*Key Engineering Materials*
*ISSN: 1662-9809, Vol. 716, pp 68-75*
*doi:10.4028/www.scientific.net/KEM.716.68*

*Submitted: 2016-02-15*
*Revised: 2016-07-11*
*Accepted: 2016-07-12*

# The Effect of Equivalent Strain on Punch Load for Cold Backward Extrusion of Copper Cans

MIŁEK Tomasz[1, a *]

[1]Department of Applied Computer Science and Armament Engineering,
Faculty of Mechatronics and Mechanical Engineering, Kielce University of Technology,
Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

[a]tmatm@tu.kielce.pl,

**Keywords:** Cold Backward Extrusion, Reduced Strain, Finite Element Method (FEM), Cans

**Abstract.** The paper presents experimental and computer modelling (FEM) results of investigations into cold backward extrusion of copper cans. The simulations were performed using QFORM software based the finite element method (FEM). The samples used in investigations were pieces of copper rods having the diameter $d_0$ = 24,5 mm and height $h_0$ = 16 mm ($h_0/d_0$=0,65). The billets were heat treated (annealed). Heat treatment is used to increase the plasticity of the material before cold backward extrusion. The material was annealed at $550^0$C for a period of 1 h, and then subjected to solution treatment in water. The flat and conical punch-face shapes with different diameter of punch used for cold extrusion ($d_s$=15mm; 16mm; 17mm; 19mm and 20mm, respectively). The deformation ratios of material in paper was defined as relative: strain of can bottom thickness $\varepsilon_h = \Delta h/h_0$ (where $\Delta h$ – the punch displacement, $h_0$ – billet height), reduction in area $\varepsilon_A = (A_0-A_1)/A_0$ and homogeneous equivalent strain $\varepsilon = \ln(A_0/A_1)$ (where $A_0$ – cross sectional area of the billet, $A_1$ - cross sectional area of the die stamping). In investigations, computer calculated and experimental force waveforms as the function of displacement and $\varepsilon_h$ were obtained. Comparing changes in forces in cold backward extrusion for different diameter of punch, it is stated that the load $P_w$ increases with an increase in $\varepsilon_h$. The effect of homogeneous equivalent strain $\varepsilon$ on punch load $P_w$ for cold backward extrusion of copper cans is presented. Both in experimental and modeling investigations, the axial force increased together with an increase in homogeneous equivalent strain.

## Introduction

Copper cans are traditionally produced in multi-stage deep drawing processes which, however, have some drawbacks, namely the design cost, material waste and inconsistent wall thickness [1,2]. Cold extrusion in comparison with other methods use in industrial application has many advantages such as: minimum material waste, high dimensional accuracy, reduction or complete elimination of machining, good surface finish, better mechanical properties of products than those of the original material due to favourable grain flow [3,4]. 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 importance of analysis for the extrusion process lies in the determination of forming load, flow characteristics, temperature and state of stress and strain [3,5]. 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 [1].

The basic process involved in cold extrusion are classified depending on their forming direction as forward, backward and radial or lateral extrusion [1,2]. 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 [1].

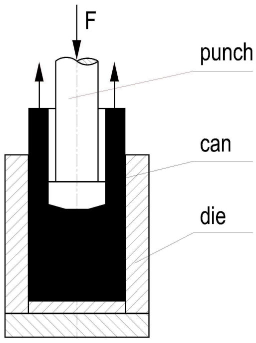

Fig. 1 Schematic representation of backward extrusion of cans.

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 [1].

The deformation ratios of material in literature [1,2,7] was defined as relative: strain of can bottom thickness $\varepsilon_h$, reduction in area $\varepsilon_A$ and homogeneous equivalent strain ε. The strain $\varepsilon_h$, is calculated according to the following formula [1,2]:

$$\varepsilon_h = \frac{\Delta h}{h_o} = \frac{h_0 - h_1}{h_0} \tag{1}$$

where:
Δh – the punch displacement in mm,
$h_0$ – billet height in mm,
$h_1$ – thickness of cup bottom in mm,

The reduction in area $\varepsilon_A$ can be estimated from the relationship given below [1,2]:

$$\varepsilon_A = \frac{A_0 - A_1}{A_0} \tag{2}$$

where:
$A_0$ – cross sectional area of the billet in $mm^2$,
$A_1$ - cross sectional area of the die stamping in $mm^2$,

The unit operation of work of plastic deformation in industrial practice is determined by the homogeneous equivalent strain ε. It is given by a formula [7]:

$$\varepsilon = \ln \frac{A_0}{A_1} \tag{3}$$

Cold backward extrusion of circular-shaped parts made from copper and the design of the tooling have been reported in some studies [3,8-10]. Those covered both experimental and computer modelling investigations. Farhoumand and Ebrahimi [3] 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. Thomas [8] conducted a series investigations into cold backward extrusion of cans for copper before and after heat treatment. He analyzed the experimental change of the force for copper cans at the reduction in area $\varepsilon_A$=0,360-0,639. Żmudzki A. et al. [9] presented numerical (FEM) and experimental results of the analysis of tests, which are performed to determine the friction coefficient in two types of metal forming processes (ring compression and combined forward – backward extrusion). Experiments were performed for copper deformed at room temperature. Żmudzki A. et al. demonstrated that friction coefficient calculated from the ring compression tests is slightly lower that that determined from the direct-indirect extrusion test. In their study, Shatermashhadi V. et al. [10], 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. In their study, Shatermashhadi V. et al. highlight that most of the materials such as aluminium, copper and magnesium which can be processed via conventional method may be processed by the their method.

The most papers are concerned with the analysis on the forming of copper in micro-backward can extrusion process [11-18]. Ch. Chang et al. [11] discussed the effects of temperature and grain size on the deformation, dimension variation, and change of microstructure of copper from combined backward and forward extrusion at the micro scale. They conducted a series of investigations into extrusion of copper micro cups with 0.1 mm thickness. Three forming temperatures: 25, 200 and 400 ºC, were considered in the micro extrusion experiments. Their studies show that the grain refinement improves material flow and thus lead to a better die filling with less variation in the rim height and wall thickness of the cup portion of the extruded part at relatively lower forming temperature. Wang et al. [12] demonstrated that forming process of dispersion strengthened copper welding electrode consists of a forward extrusion and a backward extrusion. They analyzed the characteristics of metal flow and the effect of different friction factors. Wang et al. [12] carried out the simulation of the upsetting-extruding process using Deform-2D finite element analysis software. Geisdorfer et al. [13] investigated a possibility of using an ultrafine grained copper for micro-extrusion. The microforming process of backward extrusion is carried out at room temperature using half cylindrical billets. The extrusion force, grain flow, shape representation and surface quality of the extruded micro-components are compared. Chan et al. [14] studied of size effect in micro-extrusion process of pure copper. The size effect on material deformation behaviors were characterized by grain size, part feature size, forming material size and interfacial condition. Chan et al. [14] performed research on micro-forward, backward, combined forward rod-backward can and double cup extrusions. Bazaz et al. [15] evaluated the microstructure evolution of a pure copper processed by accumulative back extrusion (ABE) method at room temperature. The analysis of microstructure and hardness showed outstanding homogeneity improvement throughout the workpieces. L. Yi et al. [16] proposed theoretical model to predict the backward extrusion force of copper-chromium alloy based on Projection Pursuit Regression (PPR).

The experimental and modelling investigations, described in the paper, aimed to determine the effect equivalent strain ε on punch load for cold backward extrusion of copper cans at strain of can bottom thickness $\varepsilon_h$=0÷0.75. The flat and conical punch-face shapes with different diameter of punch used for cold extrusion ($d_s$=15mm; 16mm; 17mm; 19mm and 20mm, respectively). The paper gives the comparison of the force waveforms obtained with different homogeneous equivalent strain ε (ε=0.47; ε=0.56; ε=0.66; ε=0.92; ε=1.10, respectively). Pure copper is selected as the testing material in this investigations due to its excellent formability and wide applications in industry.

## Models and assumptions in numerical modeling 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 [17-19]:

- equilibrium equations

$$\sigma_{ij,j} = 0 \tag{4}$$

- strain rate tensor for infinitesimal strains

$$\dot{\varepsilon}_{ij} = \frac{1}{2}(v_{i,j} + v_{j,i}) \tag{5}$$

- constitutive equations

$$\sigma'_{ij} = \frac{2\bar{\sigma}}{3\dot{\bar{\varepsilon}}}\dot{\varepsilon}_{ij} \tag{6}$$

- incompressibility equation

$$v_{i,i} = 0 \tag{7}$$

- expression for flow stress

$$\overline{\sigma} = \overline{\sigma}(\overline{\varepsilon}, \overline{\dot{\varepsilon}}, T) \tag{8}$$

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

In Eqs 4–6, 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 [17,18] 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 [18,19]:

$$F_t = m\frac{\overline{\sigma}}{3}(1 - \exp(-1{,}25\frac{\sigma_n}{\overline{\sigma}}) \tag{9}$$

where m is the friction factor, $\sigma_n$ is the normal contact pressure.

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). On the basis of literature data [20] the stress-strain relationship was adopted for numerical modelling of cold backward extrusion of copper cans.

## Methodology of experimental investigations

The investigations into backward extrusion involved the use of circular sectioned copper segments of rods with diameter $d_0$ = 24,5 mm and height $h_0$ = 16 mm ($h_0/d_0$=0,65). The billets were heat treated (annealed). Heat treatment is used to increase the plasticity of the material before cold backward extrusion. The material was annealed at $550^0$C for a period of 1 h, and then subjected to solution treatment in water.

The experimental investigations of backward extrusion was performed at the stand which included the following:

- a tool for backward extrusion, it was equipped with replaceable punches with different diameters $d_s$=15mm; 16mm; 17mm; 19mm and 20mm, respectively. The flat and conical punch-face shapes with different diameter of punch used in experiment of cold extrusion are presented in Fig. 2.
- ZD100 testing machine modified by LABORTECH firm, 1MN force (machine calibrated by PN-EN ISO 7500-1:2005 and meets the metrological requirements for class 1),
- computer stand with Test&Motion software (LABORTECH) to measure forces and displacements [21].

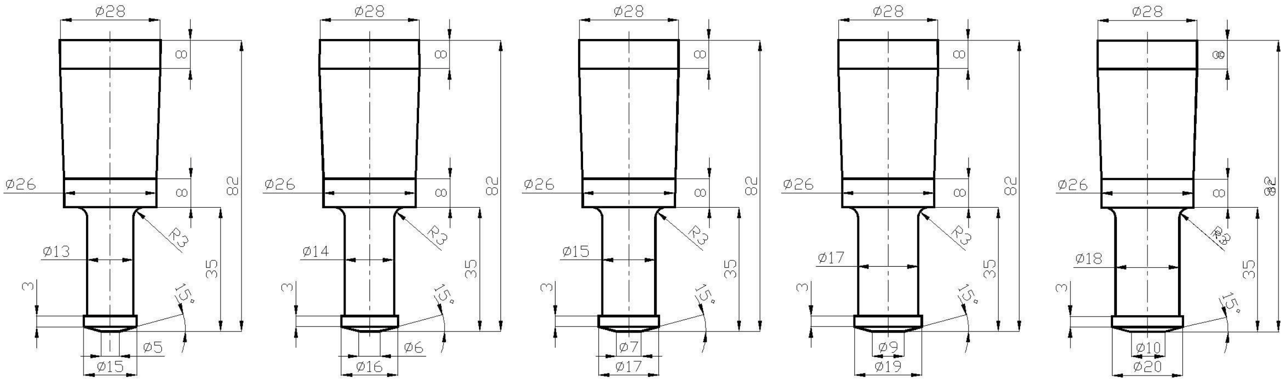

Fig. 2. The flat and conical punch-face shapes with different diameter of punch used in experiment of cold extrusion ($d_s$=15mm; 16mm; 17mm; 19mm and 20mm, respectively).

With the use Test&Motion software controlled by LaborTech electronic (external digital controller EDC), it was possible to present the experimental data in the form of graphs showing the values of forces as the function of displacement.

## Modelling and experimental results

The numerical and experimental investigations produced copper cans in cold backward extrusion with strain of can bottom thickness $\varepsilon_h$=0.75 for different homogeneous equivalent strain $\varepsilon$= 0.47÷1.1 and different reduction in area $\varepsilon_A$= 0.37÷0.67. The results of the simulation process of backward extrusion of copper cans at the maximum strain of can bottom thickness $\varepsilon_h$=0.75 showed that the model of boundary conditions, presented in previous chapter, 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 last stages of backward extrusion of copper can at different homogeneous equivalent strain $\varepsilon$= 0.47÷1.1 are presented in Fig. 3.

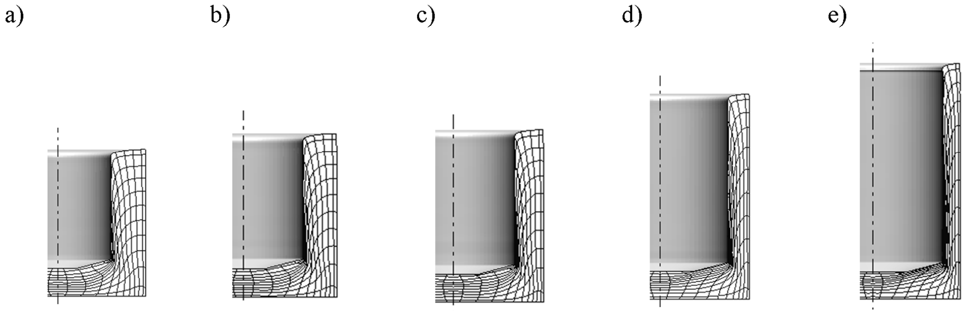

Fig. 3 Numerically calculated last stages a.- e. (which corresponded to homogeneous equivalent strain $\varepsilon$= 0.47, 0.56, 0.66, 0.92, 1.1) of backward extrusion of copper can.

The analysis of metal flow (Fig. 3) confirmed the conclusions of the literature [1-3, 7-9,19]. The analysis of the process was conducted on the basis of the results of numerically computed effective strain and flow stress distributions at intersections of backward extruded die stampings, too (Fig. 4 a, b). On the basis of the analysis of numerically calculated effective strain distribution (shown in Fig. 4 a) at the intersection of backward extruded cans made from copper, it can be stated that in the different stages of the modeling, the maximum effective strain values were found in the area of the die stamping inner wall forming. Relative high effective strains were observed in the inner radii of the bottom transition to the wall. The maximum value of the effective strain was found in the last stage of simulation of backward extrusion for copper can at homogeneous equivalent strain $\varepsilon$= 1.1 and reduction in area $\varepsilon_A$= 0.67. It occurred in the walls and reached the value of 3.364. Numerically obtained flow stress distributions are presented in Fig. 4b. The maximum value of flow stress was 420MPa.

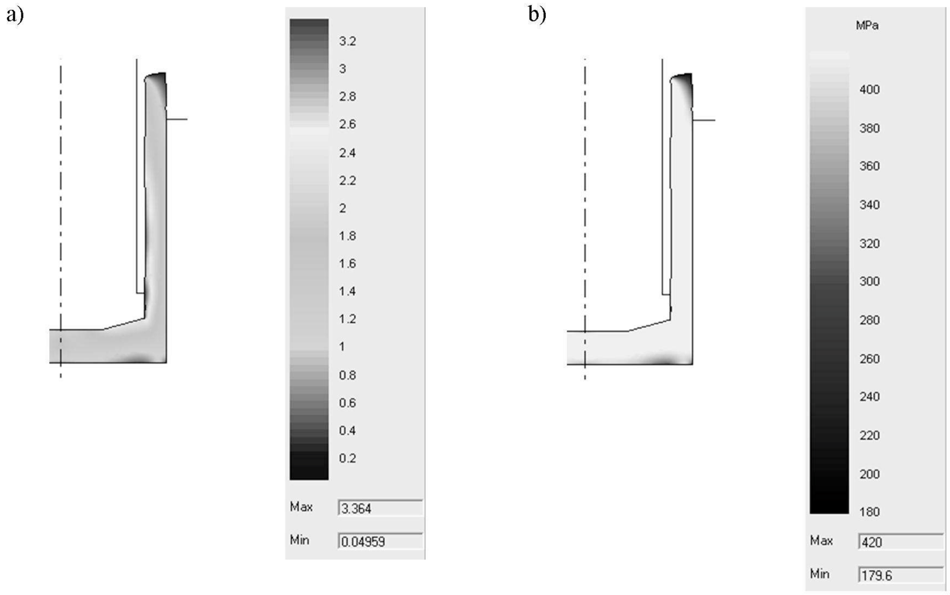

Fig. 4 Numerically computed effective strain (a) and flow stress (b) distribution at the intersection of backward extruded can for the last stage of computer modeling at homogeneous equivalent strain $\varepsilon = 1.1$

The patterns of changes in loads obtained from computer modeling and experimental investigations of backward extrusion of copper cans at different homogeneous equivalent strain $\varepsilon=0.47\div1.1$ are presented in Fig 5 a, b.

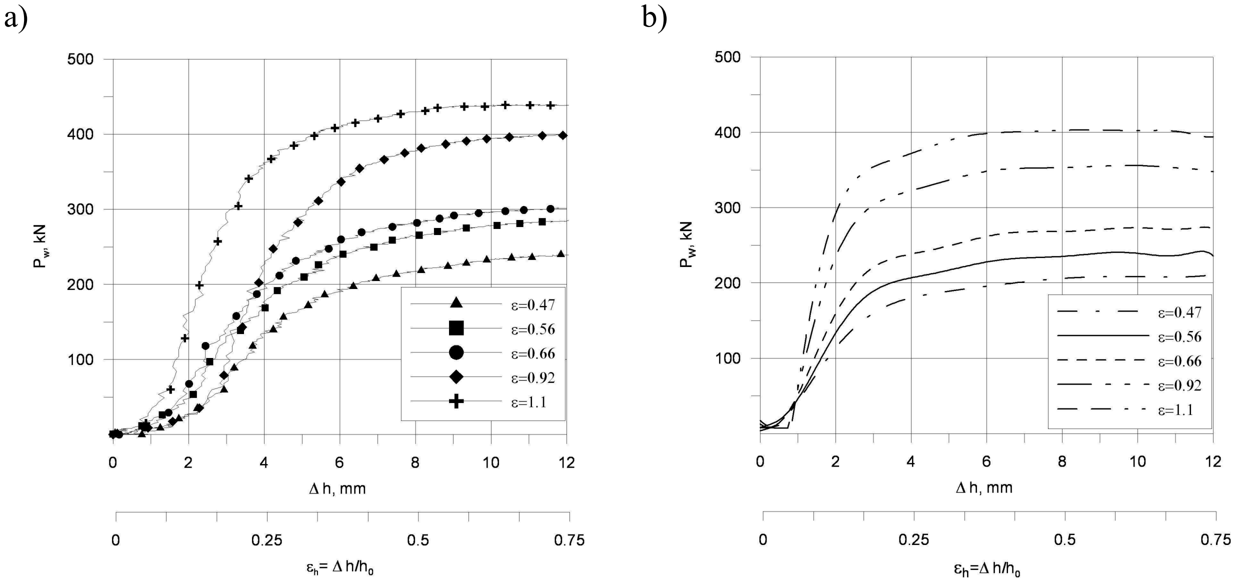

Fig. 5 Comparison between experimental (a) and computer calculated (b) force-travel diagrams of cold backward extrusion of copper cans

In the graphs , $\Delta h$ denotes the displacement of punch and distance between tools (punch and die) in deformation. The analysis of changes in numerically calculated (Fig. 5a) and experimental (Fig. 5 b) loads in cold backward extrusion of copper cans indicates that as the forming process advances in time, which are represented by an increase in the displacement $\Delta h$ and can bottom thickness $\varepsilon_h$, the force increases at different homogeneous equivalent strain $\varepsilon=0.47\div1.1$.

On the basis of the comparative analysis of forces, it was possible to state that the experimental values of forces were, in all cases, greater that those obtained numerically. The differences ranged from 7.5% (for copper cans at $\varepsilon=0.66$) to 18.9% (for $\varepsilon=0.56$). The maximum values of loads obtained in cold backward extrusion of copper cans were analyzed. The values were received at displacement Δh=12mm and can bottom thickness $\varepsilon_h$=0.75 for different homogeneous equivalent strain ε. The greatest force values were recorded in investigations at the maximum homogeneous equivalent strain ε=1.1 (calculated load $P_w$=400kN and experimental value $P_w$=438,7kN).

The effect of homogeneous equivalent strain ε on punch load $P_w$ for cold backward extrusion of copper cans is presented in Fig. 6.

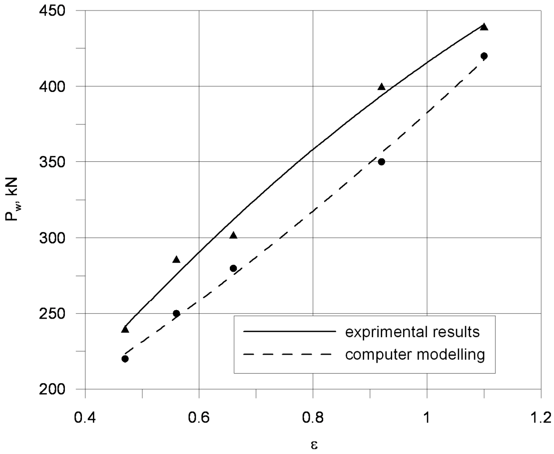

Fig. 6 Computer calculated (FEM) and experimental force vs. homogeneous equivalent strain

Both in experimental and modeling investigations, the axial force increased together with an increase in the homogeneous equivalent strain ε.

## Summary

The following conclusions were drawn from numerical and experimental investigations into cold backward extrusion of copper cans:

1. It was possible to conduct backward extrusion of copper cans at different homogeneous equivalent strain ε (ε=0.47; ε=0.56; ε=0.66; ε=0.92; ε=1.10, respectively). It is confirmed by successfully performed computer modeling and experimental tests at their relative displacement up to $\varepsilon_h = \Delta h/h_0 = 0.75$.
2. Although commercial package of QForm2D has been especially designed for numerical simulation of forging processes, the 2D FE model successfully described the backward extrusion of copper cans.
3. The pattern of changes in loads obtained from computer modeling of backward extrusion of copper cans at different homogeneous equivalent strain ε=0.47÷1.1 was very similar to experimental force profiles. The maximum experimental values of forces were, in all cases, greater that those obtained numerically (the differences between the maximum values of forces did not exceed 20%).
4. Both in experimental and modeling investigations, the axial force increased together with an increase in the homogeneous equivalent strain ε and can bottom thickness $\varepsilon_h$.

## References

[1] K. Lange, Handbook of metal forming, McGraw-Hill, Inc. USA,1985.

[2] W. A. Golowin, A. N. Mitkin, A. G. Rieznikow, Cold extrusion of metals, WNT Warszawa, 1975 (in Polish).

[3] A. Farhoumand, R. Ebrahimi, Analysis of forward-backward-radial extrusion process, Mater. Des. 30 (2009) 2152-2157.

[4] M. Plancak, M. Brameley, A. Osman F., Non-conventional cold extrusion, J. Mater. Process. Tech. 34 (1992) 465-472.

[5] S.H. Hosseini, K. Abrinia, G. Faraji, Applicability of a modified backward extrusion process on commercially pure aluminum, Mater. Des. 65 (2015) 521-528.

[6] D. Y. Yang, K. J. Kim, Design of processes and products through simulation of three-dimensional extrusion, J. Mater. Process. Tech. 191 (2007) 2-6.

[7] K. Kuczyński, E. Erbel, Obróbka plastyczna – laboratorium, Wyd. Polit. Warsz., Warszawa 1984 (in Polish).

[8] P. Thomas, The examination and analysis of the change of the force pressure in the process of backward can extrusion, Maint. Reliab. 2 (2003), 63-65 (in Polish).

[9] A. Żmudzki, R. Kuziak, M. Papaj, M. Pietrzyk, Identification of friction model in extrusion, Obr. Plast. Met. 3 (2004) 69-78 (in Polish).

[10] V. Shatermashhadi, B. Manafi, K. Abrinia, G. Faraji, M. Sanei, Development of a novel method for the backward extrusion, Mater. Des. 62 (2014) 361-366.

[11] Ch. Chang, J. Lin, Ch.-P. Siao, Effects of temperature and grain size on combined micro forward and backward extrusion of copper, Steel Res. Int., spec. edit.: 14th Int. Conf. Metal Forming (2012) 467-470.

[12] M. Wang, Y. Zhang, D. Huang, X. Liu, Numerical simulation of upsetting-extruding process of dispersion strengthened copper welding electrode, T. Nonferr. Metal. Soc. 17 (2007) 449-454.

[13] S. Geisdorfer, A. Rosochowski, L. Olejnik, U. Engel, M. Richert, Micro-extrusion of ultrafine grained copper, Int. J. Mater. Form. 1 (2008) 455-458

[14] W. Chan, M. W. Fu, B. Yang, Study of size effect in micro-extrusion process of pure copper, Mater. Des. 32 (2011) 3772-3782.

[15] B. Bazaz, A. Zarei-Hanzaki, S. Fatemi-Varzaneh, Hardness and microstructure homogenaty of pure copper processed by accumulative back extrusion, Mater. Sci. Eng. A 559 (2013) 595-600.

[16] L. Yi, Y. Dong, M. Lin, L. Zhang, X. Wang, Prediction on extrusion force in copper-chromium alloy extrusion processing based on projection pursuit regression, 2013 Int. Conf. on QR2MSE (2013) 1181-1183.

[17] QFORM 2D/3D Metal forming simulation program ver. 4.2. 2D simulation User's Guide, QuantorForm Ltd. 2007

[18] N. Biba, S. Stebunov, A. Vlasov, Material forming simulation environment based on QFORM3D software system. Steel Res. Int. 79 (2008) 611-616.

[19] T. Miłek, B. Kowalik, B. Kuliński, Evaluation of the possibility of performing cold backward extrusion of axisymmetric thin-walled aluminium die stampings with square section, Arch. Metall. Mater. 60, 4 (2015) 3043-3050.

[20] A. Mazurkiewicz, L. Kocur, Obróbka plastyczna - laboratorium, Wyd. Polit. Radom. Radom 2001 (in Polish).

[21] T. Miłek, Experimental investigations into one-sided and two-sided bulge forming of steel reducing tubes, Steel Res. Int. special edition (2012) 543-546.