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Investigation of lubrication effect on the backward extrusion of thin-walled rectangular aluminum case with large aspect ratio

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Abstract

Backward extrusion processes are being increasingly considered for the manufacture of thin-walled rectangular aluminum case with large aspect ratio in lieu of multi-stage deep drawing processes. In order to design an optimized backward extrusion process, it is necessary to determine optimal frictional conditions by studying the effects of lubrication.

In this study, numerical analysis based on the finite volume method is performed for investigating the effects of solid lubricants in aluminum backward extrusion processes. Various shear friction factors are used in the numerical study for investigating the friction effects.

Lubrication is found to have a significant effect on the final shape. Larger friction factors are associated with increased forming heights on the wide side of the rectangular container and decreased forming heights on the narrow side. Lubrication is also found to have a significant effect on earing phenomena and a friction factor of 0.2 is found to be optimal for minimizing it. The analysis results presented herein are further validated by comparing them with experimental results.

Keywords: Backward-extrusion; Friction; FVM; Metal forming; Superforge

1. Introduction

Due to the ever-increasing demand for accurate and cost effective net shape forming, it has become very important to optimize manufacturing processes. Instead of using traditional design methods based on experiments, experience, and trial-and-error, the use of computers in the design of metal forming operations has become widespread to reduce both development time and cost.

Thin-walled rectangular aluminum cases are widely used as battery cases for cellular phones. These cases are traditionally produced by multi stage deep drawing processes, but these processes have some drawbacks with respect to the design cost, material waste and inconsistent wall thickness [1]. An alternative manufacturing process under consideration for producing these containers is the backward extrusion process. Currently, backward extrusion processes are widely used to produce circular beverage cans. It has been clearly demonstrated that for the circular cans, backward extrusion is more efficient than deep drawing not only based on forming equipment requirements but also based on material wastage in subsequent trimming operations. Though the backward extrusion manufacture of rectangular sectioned aluminum cases with section aspect ratio >10 is thought to be difficult to accomplish, it remains an attractive research topic due to the potential cost benefits associated with it.

Numerical simulations of the forming process are required to reduce expensive and time-consuming experimental design practice. The formulations and algorithms for such simulations are available and presented in the literatures [2].

In bulk metal forming, an initially simple part is plastically deformed between tools to obtain the desired final shape. If this process is optimized, products with complex shapes will be produced with minimal material waste. One of the most important considerations in optimizing metal forming processes is the friction between the workpiece and forming tools. Material flow is directly linked to the frictional conditions, and this in turn influences the required forming load and the mechanical properties

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of the final product. Other aspects of product quality, such as surface finish and dimensional accuracy are also affected by the friction condition. In addition, tool design, tool life, and productivity depend on the ability to determine and control friction.

Recently, Im et al. [3] used finite element analysis to investigate the frictional conditions associated with various lubricants in a backward extrusion of an aluminum alloy and proposed global average friction conditions for optimal metal forming. This work was, however, limited to liquid lubricants and circular sections. In this study, frictional conditions associated with metallic coated lubricants for rectangular section extrusions are investigated by numerical analysis. The numerical results are validated by comparing them to experimental forming results. Also, for the validation of the friction conditions, a ring compression test is performed.

2. Background

2.1. Finite volume method

The finite-element method (FEM) based on the Lagrangian method is considered to be an accurate method for analyzing the response of elasto-plastic materials, but such analyses is generally not well suited for the severe material deformations associated with many metal-forming processes, and can also result in long CPU time to carry out the computations. Some codes for metal forming simulations are based on the rigid–plastic finite-element method. The assumption of rigid–plastic or rigid–viscoplastic material implies that the flow stress is a function of strain, strain rate, and temperature and that the elastic response of the material can be neglected. This assumption is very reasonable in analyzing metal forming problems, because the elastic portion of the deformation is negligible in most metal forming operations [4].

In the finite-element method, grid points are defined that are fixed to locations on the body being analyzed. Connecting the grid points together creates elements of material, and the collection of the elements produces a mesh. As the body deforms, in the Lagrangian method, the grid points move with the material and the elements distort. The Lagrangian finite-element solver is, therefore, calculating the motion of elements of constant mass. Because of the severe element distortion common in metal forming operations, frequent finite-element remeshing is necessary to follow the gross material deformation.

On the other hand, the finite volume method is commonly used for material flow simulations of events like sloshing, underwater explosion and helicopter ditching. Unlike a traditional FE mesh which distorts with the material, the finite volume mesh acts as a fixed frame of reference and material simply flows through it. This is particularly suited for large three-dimensional material deformation such as forging, extrusion and so on, since remeshing techniques are not required.

The numerical results reported herein are obtained by using MSC.Superforge. The governing principles for MSC. Superforge are briefly described: The deforming workpiece flows through fixed finite volume meshes using the Eulerian formulation to describe the conservation laws. An explicit dynamic procedure is used for time stepping.

The governing equations consist of the conservation laws for mass, momentum and energy and the constitutive equations.

$$\text{Mass}: \quad \frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_i)}{\partial x_i} = 0 \tag{1}$$

$$\text{Momentum}: \quad \frac{\partial(\rho v_i)}{\partial t} + \frac{\partial(\rho v_i v_j - \sigma_{ij})}{\partial x_j} = 0 \tag{2}$$

$$\text{Energy}: \quad \frac{\partial(\rho e_t)}{\partial t} + \frac{\partial(\rho e_t v_i + h_i - \sigma_{ij} v_j)}{\partial x_i} = 0 \tag{3}$$

Here, ρ and σ_{ij} are the density and Cauchy stress tensor, respectively, v_i the velocity vector, and h_i is the heat flux. Total energy e_t per unit mass is given by $e_t = e + 1/2 v_j v_j$, where e is the internal energy per unit mass. Body force terms are not considered in the above expressions and are neglected throughout the present study.

When the governing equations are integrated in time in the Eulerian coordinate system, the time step can be split into an acoustic step and an advection step. In the acoustic step, the stress and impulse waves are assumed to propagate through the control volumes in the whole domain without transportation of the material. In the advection step, on the other hand, the material flows from one control volume to another and transports the corresponding properties without updating the physical quantity associated with the material.

2.1.1. Acoustic step

Under the assumption that the mass density is constant during one acoustic step, the conservation law of mass is satisfied automatically. The volume integral form for the impulse is reduced from the conservation law of momentum to:

$$\int_V \frac{\partial v_i}{\partial t}\,\mathrm{d}V = \frac{1}{\rho}\int_S \sigma_{ij} n_j\,\mathrm{d}S \tag{4}$$

where n_i is a component of the unit normal vector on the boundary S of the control volume V. The values on the faces of the finite volume elements can be obtained from solving the Riemann problem. Then the new velocity of the finite volume element is updated by using the velocity increment evaluated from Eq. (4).

The volume integral form for the conservation law of energy becomes:

$$\rho \int_V \frac{\partial e}{\partial t}\,\mathrm{d}V - \int_V \sigma_{ij}\dot{\varepsilon}_{ij}\,\mathrm{d}V = -\int_S h_i n_i\,\mathrm{d}S \tag{5}$$

which is used to derive the heat conduction equation.

2.1.2. Advection step

In the advection step, the material and corresponding properties are transported according to the velocity updated in the acoustic step without changing the value of the physical quantity associated with the material. The mass, momentum, energy and other properties (stress/strain, phase, etc.) are transported