Numerical simulation of backward extrusion process with local acting of active friction forces

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Abstract. This article presented the results of numerical analysis of the deformation forces calculation on the backward extrusion of box-shaped details including the active friction forces action. It is shown on the example of aluminium box-shaped details, that the numerical methods of the analysis based on finite elements method, give accurate results. This allows us to recommend numerical methods for calculation of the force values acting on the working tool in backward extrusion. In addition, a numerical research enables to predict the shape change of the workpieces at any stage of the backward extrusion process. All this allows drawing conclusions about the quality of the box-shaped parts and more considerably take into account the characteristic features of the deformation during the development of the technological process.

1. Introduction

Box-shaped products of various shapes and sizes are widely used in mechanical engineering and other industries. Most of these products are made with cold plastic deformation methods that allow obtaining parts with high accuracy and good quality. Box-shaped parts are produced mainly with cold backward extrusion from a bulk blank, or by stretching and bending from a sheet blank. It should be noted that the process of cold backward extrusion has significant drawbacks, such as high specific forces acting on the working tool, which requires the use of equipment with high-energy costs. Besides the process of backward extrusion of box-shaped products, in contrast to the backward extrusion of axisymmetric products, is characterized by a complex flow of metal and a large irregularity of deformations. Thereby, after backward extrusion, the parts have strong splashes of metal in the walls, i.e. the formation of festoons starts (height irregularity of the part wall), and it leads to large metal waste [1-3].

The accumulated experimental and production data on the backward extrusion process of box-shaped products are insufficient, and it leads to difficulties in the implementation of this process to production. Therefore, we have done the research concerning the theoretical and experimental study of the stress-strain state, the influence of lubricant, the active friction forces in places of difficult flow of metal (along the narrow walls of the boxes) and other factors of the backward extrusion of box-shaped products.

Modern theoretical studies of metal forming processes are largely based on numerical analysis methods, the most effective of which is the finite element method (FEM) [4]. As a rule, the study of technological metal forming processes is carried out on finite elements models describing the motion
of a continuous medium based on the Lagrange approach. In this case, the volume of the deformable workpiece is divided into elementary volumes forming a grid of Lagrangian finite elements (FE), the nodes of which belong to the workpiece material. Due to the fact that during deformation of the workpiece, Lagrangian FE are deforming and moving with the material [4-6]; in analyzing processes characterized by large deformations, it is impossible to obtain reliable results on the shape change of the workpiece due to distortion and degeneration of the FE-grid. This is because when large plastic deformations occur, a complex metal flow with mass transfer phenomena is observed, in which the fibers of the material obtain an oriented structure. However, besides the Lagrange approach of studying the behavior of a continuous medium, there is an Euler approach in which the various fields characterizing the motion of a continuous medium [4-7]. These fields are the object of research and the stationary space of an observer filled with a moving medium is studied. In this case, the Eulerian grid of the FE model remains constant in time and is not distorted along with the material, and during the solution, the motion of the deformable continuous medium inside the Eulerian FE-grid is considered. As a result, it becomes possible to solve the problem of large deformations and to take into account the phenomena of mass transfer in modeling the technological metal forming processes which are characterized by large plastic deformations [6-11].

This article is dedicated to a three-dimensional finite element simulation of the backward extrusion of box-shaped parts based on the Eulerian behavior of continuum in the ANSYS / LS-DYNA finite element package [12].

2. Finite elements model of the backward extrusion the box-shaped parts and formulation of the research problem

Due to the fact that the process of backward extrusion of box-shaped parts with the same wall thickness and relative to parallel sides is symmetrical was considered a quarter of the section of the workpiece and the tool as shown in Figure 1(a).

![Figure 1. Solid (a) and finite element (b) models of the backward extrusion process.](image)

The Euler model of the workpiece and the space, in which the metal flow was studied, was formed from 66940 three-dimensional solid-state hexahedral elements with the same elastoplastic properties as shown in Figure 1(b). The working tools (matrix and punch) were modeled in a Lagrangian formulation using rigid shell elements that were in contact with the Eulerian FE-model. To describe the interaction of Lagrangian elements with the Euler environment used the built-in capabilities of the LS-DYNA software package. The speed of the punch movement was taken constant and equal to 10 mm/s.

The study of the backward extrusion process was carried out for aluminum AD1, copper M1 and lead C1 box-shaped parts (non-ferrous metal grades correspond to Russian designations). In addition,
was simulated twelve variants of sample deformations for each type of material. The parameters of the backward extrusion model the box-shaped parts are given in table 1.

**Table 1.** The parameters of the backward extrusion the box shaped parts.

| Process parameters | Box wall thickness |
|--------------------|--------------------|
|                    | 2 mm  | 4 mm     |
| Workpiece width, mm| 20    | 20       |
| Workpiece length, mm| 50    | 50       |
| Workpiece height, mm| 9     | 13       |
| Punch stroke, mm   | 7     | 9        |
| Punch rounding radius, mm| 0.5 | 0.5 |
| Matrix rounding radius, mm| 1 | 4 |

As it was noted before, the behavior of the workpiece materials was described by a model with elastoplastic properties as shown in Figure 2. The tool material (punch, fixed matrix and movable wall of the matrix) was considered as rigid.

**Figure 2.** Elastoplastic characteristic of non-ferrous metals with bilinear isotropic hardening.

Let’s consider the principle of determining the specific deformation forces in the backward extrusion of workpieces using the example of extruding aluminum alloy AD1, whose mechanical characteristics in cold deformation can be described by a model of an elastoplastic medium with bilinear isotropic hardening as shown in Figure 2 with the following characteristics: flow stress \( \sigma_f = 35 \) MPa; elastic modulus \( E = 0.72 \times 10^5 \) MPa; hardening modulus \( E_y = 170 \) MPa; Poisson’s ratio \( \nu = 0.31 \); density \( \rho = 2710 \) kg/m\(^3\). The speed of the punch movement corresponded to the press characteristics and was taken to be constant and equal to 10 mm/s [13].

3. **Research results**

The results of the calculation of the power parameters of the backward extrusion the boxes from aluminum alloy AD1 with a wall thickness of 2 mm and a friction coefficient of 0.2 under various conditions of deformation are presented in the graphs of Figure 3.
**Figure 3.** The dependence of the change in specific forces (pressure on the punch) (MPa) on the bottom thickness in backward extrusion of aluminium AD1 with the wall thickness of 2 mm and a friction coefficient of 0.2 for box-shaped parts: 1 – the wall is stationary; 2 – the wall is free; 3 – the narrow matrix wall is movable, the advance is 1.9.

On the graphs of Figure 4 there the results of the analytical calculation (curve 1), the results of numerical FEM analysis (curve 2) and experimental data (curve 3) the dependence of the specific forces of backward extrusion of the box-shaped parts from the punch stroke.

**Figure 4.** Change of punch specific forces depending on the punch stroke in cases of backward extrusion without active friction forces (a) and the backward extrusion with active friction forces acting along the narrow walls of the matrix (b): 1 – results of an analytical calculation; 2 – the results of numerical FEM analysis; 3 – experimental data.
It was found as a result of analytical and numerical calculation that the nature of the change in specific forces is the same for both cases of the backward extrusion process – in case when active friction forces are don't act and when the active friction forces acting along the narrow walls (see Figure 3). At the same time, there is a good convergence of the results obtained analytically and using the FE-method with practical ones (see Figure 4) [13, 14].

The analysis of the graphs of the analytical calculation of specific forces deformation (see Figure 4, curve 1) has showed that at the second stage of backward extrusion, when the penetration depth of the plastic deformation zone under the punch is less than the height of the workpiece under the punch, the deviation of the calculated data obtained analytically and numerically, from experimental results does not exceed ~10%. However, at the third stage of backward extrusion, when the depth of penetration of plastic deformation is equal to the height of the workpiece under the punch, there are significant discrepancies between theoretical and practical results. In addition to modification the nature of the change in specific forces, deviations between theoretical and practical results at the end of process reach ~25%.

Due to the fact that the graphs built on analytical dependencies and on the basis of a numerical FEM experiment are identical, it can suggest that at the third stage of the backward extrusion process there is a discrepancy in the values of some parameters (primarily the friction coefficient) of the process adopted in theoretical studies and in the practical implementation of the process.

In addition, during the calculation, some parameters affecting the force of backward extrusion, such as the deformation of the tool and the matrix, the change of the friction coefficient in the developed plastic zone of the deformation area were not investigated, while in theoretical studies, the tool was considered absolutely rigid, and the coefficient of friction is constant.

However, the results of theoretical and experimental studies (see Figure 3 and Figure 4) showed that the use of active friction forces only along the narrow walls of the matrix made possible to reduce the force of backward extrusion to ~10%. Obviously, this is because of the fact that under the action of active friction forces, the penetration depth of plastic deformation is deeper than in the first case of process by ~13…20)% and, therefore, the influence of small external zones operating in the elastic zone energy on the energetic and power parameters of the process is not so noticeable.

Besides the deformation forces, the workpiece shape changing was determined in numerical method of analysis of backward extrusion. So, the Figure 5 shows the contours of the deformed workpiece from aluminium alloy AD1, obtained by backward extrusion without the action of active friction forces and taking into account the action of active friction forces along the narrow wall of the matrix with advance in 1.9.

It was found as a result of the numerical experiment, that in the first case of the process of backward extrusion, proceeding without the action of active friction forces, the difference in height between the wide and narrow walls of the box reaches ~6.35 mm. In this case, the height of the wide wall is ~22.75 mm and it is higher than the height of the narrow one. In the second case, under the action of active friction forces on the narrow side of the matrix with an advance in 1.9, the difference in wall height reaches ~0.10 mm, and the height of the wide wall is ~20.20 mm and it is less than the height of the narrow one.

Moreover, the numerical FEM modeling of the backward extrusion process has showed that in the deformation process, there is weighting of the metal in the corners of the boxes from the matrix bottom as shown in Figure 5. Exactly the same effect was observed in the practical implementation of the process. It was determined as a result of numerical FEM modeling, that in backward extrusion without the action of active friction forces, the weighting begins at a box bottom thickness of ~(1.75...1.7)a. When extruding with the action of active friction forces, the metal weighting in the corners begins at a box bottom thickness ~(2.3…2.2)a, where a – is the box wall thickness.
The punch stroke, mm | The workpiece appearance
---|---
0 | ![Image](a)
3.5 | ![Image](b) ![Image](c)
7 | ![Image](b) ![Image](c)

**Figure 5.** The appearance of the deformed workpiece at different points in time: (a) – not deformed workpiece; (b) – backward extrusion without active friction forces; (c) – backward extrusion with active friction forces.

On the Figure 6 can be seen the photographs of boxes pressed-out in the experiment under the same conditions in which the calculation was performed for punch stroke the 7 mm. Comparison of results shown in the Figure 5 and Figure 6 shows that there are practically no differences between the shape of the upper part of the samples obtained by a numerical solution and as a result of a full-scale experiment.

**Figure 6.** Appearance of samples from aluminium alloy AD1 obtained by backward extrusion with lubricant made of with a wall thickness of 2 mm: (a) – backward extrusion without active friction forces; (b) – backward extrusion without active friction forces and with a free loose matrix (advance in 0.5); (c) – backward extrusion with active friction forces along the narrow walls of the matrix with a speed of advance 1.5; (d) – backward extrusion with active forces of friction along the narrow walls of the matrix with the advance speed of 1.9.
4. Conclusions
As a result of the theoretical studies, we have obtained the mathematical models that allow determining the deformation forces and the shape of the boxes at any stage of the backward extrusion process, including the conditions of actions of active friction forces.

It has been established that analytical dependences and numerical methods for FEM analysis based on the Eulerian description of the motion of a continuous medium give the qualitative results suitable for calculating the forces affecting a working tool in backward extrusion. The nature of the forces change, calculated analytically and numerically, agrees well with the experimental data.

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