BACKWARD COLD EXTRUSION OF ALUMINUM AND STEEL BILLETS BY NON-CIRCULAR PUNCH

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Abstract

One of the significant trends in current development of cold extrusion technology is to broaden the assortment of the workpiece complexity. In this regard cold extrusion of non-axisymmetric components makes possible to extend implementation of this technology in industrial practice. Current paper deals with backward extrusion with the non-circular punch in order to determine main process characteristics, such as load-stroke diagram and average pressure. Process has been investigated numerically (FE Simufact Forming v10 code) and experimentally. For the experimental work special tooling was designed and made. Mild steel and aluminum material were employed. Relevant conclusions are drawn.

Keywords: cold extrusion, non – circular punch, load, pressure, FE analysis, experiment

1 Introduction

Cold extrusion of steel is characterized by improved mechanical properties of the workpiece, minimum material and energy consumption and short production time. Owning to these advantages cold extrusion is successfully applied in different branches of manufacturing industry, especially in car production [1-2]. Further development of this technology goes towards even broader industrial implementation, which can be achieved by introducing various improvements and innovations in the process planning and process realization. One of the important focal point in this direction is increase of the range of workpiece complexity. In this regard extrusion of non–axisymmetric components significantly extends the spectrum of possible workpiece geometries.

There has been relatively little work on this subject. In [3] author presents the investigation of backward extrusion with various punch geometries. Container stresses was determined analytically and experimentally.

Analytical calculation of forces in extrusion with non-circular punches is proposed in [4]. Obtained results for circular and non-circular punches are compared and discussed.

In [5] authors investigated impact of punch head geometry on main parameters in backward extrusion process. Stress distribution within the workpiece volume as well as radial stress at the container wall were determined and analyzed.
Double backward extrusion with simultaneous material flow in two different directions was analyzed analytically, numerically (FE) and experimentally by [6]. Positions of neutral radius, i.e. radius where no radial movement of the material takes place was predicted as well as maximum axial stress. It has been determined that friction exhibits a significant influence on both investigated parameters.

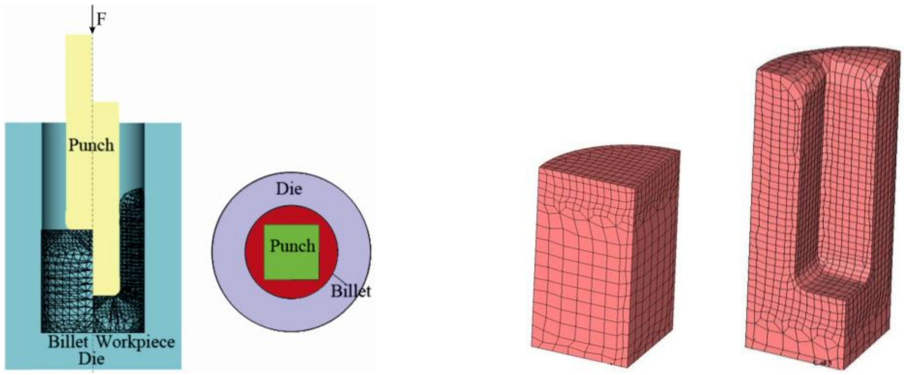
Plancak et al. [7] examined non-conventional cold extrusion process. Material flow as well as force-load characteristics for two different extrusion operations have heed determined.

Current paper elaborates numerical and experimental analysis of backward extrusion by the punches with square cross sections. Materials of workpieces were mild steel and aluminum. Two different lubricants were used in order to determine the impact of friction on load – stroke characteristics and average punch pressure.

2 Numerical simulation

Backward cold extrusion of cylindrical billet by the punch with square cross section was analyzed numerically using Finite Element Method, program package SimufactForming V10. The die, punch and billet used in simulation were modeled in CAD program SolidEdge V18, transformed into .stl file and then imported in SimufactForming. In **Fig.1** punch, die and billet in initial and final process phase (a) and a quarter of the billet with mesh before and after deformation (b) are presented.

Only a quarter of the Ø28x28mm cylindrical billet was employed in simulation in order to reduce simulation time and necessary memory space. Boundary conditions were set by the use of symmetry planes. Hexahedral type of elements with 0,5mm size was applied. For such conditions, one quarter of Ø28x28mm cylindrical billet contains 14598 elements and simulation time lasted approximately one hour. Due to large deformation Overal Hex mesher criterion was used. Punch and die are set as a rigid bodies, press velocity was 2 mm/s.



a) b)

Fig.1 Shame of the process (a) and billet before and after deformation (b)

Two lubricants were used in simulation as well as in experiment: mineral oil and MoS_2. Friction factor m for mineral oil was $m=0.20$ and for MoS_2 $m=0.17$. Friction factors are determined by ring test [8-9].

Flow curve for steel Ck10 and aluminum Al99.5 were determined by Rastegajev test [10-11] and approximated by the equation (1) and (2):

$$\sigma_e = 660 \cdot \varphi^{0.23} \frac{N}{mm^2} \text{ - Ck10} \qquad (1)$$

$$\sigma_e = 160 \cdot \varphi^{0.11} \frac{N}{mm^2} \text{ - Al99.5} \qquad (2)$$

3 Experimental work

Backward extrusion of Al99.5 and Ck10 workpieces was conducted in Laboratory for Metal Forming, University of Novi Sad, on 6300KN Sack&Kiesselbach hydraulic press (**Fig.3**), with die velocity of 2mm/s. Experiments were performed under a room temperature by four punches with different square cross sections (**Fig.4**). In **Fig.2** punch with two extruded aluminum workpiece is presented.

Billet materials, their geometries and friction factors were equal to those analyzed in numerical simulation. Workpiece geometry as well as logarithmic deformation (φ) for four different punch cross sections are given on **Fig.4.**

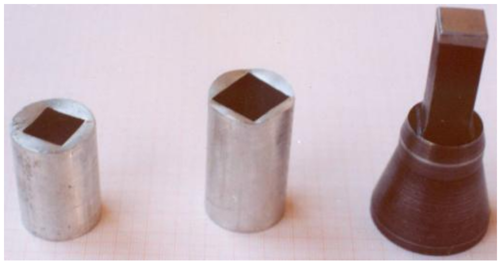


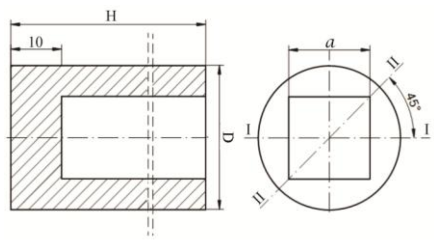
Fig.2 Punch with two aluminum workpieces

Fig.3 Sack&Kiesselbach hydraulic press

4 Results discussion

4.1 Extrusion load

In **Fig.5** and **Fig.6** load-stroke diagrams obtained by numerical simulation and by



$a[mm]$	$A_0 = \frac{D^2\pi}{4}[mm^2]$	$A_p = a^2[mm^2]$	$\varphi = \ln(\frac{A_0}{A_0 - A_p})$
12.62	615.44	159.26	0.30
14.90	615.44	222.01	0.45
16.70	615.44	278.89	0.60
18	615.44	324	0.75

Fig.4 Workpiece geometry

experiment, for both materials (Al and Ck10 steel) and two different friction factors (m = 0.2 and m = 0.17 retrospectively) are given.

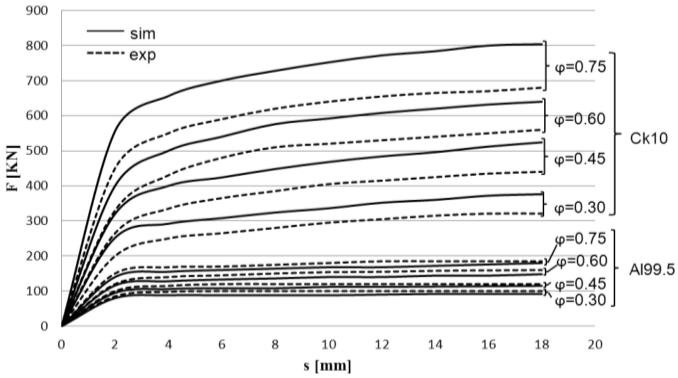


Fig.5 Forming load - stroke diagram for steel m=0.20

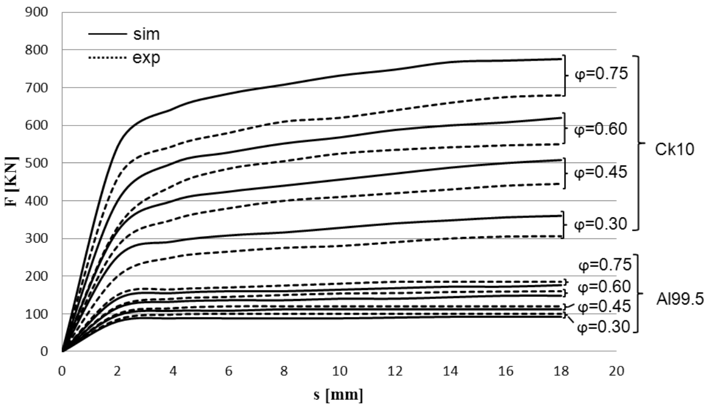


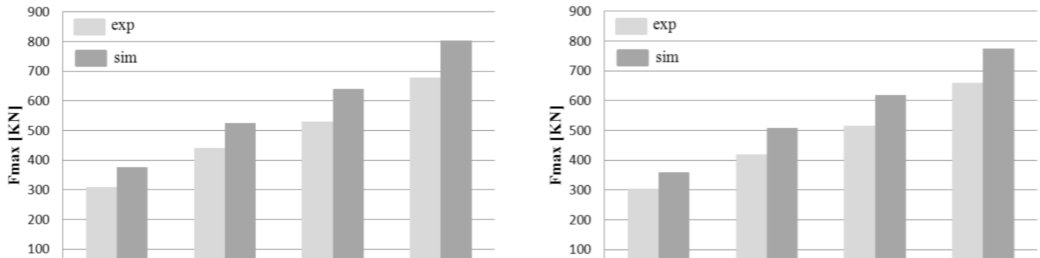
Fig.6 Forming load - stroke diagram for steel m=0.17

As it can be seen, load-stroke diagram exhibits steep rise in the initial phase of the process and continues with moderate load rise, without inflexion points. As expected, highest load values are obtained at the end of the process for highest logarithmic deformation ($\varphi = 0.75$). A certain discrepancy can be noted between experimental and numerical results, which is much more pronounced in steel than in aluminum extrusion. Maximum deviation between numerical and experimental load is 16% when friction factor is m=0.2 (Fig.5) and 14% in case m=0.17 (Fig.6).

Impact of logarithmic deformation on maximal extrusion load for aluminum and steel billets and for two friction conditions is graphically presented in **Fig.7** and **Fig.8**.

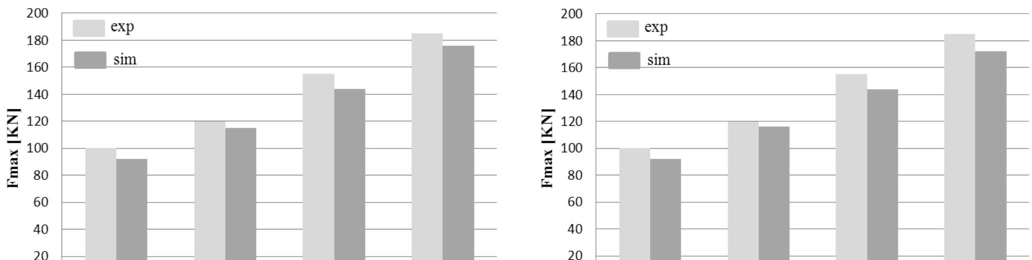
4.2 Average punch pressure

Interdependence between average punch pressure "p_{ave}" and logarithmic deformation, obtained as: p = F/A (F-extrusion load, A- punch cross section area), is shown in **Fig.9** for both friction conditions and two investigated materials. In case of steel extrusion numerical simulation gives somewhat higher values for "p_{ave}" than experiment (approximately 18%) whereas in aluminum extrusion there is practically no difference in average pressure values predicted numerically and obtained experimentally. Similar as it can be found in relevant literature, slightly pronounced pressure minimum at approximately $\varphi = 0.5$ can be noted in current investigation.



m=0.20 m=0.17

Fig.7 Effect of logarithmic deformation on maximal load for steel



m=0.20 m=0.17

Fig.8 Effect of logarithmic deformation on maximal load for aluminum

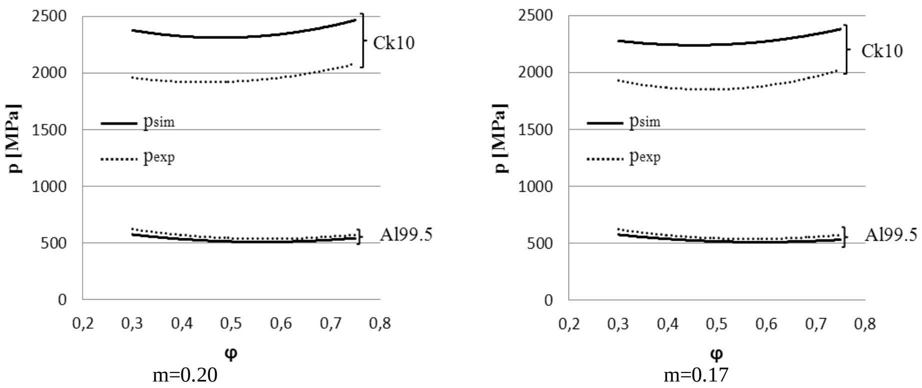


Fig.9 Dependence between average pressure and logarithmic deformation for steel and aluminum

5 Conclusion

Cold extrusion technology has the features of high productivity, improved mechanical properties of extruded components, low material waste and energy consumption. Further, even broader application of this technology in industrial practice requires permanent development and innovations. One of the important research and development direction is extrusion of components with complex, non-axisymmetric geometries.

In the presently reported work backward cold extrusion by the punch with square cross section is elaborated. Two different workpiece materials and two different friction conditions are considered. Experiments were carried out in order to validate FE numerical analysis. Obtained results confirm feasibility of the process, which can be successfully combined with other extrusion processes. Minor deviation between force values obtained experimentally and numerically can be attributed to the uncertainty in friction and flow stress determination and in setting up the model for numerical simulation.

Further insight into the process characteristics and details is needed in order to optimize cold extrusion procedure. Comparison of the circular and non-circular extrusion in terms of main process parameters and in terms of workpiece quality (homogeneity of mechanical properties) will be performed in future work on this subject.

Acknowledgements

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