Available online at www.sciencedirect.com
ScienceDirect
Materials and Design 29 (2008) 1182–1189
Materials & Design
www.elsevier.com/locate/matdes

A theoretical and experimental study for forward extrusion of clover sections

Tahir Altinbalik *, Önder Ayer

Trakya University, Faculty of Engineering and Architecture, Department of Mechanical Engineering, 22030 Edirne, Turkey

Received 3 January 2007; accepted 10 May 2007
Available online 25 May 2007

Abstract

Forward extrusion of clover section from different billet diameters has been investigated. The die profile is given by radius function to construct the new kinematically admissible velocity fields for three dimensional extrusion and then by using the upper bound method total extrusion loads are obtained. In the experimental studies, lead billets which having same initial heights but three different diameters have been extruded with the same strokes in order to verify the analysis. Die land length/billet diameter ratio was taken equal or greater than 0.6 as recommended in literature. A good agreement was found between the measured and the predicted load and so it is suggested that present analysis could be used the other commercial materials.

Keywords: Extrusion; Upper bound analysis; Clover

1. Introduction

Extrusion is an important metal forming process where the cross-sectional area of a block of metal utilizing force on it to flow through a die related with a certain shape. The extrusion process has been affected by many factors such as die profile, frictional condition at the tool–workpiece interface, mechanical properties of the material and extrusion ratio [1]. It has been a focus center for the researches to study of extrusion process because of significance of industrial field. Approximately, one-third of the annual world aluminium production of 20 million tons is delivered as extruded sections. [2] The basic needs of this process are to succeed the desired product providing exact mechanical and metallurgical properties without having any defect. The manufacture of high strength products with good surface finish is maintained to use cold shape extrusion in a large extent. Cold extrusion is used an area of application from simple axisymmetric products to complicated sections such as gears and splines as an umbrella process. During the extrusion process, the design of die profile plays an important role about load and energy requirement, surface quality of product, heat generation and dead zone formation and defect occurred on the product. Predicting the required forming load with a reasonably accuracy in a simplified way and to guarantee complete filling of the die cavity for each protrusion are taken into the consideration to determine the major design parameter in the design of the cold extrusion.

Instead of conventional machining, the forging process has been widely applied in manufacturing of gear or similar shapes due to the reduction of production cost. However process design with high precision is not easy since control of material flow is not simple for forging of near-net shape manufacturing. On the other hand, process design with high precision has some disadvantages of close control of material flow in the conventional forging process. The most striking barrier in the forging of gear is to be obtained the evolvent profile and filling of the sharp tip of the gear in the die in some conditions. As it is known high forming loads are not only related with product quality but also related

* Corresponding author. Tel.: +90 284 226 1217.
E-mail address: tahira@trakya.edu.tr (T. Altinbalik).

0261-3069/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2007.05.004

Nomenclature

e, q	optimization parameters
$f_1(z)$, $f_2(z)$	profile functions
d_0	billet diameter (mm)
L	die length (mm)
L_b	length of the billet (mm)
r, θ, z	cylindrical coordinates
$R(\theta,z)$	radius function
$\Omega(\theta,z)$	continuous function relating to V_θ (rad/s)
m	friction factor
V_m	mean velocity (mm/s)
V_0	punch velocity (mm/s)
V_r, V_θ, V_z	velocity components of cylindrical coordinates
ΔV	velocity discontinuity
W_d	internal power of deformation
W_{fd}	frictional power consumption in the die
σ_0	flow stress of the material (MPa)
τ	frictional shear stress (MPa)
J^*	total energy
F_{fc}	frictional force between material and the container (kN)
x	die land length (mm)

with the tool life. Therefore it is suggested that the convenient geometrical parts may be manufactured by using extrusion process.

In previous works dealing with effects of die geometry, extrusion speeds, loading rates and aspect ratios of billets on the extrusion pressure of cold extrusion process have been undertaken by various researchers [3–6]. Onuh et al. [7] studied the effect of the extrusion speed and die geometry in the cold extrusion of aluminium and lead alloys. In his paper different extrusion parameters such as die angles, reduction in area and extrusion speed on the quality of the extrusion product were investigated experimentally. He also demonstrated that the frictional load is virtually independent of the section shape. A study was carried out by Gouveia et al. [8] using the Lagrange and Euler–Lagrange functions to modeling the cold extrusion process. He also compared the numerical results taken from simulation with those experimental results. Shafry et al. [9] studied three dimensional die design for extrusion. In his study, he demonstrated that specimens of the same shape complexity factor but different profiles extruded with almost the same extrusion loads. In another study, Lee et al. [10] described that for the purpose of general surface model on a gear–spline part and applied the UB analysis with optimum die-surface design in extrusion. He also offered a general surface model to define the geometry of the product without using analytical functions. A theoretical study was done by Song and Im [11,12] to the determination of the effect of teeth number on load and die filling ratio for forward extrusion of spur gear. Song defined the major design parameter which describes the risk of having underfilling in gear extrusion and suggested that its value should be over 2.6. A generalized analysis was suggested by Yang et al. [13] using the upper bound method with different die geometries of arbitrarily shapes. The theoretical analyses were carried out for the extrusion of square, rectangular and elliptic sections from round billets but experiments were only done the square and elliptic sections for aluminium alloys at room temperature. In the mentioned study, product shape complexity, the effects of area reduction, die land and frictional condition were discussed in relation to extrusion pressure. Gunasekera and Hoshino [14] contributed on an upper bound solution for the extrusion of polygonal sections using cylindrical billets. In the mentioned study Gunasekera choose a flat-face die and simulated the material flow over the dead metal zone which was supposed as a streamlined die. Han et al. [15] made a similar work with Gunasekera choosing a clover section which is often used for cams and trochoidal gears of external gear pumps. Required velocity field for upper bound solution was derived with the help of analytical function of die surface by Han. Therefore, the kinematically admissible velocity fields were obtained in a less computer time and shortened calculation period. Han expressed that this method could be suitable to use of effective die design and control of material flow in the complicated three-dimensional extrusion process. However, the dies which were used by Han would produce the change of flow direction both inlet and outlet of the die, on the other hand this situation was taken into consideration as velocity discontinuities.

Ajiboye and Adeyemi [16,17] investigated experimentally and theoretically the extrusion pressure of shaped sections. In mentioned study the effect of the die land in cold extrusion of lead specimens was investigated and simulated the process by using generalized UB analysis. Ajiboye recommended that the die land length/billet diameter ratio preferred equal or to greater than 0.6 not to bend of extruded product for designing a convenient extrusion die to extrude lead material. Ajiboye was formulated die surface to ease the metal flow as Han did and solved the upper bound equation. However the exit cross-section which used in the experiments by Ajiboye was not clover-section. The analysis of the extrusion pressures by the upper bound method have been extended theoretically by Ajiboye for the evaluation of the extrusion pressures to complex extruded sections such as square, rectangular, *I* and *T*-shaped sections in another study [18].

In the present work, the die profile is given by radius function to construct the new kinematically admissible velocity fields for three dimensional extrusion. It is known that close observation of the dead metal zone is, in gen-