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EVALUATION OF THE POSSIBILITY OF PERFORMING COLD BACKWARD EXTRUSION OF AXISYMMETRICAL THIN-WALLED ALUMINUM DIE STAMPINGS WITH SQUARE SECTION

OCENA MOŻLIWOŚCI WYCISKANIA PRZECIWBIEŻNEGO NA ZIMNO OSIOWOSYMETRYCZNYCH WYPRASEK Z CIENKĄ ŚCIANKĄ O PRZEKROJU KWADRATOWYM Z ALUMINIUM

The paper presents evaluation of the possibility of performing cold backward extrusion of axisymmetrical thin-walled aluminum (Al 99.50, ENAW-1050A) die stampings with a square section at the strain $\epsilon = \ln(A_0/A_1) = 2$ (where A_0 – cross sectional area of the billet, A_1 - cross sectional area of the die stamping), and the ratio $h_1/b = 3.6$ (where h_1 – height of the die stamping in mm, b – width of the base of the die stamping in mm). The analysis was conducted on the basis of the results of computer modelling (FEM) and experimental investigations on backward extrusion. The boundary conditions for numerical calculations were determined experimentally with respect to the flow curve and mechanical properties of aluminum. The results of investigations into backward extrusion of thin-walled square-sectioned aluminum die stampings might be used as guidelines to develop a technological process for industrial practice.

Keywords: backward extrusion, finite element method (FEM), thin-walled die stampings,

W artykule przedstawiono ocenę możliwości wykonania wyprasek o przekroju kwadratowym z cienką ścianką z aluminium Al 99,50 (ENAW-1050A) metodą wyciskania przeciwbieżnego na zimno przy odkształceniu zastępczym $\epsilon = \ln(A_0/A_1) = 2$ oraz stosunku wysokości do szerokości wypraski $h/b = 3,6$. Analizę przeprowadzono na podstawie uzyskanych wyników modelowania komputerowego (MES) oraz badań doświadczalnych wyciskania przeciwbieżnego. Na potrzeby symulacji komputerowej procesu wyciskania na zimno określono eksperymentalnie warunki graniczne w zakresie krzywej umocnienia oraz własności mechanicznych dla aluminium. Uzyskane wyniki wyciskania tego typu wyprasek z aluminium na zimno można wykorzystać do opracowania wytycznych dla wspomnianej technologii w warunkach produkcyjnych.

1. Introduction

The process of backward extrusion still plays an important role in the manufacturing industries [1]. It has been conventionally used for the production of axisymmetrical thin-walled products. It offers some advantages over other production techniques, such as deep drawing, bulge forming [2] and hydromechanical bulge forming (hydroforming) [3].

In the extrusion process, the material is first compressed in a chamber, and when deformed, it is forced to flow through the die. The die opening corresponds to the cross-section of the required product. Items having a constant cross-section can be produced with this method since the die geometry remains the same during the entire operation. It is basically a hot working process, but cold extrusion can also be performed, particularly for softer materials. The backward extrusion process (Fig. 1), in which metal flows in the opposite direction to that of the punch movement, is relatively more energy efficient. In the process, friction is considerably reduced, because the friction along the chamber walls does not need to be overcome. The process,

however, is not used extensively because it puts limits on the length of the extruded components. Also, it is not very convenient to handle extruded products through a moving punch [4].

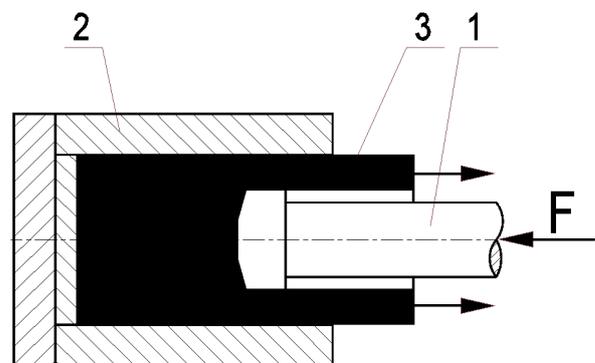


Fig. 1. Schematic representation of backward extrusion of hollow shapes where: 1 – punch, 2 – die, 3 – die stamping

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The material coming through the orifice formed by the punch land and the die wall undergoes no strain after this point. The remaining volume between the punch and the die bottom (or the ejector) is only partly located in the deformation zone. Depending upon the geometrical and friction conditions, a dome-shaped rigid plastic zone is formed in this region. The factors that affect the zone mentioned above include the can bottom thickness and the reduction in the area. The latter, i.e. the strain, is calculated according to the following formula [4]:

$$\varepsilon = \ln \frac{A_0}{A_1} \quad (1)$$

where:

A_0 – cross sectional area of the billet in mm^2

A_1 – cross sectional area of the die stamping in mm^2

When compared with other manufacturing processes, backward extrusion offers many advantages, including lower material consumption, higher dimensional accuracy and surface quality, adequate mechanical and microstructural properties and the elimination of subsequent operations. Although backward extrusion has significant capabilities in production, it also shows some limitations. The unsteady deformation zone, which causes different strain distribution through the extruded part, is one of problems [5].

The use of cold formed parts, made of aluminum and aluminum alloys, has increased significantly. That results from good formability of the materials, and yet high strength which can be obtained in the final product. Examples of applications include tubes, cans for electronic housings and electromotors, oil filters, pump housings, hydraulic cylinders, high pressure cylinders, shock absorbers, bicycle components, automotive transmission and power steering components, light reflectors, and components for the defence industry [6]. Rectangular thin-walled aluminum shapes are widely used as casings of mobile phone batteries. These casings are traditionally produced in multi-stage deep drawing processes which, however, have some drawbacks, namely the design cost, material waste and inconsistent wall thickness. Backward extrusion could be considered an alternative manufacturing process for the production of these containers [7].

2. State of the art and aim of investigations

Cold backward extrusion of parts made from aluminum and the design of the tooling have been reported in some studies [1,5-20]. Those covered both experimental and computer modelling investigations.

In their study, Shatermashhadi V. et al. [1], proposed a method of backward extrusion using small diameter billet. Their die setup consisted of three major components, namely the fix-punch, the moveable punch and the matrix. They demonstrated that the load was reduced to about less than a quarter when compared with the conventional backward extrusion process. Shatermashhadi V. et al. also conducted numerical investigations, in which the DEFORM 3D software was used for FE simulations. In their latest work [5], they discussed the applications of the modified process to commercially pure aluminum.

Bay [6] discussed different types of alloys, their individual properties and applications, and also special requirements concerning tool design for cold forging of aluminum.

Kim et al. [7] evaluated the effects of lubricants in backward extrusion of a rectangular aluminum case with large aspect ratio. The analysis of backward extrusion of a rectangular aluminum box for electrical battery casing was performed using MSC Superforge, a commercial finite volume software. The numerical analysis showed clearly that a friction factor of 0.2 yields an optimal forming shape, which was independently confirmed by the experimental results.

Farhoumand and Ebrahimi [8] examined the effects of geometrical parameters including die corner radius and gap height, and also of the process conditions, such as friction, on the radial-backward extrusion process.

Zasadziński [9] evaluated the usefulness of different methods for continuous extrusion of aluminum and its alloys, on the basis of the analysis of active friction forces possible to achieve in these methods. The Linex, Extrolling, Conform processes, as well as two methods proposed by the author were analysed.

Czyżewski and Kocańda [10] presented the results of the numerical analysis of cyclic loading of forward extrusion dies. They compared of the results of calculations for simplified and complicated models. Based on the results of the analysis, recommendations for selection of appropriate models of deformation processes with cyclic loading were produced.

In Wang et al. [11], recent developments in the friction testing techniques for aluminum extrusion processes were discussed and detailed comparisons of these techniques were made.

Lee and Kwan [12] proposed a modified kinematically admissible velocity field for the backward extrusion of internally circular-shaped tubes from arbitrarily shaped billets. From the proposed velocity field, the upper-bound extrusion load and average extruded height for regular polygonal-shaped billets were determined with respect to the chosen parameters.

Bakhshi-Jooybari et al. [13] conducted experimental and numerical study of the optimum die profile in backward rod extrusion. They obtained the optimal die profile in backward lead rod extrusion by using the slab method and a developed algorithm. Bakhshi-Jooybari et al. determined the optimum die angle for the conical die in similar conditions by using the FEM software (ABAQUS).

Olejnik et al. [14] conducted research, the aim of which was to compare backward extrusion of a micro-cup made of commercially pure aluminum Al 1050 and of ultrafine grained aluminum Al 1070).

D.-C. Chen et al. [15] investigated the plastic deformation behaviour of an aluminum billet during its cold axisymmetrical extrusion through a conical die using DEFORM 3D software. They examined the relative effects of the semi-angle of the die, the extrusion ratio and the friction factors on cold forward extrusion of aluminum.

Saboori et al. [16] conducted experimental and numerical (ABAQUS) studies on energy consumption in forward and backward rod extrusion. They determined the extrusion energy for the two optimal conical and curved dies for aluminum and lead billets. The results of the analysis demonstrated that the energy required to deform aluminum and lead billets in the

optimum curved die is considerably lower than that in the optimum conical die.

Y.H. Kim and Park [17] studied backward extrusion process with low die rotation. The objective of the investigations was to address the problems related to conventional backward extrusion process, namely the necessity of using a large forming machine, the difficulty in selecting the die material due to high surface pressure, costs related to the reduction in noise and vibration generated from the forming machine, and others. They analyzed the experimental results for torsional and conventional backward extrusions. The results were compared using two methods, i.e. upper bound technique for computing the velocity field, and FEM simulation with DEFORM-3D.

Thomas [18,19] conducted a series of experimental investigations into cold backward and combined extrusion of pure aluminum cylindrical stampings. In his studies [18], Thomas discussed the results obtained for different radii of the die insert resistant surfaces transition into the backward and forward region. He noted that the change in inclination of the resistant part of the die insert for a given displacement of the stamp affects the monotony of the profile of stress force values, however, that does not significantly influence the change in the maximum values of the stress force.

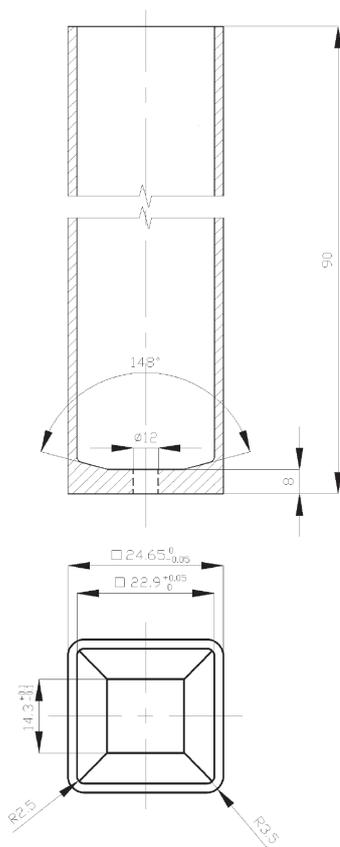


Fig. 2. Shape and dimensions of thin-walled die stampings with square section, made from aluminum Al 99.50 (ENAW-1050A)

Biba et al. [20] analyzed the interaction between the material flow and deformation, and temperature of the tooling

set in the simulation (QFORM) of thin profile extrusion technology. Their studies demonstrated it is important to account for the fine effects of bearing area displacement and inclination as those significantly affect the material flow in case of complicated hollow dies.

Cold backward extrusion of aluminum has been used for years, however, the extrusion technology has not been investigated thoroughly so far. That especially concerns thin-walled aluminum parts with a square section, extruded at high levels of strain.

The experimental and modelling investigations, described in the paper, aimed to determine the possibility of cold backward extrusion of axisymmetrical thin-walled die stampings with square section, made from aluminum Al 99.50 (ENAW-1050A) for the strain $\varepsilon = \ln(A_0/A_1) = 2.02$ and the ratio $h/b = 3.6$ (where h_1 – height of the die stamping in mm, b – width of the base of the die stamping in mm). The shape and dimensions of thin-walled die stampings with square section, made from aluminum Al 99.50 (ENAW-1050A) are presented in Fig. 2. The investigations could also be helpful while applying the method to industrial practice.

3. Models and assumptions in numerical modelling with QFORM-2D

The extruded material is considered to be incompressible rigid-plastic continuum and elastic deformations are neglected. The system of governing equations includes the following [20,21]:

- equilibrium equations

$$\sigma_{ij,j} = 0 \quad (2)$$

- compatibility conditions

$$\dot{\varepsilon}_{ij} = \frac{1}{2} (v_{i,j} + v_{j,i}) \quad (3)$$

- constitutive equations

$$\dot{\sigma}'_{ij} = \frac{2\bar{\sigma}}{3\varepsilon} \dot{\varepsilon}_{ij} \quad (4)$$

- incompressibility equation

$$v_{i,i} = 0 \quad (5)$$

- expression for flow stress

$$\bar{\sigma} = \bar{\sigma}(\varepsilon, \dot{\varepsilon}, T) \quad (6)$$

where σ'_{ij} and $\dot{\varepsilon}_{ij}$ – components of stress and strain-rate tensors, v_i – velocity components, σ'_{ij} – deviatoric stress tensor, $\bar{\sigma}, \varepsilon, \dot{\varepsilon}$ – effective stress, strain and strain-rate, respectively, T – temperature.

In Eqs 2–6, summation convention is used. The prime

denotes a derivative with respect to the axis following it. The indexes i and j for two-dimensional problems vary from 1 to 2, and repeated subscript represents summation.

The friction model proposed by Levanov et. al [21] is used for the contact region of workpiece surface. Eq. (7) can be considered as a combination of the constant friction model and the Coulomb friction model. The formula combines the advantages of both models [21]:

$$F_i = m \frac{\bar{\sigma}}{3} (1 - \exp(-1,25 \frac{\sigma_n}{\bar{\sigma}})) \quad (7)$$

where m is the friction factor, σ_n is the normal contact pressure.

4. Methodology

The material for experimental investigations into backward extrusion were samples made from aluminum Al 99.50 (ENAW-1050A). The mechanical properties of the material, determined by static tensile testing, are presented in TABLE 1 (columns 3 -7). Additionally, TABLE 1 (columns 8 and 9) gives the strain hardening exponent n and the material constant C . Those were determined with the Rastigaev's method of upsetting specimens with necks.

The calculations of metal flow and distributions of effective strain, flow stress and changes in force were carried out using the commercial code QFORM2D, based on the Finite Element Method (FEM). The flow stress characteristics were given as a function of the strain rate:

$$\bar{\sigma} = C \bar{\varepsilon}^n \quad (8)$$

On the basis of experimental investigations, Eq. (9) was adopted for numerical modelling of aluminum backward extrusion (n and C are given in TABLE 1):

$$\bar{\sigma} = 152 \bar{\varepsilon}^{0.25} \quad (9)$$

The experimental part of the research on backward extrusion was conducted on APT/LAGAN DPL-1600 hydraulic press with special tooling. The machine is located in Skarżysko Kamienna, at MESKO S.A. company. Fig. 3 shows the diagram of the press tools for backward extrusion of axisymmetrical thin-walled aluminum die stampings with a square section used in the experiment.

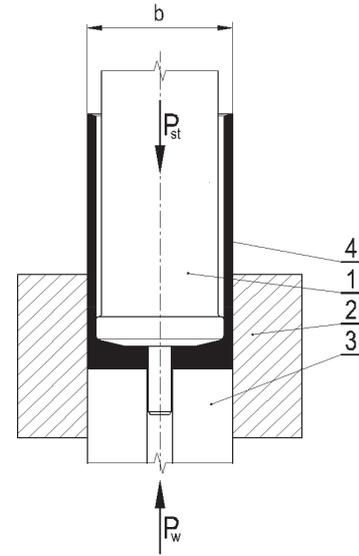


Fig. 3 Diagram of backward extrusion of axisymmetrical thin-walled aluminum die stampings with a square section, where: 1 – punch, 2 – die, 3 – shedder, 4 – die stamping, P_s – punch load, P_w – resisting force of shedder

The samples used in computer modelling were pieces of square-sectioned aluminum rods having the width of $b_0=24.5\text{mm}$, length of $l_0=14\text{mm}$. The experimental investigations into backward extrusion involved the use of square sectioned aluminum segments of rods with width $b_0=24.5\text{mm}$, length $l_0=17\text{mm}$ and the diameter of port $d_0=12\text{mm}$. The samples were heat treated (annealed). Heat treatment is used to increase the plasticity of the material before cold backward extrusion. The material was annealed at 410°C for a period of 1 h, and then subjected to solution treatment in water.

5. Modelling and experimental results

The results of the simulation process of backward extrusion of thin-walled square-sectioned aluminum die stamping at the ratio $h_1/b=3.6$ showed that the model of boundary conditions, presented in Chapters 4 and 5, proved adequate. To analyze metal flow in the computer program, the flow lines were imposed. They form a grid that makes it possible to view the displacement and distortion of the metal selected volumes in deformations. In the simulation, ten inner flow lines along the OX and OY axes were assumed. Numerically calculated stages of backward extrusion are presented in Fig. 4.

TABLE 1

The mechanical properties of Al 99.50 (ENAW-1050A)

AA No.	DIN No.	R0.2 [MPa]	Rm [MPa]	A [%]	A11.3 [%]	Z [%]	C [MPa]	n
1	2	3	4	5	6	7	8	9
1050	Al 99.50	24	82	46	34	86	152	0.25

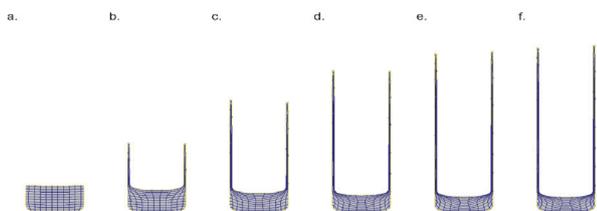


Fig. 4 Numerically calculated stages a.-f. (which corresponded to 5, 10, 15, 20, 25, 30 steps) of backward extrusion of thin-walled square-sectioned aluminum die stampings

The computer modelling of backward extrusion was conducted for different friction conditions at tool/workpiece interface. Those were as follows: mineral oil used in cold deformation of aluminum alloys at the friction factor $m=0.2$; and absence of the lubricant at the friction factor $m=0.8$, which corresponds to insufficient lubrication at the interface; and ideal conditions at the friction factor $m=0$, when friction is disregarded.

On the basis of the analysis of numerically calculated effective strain distribution (shown in Fig. 5) at the intersection of backward extruded die stamping made from aluminum with a square section, it can be stated that in the different stages of the modelling, the maximum strain values were found in the area of the die stamping wall forming. Numerically computed effective strain distribution at the intersection of backward extruded die stampings for the friction factor $m=0.2$ for the last stage of computer modelling is presented in Fig. 5. The maximum value of the effective strain was found in the last stage of simulation of backward extrusion. It occurred in the walls and reached the value of 4.868. The minimum value of the effective strain was 0.019. Relatively high effective strains were observed in the radii of the bottom transition to the wall. When the effective strain distributions at friction factors $m=0$ and $m=0.2$ were compared, no relevant differences were found.

Analyzing the numerically calculated flow stress distribution at the intersection of backward extruded die stamping with a square section, made from aluminum for different friction conditions at the tool/workpiece interface, it was found that the maximum values occurred in the extrusion areas where the maximum values of effective strain were observed. Numerically obtained flow stress distributions are presented in Fig. 6. The flow stress maximum value of 237.9 MPa was found for the friction factor $m=0.8$. The highest values of flow stress at friction factors $m=0$ and $m=0.2$ were comparable (219 MPa and 220 MPa, respectively).

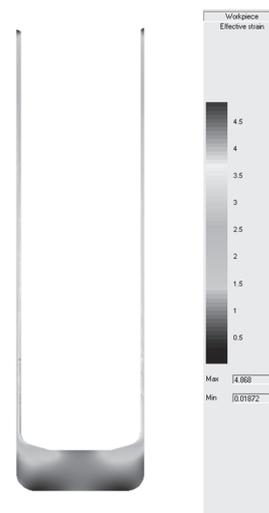


Fig. 5. Numerically computed effective strain distribution at the intersection of backward extruded die stampings at the friction factor $m=0.2$ for the last stage of computer modelling

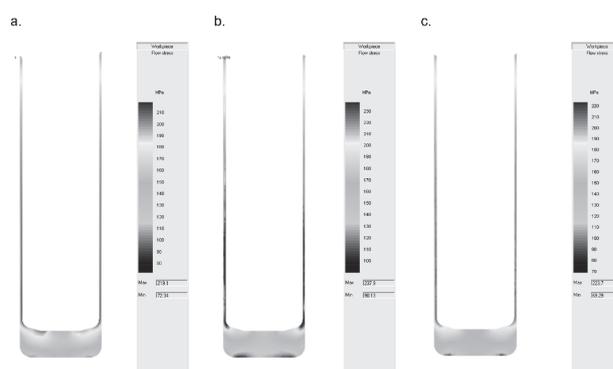


Fig. 6. Numerically computed flow stress distributions at intersections of backward extruded die stampings for the last stage of computer modelling for various friction factors: a. $m=0$; b. $m=0.8$; c. $m=0.2$

The pattern of changes in loads obtained from computer modelling of backward extrusion of thin-walled square-sectioned aluminum die stampings at the ratio $h_1/b=3.6$ and different friction conditions are presented in Fig. 7. In the graph, the distance denotes the distance between tools (punch and die) in deformation. The analysis of changes in numerically calculated loads in cold backward extrusion of aluminum die stampings indicates that as the forming process advances in time, which is represented by an increase in the percentage value, the force increases at different friction conditions.

Significant differences were found in the maximum values of the loads for different friction factors. The greatest maximum calculated load was obtained for die stampings extruded without lubricant (9.08 MN) and was higher than both the highest values under ideal conditions (0.366 MN), and when mineral oil was used (2.53 MN).

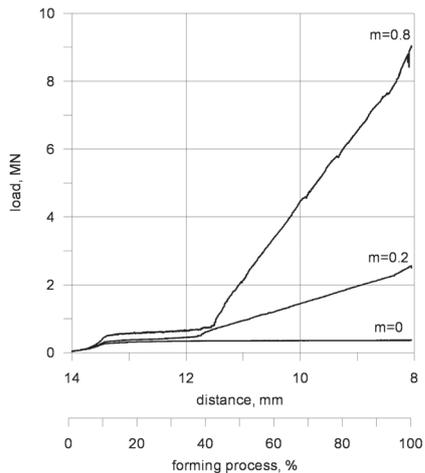


Fig. 7. Numerically calculated loads vs. distance (percentage of the execution of the forming process) obtained for backward extrusion of thin-walled square-sectioned aluminum die stampings under different friction conditions

Experimental investigations into backward extrusion of aluminum die stampings were conducted at the MESKO S.A. company. Those were preceded by preliminary tests on cold backward extrusion of lead, which aimed at precisely determining the displacement of the punch for the assumed thickness of the web of die stampings. The selection of lead for the initial investigations was related to its excellent plastic properties (elongation A11.3 approx. 70% and reduction of area Z approx. 100%), which results in the material being widely used for cold extrusion.

Commonly used lubricants, mineral oil and zinc stearate were chosen for the experiment. The view of the tool for backward extrusion is presented in Fig. 8.



Fig. 8 View of the tool for backward extrusion, MESKO S.A. company

Thin-walled die stampings with square section, made from lead, were cold backward extruded at the ratio $h_1/b=8.5$ (which corresponded to the height of the die stamping $h_1=210\text{mm}$). A vast majority of tests was conducted for die stampings made from aluminum at the ratio $h_1/b=3.6$. The analysis of the distribution of the wall thicknesses in extruded die stampings was made. Thickness measurements of the walls did not demonstrate relevant differences and thicknesses were found to be within established

dimensional tolerances. The measurements were taken with the coordinate measuring machine Prismo-Navigator by Zeiss OKM Jena company, the measuring accuracy of which was up to $1\ \mu\text{m}$.

Examples of backward extruded thin-walled die stamping made from lead and aluminum obtained in experimental procedures are presented in Fig. 9.

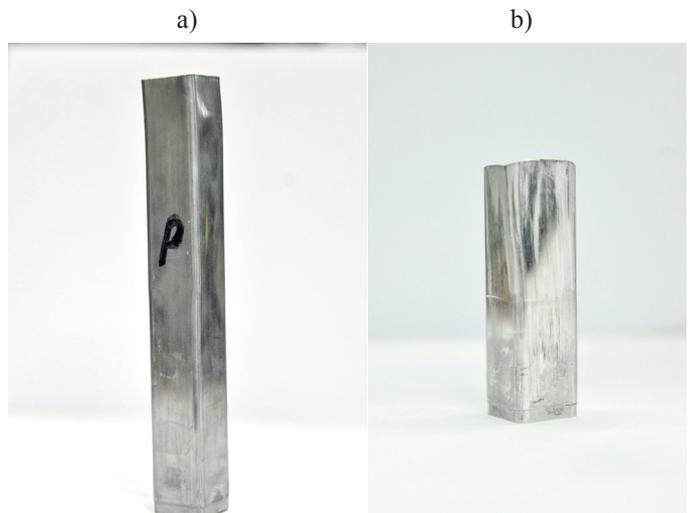


Fig. 9. Experimentally obtained backward extruded thin-walled square-sectioned die stampings made from lead (a) and aluminum (b)

It should be noted that experimental investigations into cold backward extrusion of thin-walled die stamping made from aluminum at the ratio higher than $h_1/b=3.6$ were not successful, therefore the authors will continue research into this field in the future.

6. Conclusions

The following conclusions were drawn from numerical and experimental investigations into backward extrusion of thin-walled square-sectioned die stampings:

1. It is possible to perform cold backward extrusion of thin-walled square-sectioned aluminum die stampings at the ratio $h_1/b=3.6$, and lead die stampings at the ratio $h_1/b=8.5$. That was confirmed by the tests successfully carried out at the MESKO S.A. company in Skarżysko Kamienna.
2. Regardless of the friction conditions, the numerically calculated load increased with an increase in the displacement of the punch. The same dependence was observed in experimental investigations, in which mineral oil was used as a lubricant.
3. It is necessary to continue investigations into cold backward extrusion of thin-walled die stamping made from aluminum at the ratio higher than $h_1/b=3.6$.
4. The results obtained in the present study might be used as guidelines to develop a technological process for manufacturing die stampings of this kind using the method of cold backward extrusion. Those could also be helpful while applying the method to industrial practice.

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