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Die design and experiments for shaped extrusion under cold and hot condition

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Abstract

The paper presents designing, fabrication and experiments for shaped extrusion of aluminum alloy (Al 2024) and lead alloy (70Pb30Sn). Flat and conical dies of H, T, L, elliptical and two-hole sections have been designed on the basis of upper bound technique by the authors for cold and hot extrusion. Hot extrusion has been performed in the temperature range 300–500 °C. Experimental investigation have been conducted for average extrusion pressure in cold case for lead alloy (70Pb30Sn) billets and in hot case for commercial grade aluminum (Al 2024) billets respectively. Extrusion pressure in the both cases has been compared with the theoretical work by the author for cold extrusion and for hot extrusion of aluminum alloy, result have been compared with a finite element based commercial package HyperXtrude. Theoretical results obtained by the upper bound technique and the HyperXtrude compares well with the experiments.

Keywords: Extrusion; Upper bound technique; Finite element method; Die design

1. Introduction

An extrusion die through a proper die arrangement plays an important role to extrude complicated shapes. Different dies have been used for cold and hot extrusion of solid as well as hollow sections. The aim of die design has been to withstand a long die life with better mechanical and metallurgical properties for extruded products without defect. A good die design involves: design of optimal die length with proper bearing length and surface finish, selection of die profile, die arrangement, run speed and proper heat treatments, etc.

An extensive literature exists on optimal die profile and design based on power minimization criteria using the slip line field technique, the upper bound technique and the finite element method. Gunasekera and Hoshino1 [1], Yang et al. [2], Balaji et al. [3], Joun and Hwang [4]; Reddy [5] and Kumar et al. [6] are some of them. Several attempts have been made to analyse cold as well as hot extrusion problems. Some of the cold cases are due to Gatto and Giarda [7], Boer and Webster [8], Lee et al. [9], Yang et al. [10–12], Gunasekera and Hoshino [1], Shim et al. [12], Joun and Hwang [13,4], Onuh [14] and most recently by Kumar et al. [15,16]. A variety of sections both simple and complicated including many with re-entrant sections are cold extruded economically with high-dimensional accuracy. There has been a considerable interest in the investigation by Fragomeni [17] on the effects of die profile geometry and extrusion parameters for structure of flow patterns, extrusion pressure and mechanical properties of the product.

Many authors have shown that streamlined dies are superior to straight converging dies for reducing extrusion pressure in cold as well as hot conditions. Kumar et al. [15,16] proposed a feature-based upper-bound analysis with strain hardening suitable for die design of non re-entry and re-entry cold extrudable shapes. In case of hot extrusion, some of the recent attempts are due to Altan et al. [18], Sheu and Lee [19], Hao and Li [20], Zienkiewicz et al. [21], Smelsor [22] and Reddy et al. [23]. Recently commercial software HyperXtrude [24], DEFORM-3D and FLUENT are being used for hot extrusion die design extensively. HyperXtrude [24] is hp-adaptive finite element program to analyze fluid flow and heat transfer problems commonly encountered in plastics and metal processing industry where materials undergo plastic deformation and flow is described by incompressible Navier–Stokes equations. HyperXtrude saves design and analysis engineer's time from performing several mesh generation and analysis cycles that are common with conventional numerical tools.

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In the present work an attempt has been made to design and fabricate solid extrusion dies along with backers for H, L, T, two-hole and elliptical sections and to analyze extrusion under cold and hot conditions for the commercial grade aluminum (Al 2024) and the lead alloy (70Pb30Sn), respectively. Load versus ram displacement obtained from the experiment has been compared to verify with the theoretical work Kumar et al. [15,16] for cold extrusion of lead alloy. Commercially available FE software HyperXtrude [24] has been used to verify the hot extrusion case of the aluminum alloy.

2. Design and manufacturing of extrusion die

Geometry and profile of an extrusion die constitute very important aspect of die design and determines the extent of redundant work done during the deformation. It cannot be totally avoided in extrusion process rather it can be minimized by choosing a proper die profile that minimize the extrusion pressure. Optimal die profile has been expressed as a function of several parameters as a polynomial with multiplying constants. The present work is mainly related to design of dies for solid sections to full-fill the following requirements as: (i) to design accurate dimensions and product shape, so as to avoid need for any corrective work, (ii) to have the maximum possible working life, (iii) to have the maximum length of the extruded section, (iv) with a good-quality surface finish maintaining over many extrusions (i.e. infrequent die cleaning), (v) high extrusion speeds, and (vi) to have a low manufacturing cost.

Following six factors have been considered in design and construction of a die design according to Laue and Stenger [25], i.e.: (a) the flow pattern, (b) maximum specific pressure, (c) geometrical shape of the section, (d) wall thickness and tongue sizes, (e) shape of the bearing surfaces, and (f) the tolerances of the section. Following five common basic rules are also followed for initial layout of a die for solid shape and to determine the position of die aperture as: (i) the center of gravity of the section, where most material flows should be placed as close to the edge of a die because the material tends to flow faster in the center than at the edge, (ii) large cross sections run relatively more quickly than smaller and thinner sections and therefore, allows for balancing to be achieved without different bearing lengths, (iii) symmetrical section is always placed with the axis of symmetry considering with centre of a die, (iv) in case of multi-hole die, the aperture should be arranged as symmetrically as possible, (v) layout of a multi-hole die is arranged to prevent extrusions from rubbing together or running on top of each other as they leave the press, and (vi) length of the die lands should be at least twice the wall thickness for aluminum section with minimum value of 2.5–3 mm.

The dimensioning of dies has been made according to stress criteria proposed by Laue and Stenger [25] and proper tongue length and die deflection rules have been considered in the die design. Pressure on the die, bending of the die, shearing stresses and equivalent stresses due to bending and shearing have been calculated according to Schmoeckel et al. [26] and Vijay [27]. For conical and flat dies, rules proposed by Laue and Stenger [25] are followed for the proper die bearing and corner radius design.

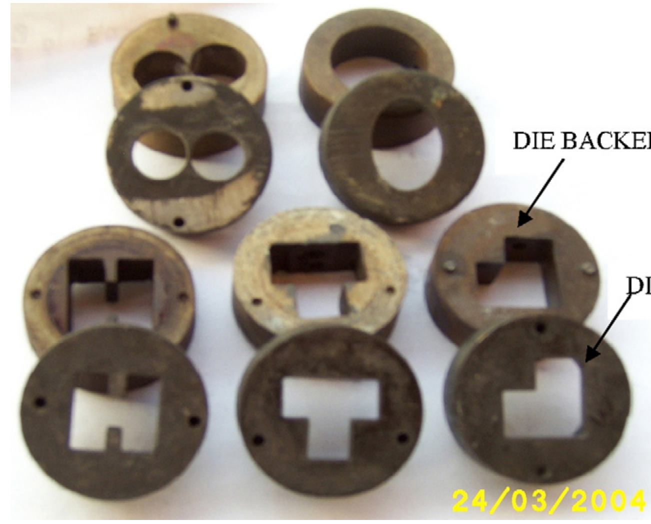

Fig. 1. Designed dies the die backers.

Thickness of the die depends on extrusion load and therefore a proper die backer is required. Following thicknesses 13, 15, 20, 25, 30, 40, 50, 70 and 100 mm are commonly used for backer design as standard practice.

Three factors have been considered in selecting a proper material for a die and the die backer and the pressure pad. These include (a) press capacity, (b) pressure required for extrusion, and (c) maximum temperature developed. The extrusion set-up toolings as fabricated by Bishwajit [28] has been used to conduct all the experiments mentioned. The set-up includes die and die holder, ram, dummy block, die backer, pressure pad, bolster, and horseshoe clamp and die holder carrier, etc.

After careful design of an extrusion die and the backer, it is manufactured by machining. Dies and pressure pad are hardened by heating up to 800° C at the rate of 400° C per hour and holding at 800° C for 2 h inside a heating chamber and then quench to servo-cutting oil. The fabricated dies along with die backers have been shown in Fig. 1.

A small billet heating arrangement (induction type) has also been fabricated. The temperature of each billet is measured and controlled in the said induction furnace using thermocouples to control the temperature ranging from 25 to 460° C. After heating to a desired temperature, the billet is removed form the induction coil and fed to the container for extrusion.

3. Experiments and validation

Experiments on the fabricated set-up by Bishwajit [28] have been performed using H, L, T, two-hole and elliptical dies manufactured in the Section 2. Average extrusion pressures for all the section is determined experimentally and load versus ram displacement curve have been drawn. A comparison of the extrusion pressure for cold extrusion of lead alloy is made with theoretical work obtained by the upper bound analysis Kumar et al. [15,16]. HyperXtrude [24] has been used to analyze the hot extrusion of aluminum alloy (Al 2024) using flat and conical dies. Following are the process