7]:

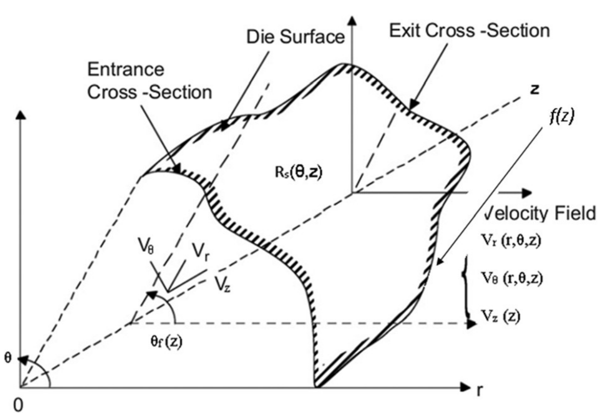

Fig. 1 General die shape [6]

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