ISSN 1392–1207. MECHANIKA. 2015 Volume 21(4): 329–333

Influence of deformation on metal structure in the forward microextrusion process

K. Mogielnicki*, J. Piwnik**
**Faculty of Mechanical Engineering, Bialystok University of Technology, Bialystok, Poland, E-mail: k.mogielnicki@pb.edu.pl*
***Faculty of Mechanical Engineering, Bialystok University of Technology, Bialystok, Poland, E-mail: j.piwnik@pb.edu.pl*

crossref http://dx.doi.org/10.5755/j01.mech.21.3.9553

1. Introduction

Comparing microforming to traditional forming process it can be observed, that while going to a microscale, parameters such as grain size or surface structure are not changed [1, 2]. Relationships between the dimensions of the manufactured items and morfometric parameters of their microstructure and surface stereometry, both items and tools are different in macro and microscale. This leads to the size effect formation, which presence does not permit direct application in microforming of metals available technological knowledge relating to conventional forming methods [3, 4].

Microforming is a young technology, but more and more research centers in the world deal with it. Currently works refer to experimental diagnosis of the impact of size effect on metal forming processes and of the products mechanical properties. In parallel, together with the reports of these works results, attempts to take into account and apply the identified phenomena in all sorts of software simulating the metal deformation processes are undertaken eg. [5, 6].

Experimental studies of metal microextrusion have been presented in a thematic literature for two decades [7]. Influence of the containers and dies surfaces smoothness and a material grain size on the mechanical properties of the product have been investigated – size effect. Similarly, as in the case of macroscale, in microscale there are conducted: a forward microextrusion eg. [8, 9], a backward microextrusion eg. [10] and an angled one [11, 12]. These processes are carried out in dry conditions, with lubrication, at ambient and elevated temperatures. These parameters appear to have different, often heightened influence on mechanics of deformation in the microscale. Miniaturization of these processes introduces need to further understand the peculiarities with it emerging. In microscale material can no longer be treated as a homogeneous, because in the area of deformation it can be just a few grains. It should also be taken into account the influence of container surface roughness, which significantly affects on deformation processes at the microscale level.

2. Experimental investigations

In order to determine the influence of tool roughness on metal plastic flow in the forward microextrusion process conducted in dry conditions, the toolkit author's copyright project was designed and manufactured [6]. There are two containers and two rectangular dies of the same size, differing only in the degree of containers roughness, hollowed in the halves of the bodies (Fig. 1). The diameter of the containers is D_p = 1.8 mm, while the dies D_m = 0.9 mm. Toolkit includes also the piston that presses on the "floating" over his face punches. Body and the piston are made of X210Cr12 steel, and punches of bearing steel 100Cr6. Samples made of aluminum and copper were extruded (Fig. 2). In order to illustrate the material structures, samples made of annealed electrolytic copper Cu99.99E have been used.

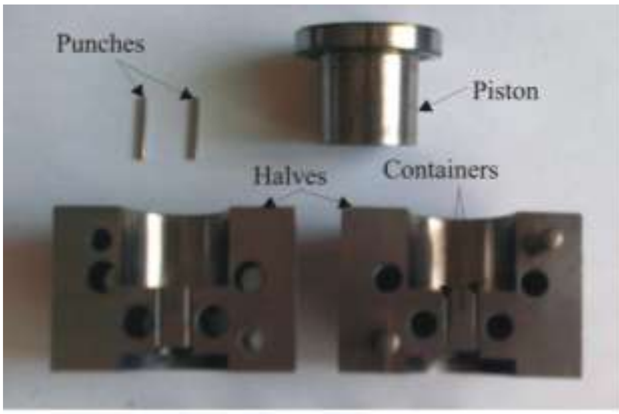


Fig. 1 View of the toolkit for forward microextrusion [6]

Fig. 2 Extruded samples [6]

Containers and dies were drilled with the use of the EDM method. In order to obtain diverse wall roughness of containers, they were drilled with different degrees of energy pulsed electric discharge. In order to determine the degree of containers roughness, the roughness profiles were designated using laser microscope LEXT OLS4000 3D, and average values of parameter Ra were determined for each. As a result of the measurements, following values were obtained: Ra = 1.2 µm and Ra = 3.5 µm. Fragments of received profiles of the tested containers are shown in Figs. 3 and 4.

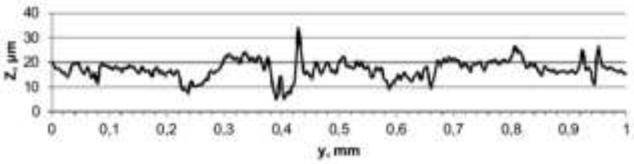


Fig. 3 Profile of the container roughness $Ra = 1.2$ μm, measured along an axis [6]

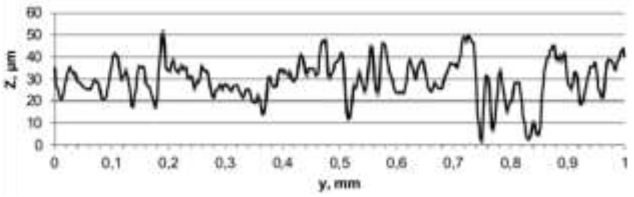


Fig. 4 Profile of the container roughness $Ra = 3.5$ μm, measured along an axis [6]

Extruded samples were sunk in epoxy resin and their metallographic sections were prepared. The microscopy images at the longitudinal sections of samples before and after extrusion were obtained. Width measurements of the strips with highly deformed structure caused by containers roughness in the places where these bands are the widest were realized. Measurements were conducted using MultiScan software, that allows morfometric analysis of objects in the scaled photographs.

Fig. 5 shows the material structure in the longitudinal section of the sample before extruding. At the edge (Fig. 5, photo a) and inside (Fig. 5, photo b) of the sample a homogeneous grains distribution appears.

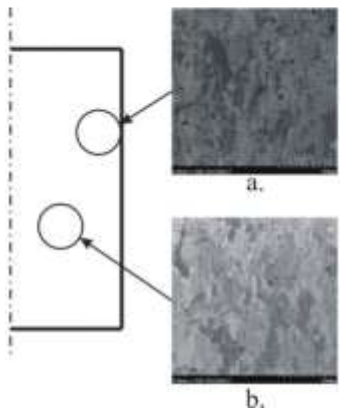


Fig. 5 Initial copper grain structure

At the section of extruded in a container with the roughness $Ra = 1.2$ μm sample a narrow strip of deformed structure at the outer edges of its upper part is visible (Fig. 6, photo d and e). Core of the sample remained unchanged and grains in this area have an original, uniform layout (Fig. 6, photo a and b). In the areas of the upper outflow and die a fragmented structure appears (Fig. 6, photo c and f), caused by intensification of deformation. Lower part of the sample shows also significant fragmentation of the structure, especially at its outer edge (Fig. 6, photo g).

Sample extruded in the container with roughness $Ra = 3.5$ μm have a broader range of deformed grains at the outer edge of its upper part (Fig. 7, photo b, c and d). Core of this part, as in the previous case, has an uniform grain structure (Fig. 7, photo e and f).

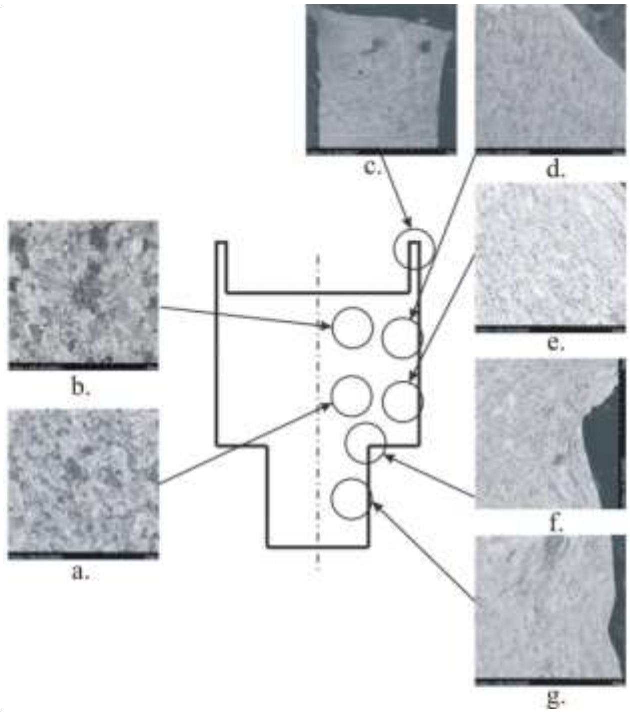


Fig. 6 Grain structure of forwardly extruded copper in a container with roughness $Ra = 1.2$ μm; magn. × 500

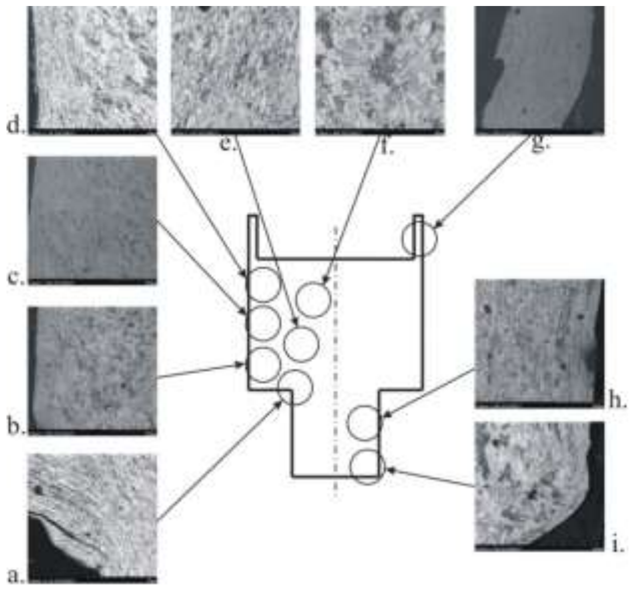


Fig. 7 Grain structure of forwardly extruded copper in a container with roughness $Ra = 3.5$ μm; magn. × 500

Figs. 8 and 9 show the differences in the width of the bands of strongly deformed grains in the vicinity of a containers roughness. Photos showing the bands at half height of the containers have been selected. In the sample extruded in a container with the roughness $Ra = 1.2$ μm range of fragmented grains was estimated to be about 50 μm. In turn, in sample extruded in container with the roughness $Ra = 3.5$ μm this range has a width approximately 200 μm.

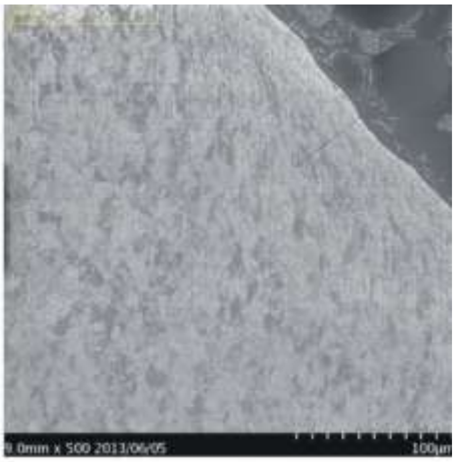

d.

Fig. 8 Bands of strongly deformed grains width measurement in the sample extruded in the container with roughness Ra = 1.2 μm

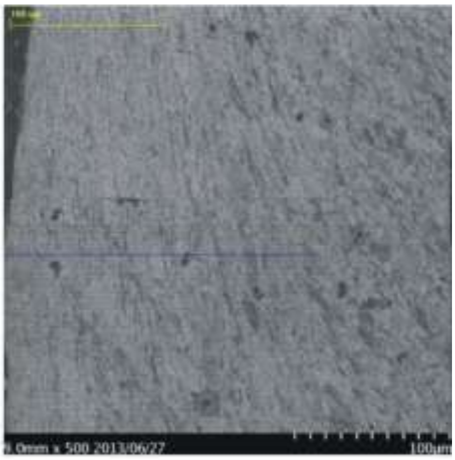

c.

Fig. 9 Bands of strongly deformed grains width measurement in the sample extruded in the container with roughness Ra = 3.5 μm

3. Microextrusion process modeling conditions

Axially symmetric extrusion process allowed to carry out simulations in a half sections what reduced time of calculation. Simulations have been performed using software DEFORM based on the theory of plasticity and using FEM. Tool elements were treated as a rigid bodies. Simulations have been carried out with keeping constant punch velocity equal v_0 = 0.01 mm/s and workpiece temperature T = 20°C. Workpiece material was considered as a homogeneous, plastic with isotropic hardening, described by the stress-strain curve defined for the experimentally investigated one. Its model was introduced to the software library of curves.

The container was D_p = 1 mm in diameter, while the die D_m = 0.5 mm (Fig. 10). Initial length of the workpiece model was 2.5 mm. Modeled meshes have been designed with the greatest possible number of elements, what was intended to take into account the variable geometry of the containers surfaces. These meshes had respectively: 7 and 9 thousand of elements. Workpieces were designed in the form of rectangles, connected with the peeks of containers roughness. While extruding the material filled triangles, which was the signal, that the mesh sensitivity is sufficient and takes into account the surface

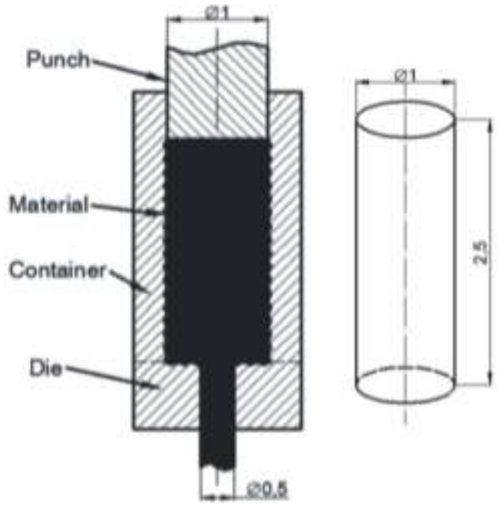
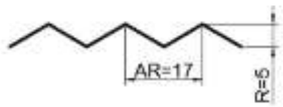


Fig. 10 Adopted for calculations model for forward micro-extrusion

roughness of the containers.

Motives method according to the PN-EN ISO 12085:1999/AC:2009 divides a roughness profile into so-called motives. A motive is a part of the original profile between the highest points of two local, not necessarily neighboring, peaks of the profile. Using the motives method, the average length AR and average depth R of the motives for both roughness profiles have been determined, with a given 95% confidence interval using the normal distribution:

1. R = 4.89 ± 1.09 μm AR = 16.66 ± 2.05 μm,
2. R = 13.87 ± 2.30 μm AR = 26.27 ± 3.41 μm.



a

b

Fig. 11 Average profiles of containers roughness: a) Ra = 1.2 μm; b) Ra = 3.5 μm

In order to illustrate the influence of container roughness on metal deformation process during microextruding the numerical models of roughness were designed and introduced into simulations (Fig. 11). At the tool-workpiece interface a zero friction factor has been given. The friction was the resistance of the material movement caused by a container roughness wave.

4. Results of the microextrusion numerical analyses

Fig. 12 shows half sections of the forwardly extruded workpieces in containers with top layers characterized by triangular profiles. Finite element meshes are dense enough to take into account variability of the material geometry in the vicinity of the containers roughness.

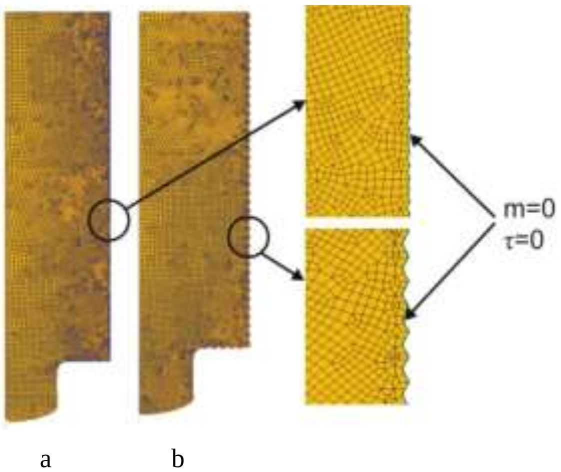


Fig. 12 Workpieces with the finite element mesh during extruding in the containers with roughness modeled in the form of triangle motives: a) R = 14 μm, AR = 26 μm; b) R = 5 μm, AR = 17 μm

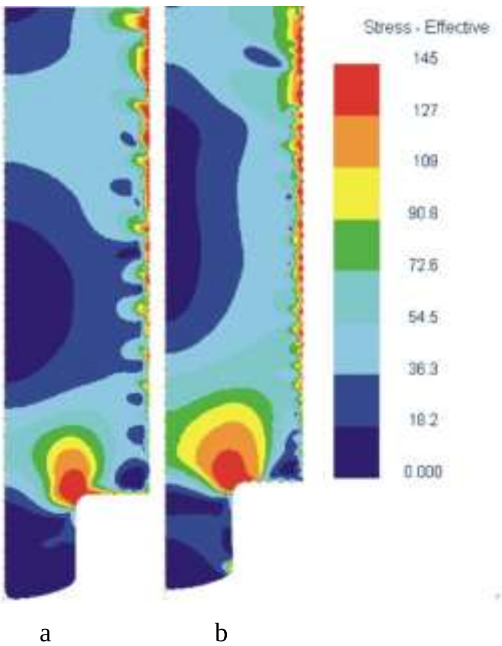


Fig. 13 Effective stress distributions while forward extruding with motives parameters: a) R = 14 μm, AR = 26 μm; b) R = 5 μm, AR = 17 μm

Forward microextrusion in container with the roughness wave numerical simulations following effective stress $\bar{\sigma}$ distributions revealed (Fig. 13). Effective stress in the material is characterized by specific distribution in the vicinity of the wave. $\bar{\sigma}$ increases with increasing motive parameters and with the height of the container.

Fig. 14 shows the deformation of the material using a stratified strain effective images $\bar{\varepsilon}$. In the vicinity of the wave there is a significant change in the conditions of deformation. With increasing motives depth increases strain value in the workpiece section.

Particles velocities distributions (Fig. 15) reveal the slow of movement of the layers in the container roughness vicinity. The larger motives dimensions the bigger volume of the material with reduced speed – dead zone. This dependency compared to images of the strain fields suggests, that in the initial phase of material flow a significant deformation of the material and the flow suppression is followed. As a result, a conical surface area rises, in respect of which an intensive shearing is followed by.

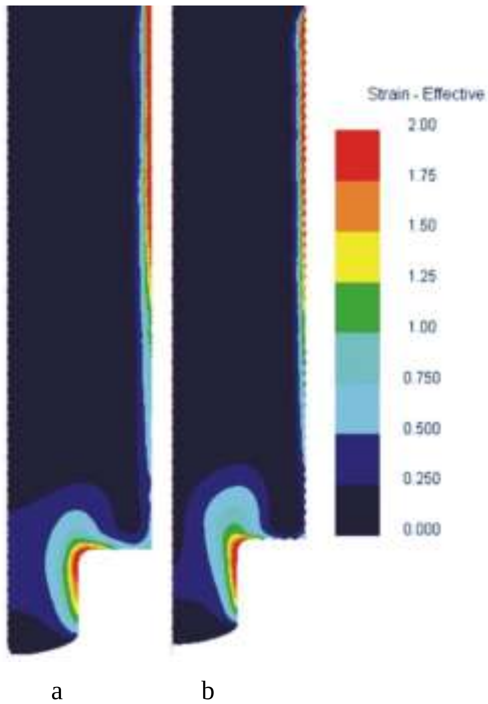


Fig. 14 Effective strain distributions while forward extruding with motives parameters: a) R = 14 μm, AR = 26 μm; b) R = 5 μm, AR = 17 μm

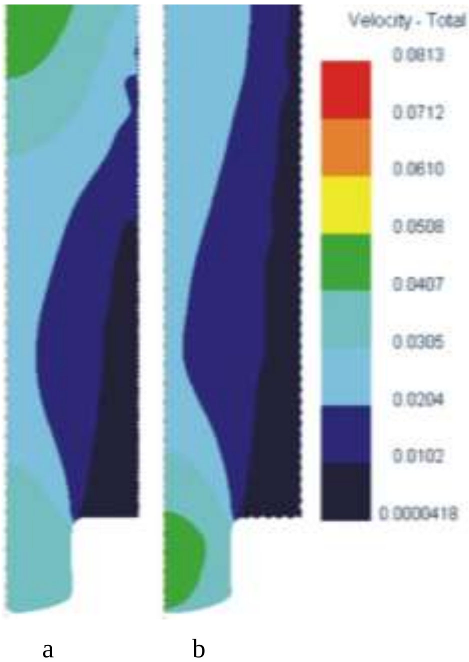


Fig. 15 Velocity distributions while forward extruding with motives parameters: a) R = 14 μm, AR = 26 μm; b) R = 5 μm, AR = 17 μm

5. Conclusions

Analyzed microextrusion processes were characterized by a large ratio of the container roughness value Ra to its diameter D_p. In experimental part of investigations, microextrusion cases with the above relation Ra / D_p equaling 0.00067 and 0.00194 have been examined. This gives respectively 11 and 39% of participation of the fragmented by the containers roughness grain structure layers in the inputs cross sections. Volume of the fine grained structure depending on the roughness of a container is the source of size effect in this case. This phenomenon has been confirmed experimentally and numerically. Reduction of the degree of roughness or increasing in the dimensions of the input will result in the disappearance of this occurrence.

Subsequent studies should be focused on identifying and recognizing the value of the parameter, which allows to specify the appearance of the size effect resulting from the impact of containers roughness. This parameter could be the ratio of a surface roughness *Ra* to a container diameter D_p: Ra / Dp. Line forecasting of this ratio value, based on the obtained data suggests, that when it is equal to 0.0002, the participation of fine grained structure at the input cross section will be negligibly small. It will be, therefore, the size effect emergence value during forward extruding of the tested metal. This estimate should be verified experimentally. Precise determination of this start parameter value would allow to determine the container diameter and its degree of roughness, to which modeling of container surface roughness wave in forward microextrusion numerical simulations would be appropriate.

References

1. **Vollertsen, F.; Hu, Z.; Niehoff, H.S.; Theiler, C.** 2004. State of the art in micro forming and investigations into micro deep drawing, Journal of Materials Processing Technology 151(1): 70-79. http://dx.doi.org/10.1016/j.jmatprotec.2004.04.266.
2. **Vollertsen, F.; Schulze Niehoff H.; Hu, Z.** 2006. State of the art in micro forming, International Journal of Machine Tools and Manufacture 46(11): 1172-1179. http://dx.doi.org/10.1016/j.ijmachtools.2006.01.033.
3. **Engel, U.; Eckstein, R.** 2002. Microforming – from basic research to its realization, Journal of Materials Processing Technology 125: 35-44. http://dx.doi.org/10.1016/S0924-0136(02)00415-6.
4. **Zimniak, Z.; Pondel, B.** 2007. Micro metal forming, Metal Forming 18: 29-36.
5. **Geißdörfer, S.; Engel, U.; Geiger, M.** 2003. Mesoscopic model-simulative approach to the scatter of process factors in microforming, Hollmann (Ed.): Strahltechnik 24: 81-88.
6. **Piwnik, J.; Mogielnicki, K.** 2014. Experimental and FE analysis of aluminium alloy plastic flow in the forward microextrusion processes, Archives of Metallurgy and Materials 59(2): 521-525. http://dx.doi.org/10.2478/amm-2014-0086.
7. **Mogielnicki, K.; Garbala, K.; Piwnik, J**. 2010. Overview of tool concepts for microextrusion, Scientific and Didactic Equipment 15: 113-118.
8. **Withen, C.P.; Marstrand, J.R.; Arentoft, M.; Paldan, N.A.** 2005. Flexible tool system for cold forging of micro components, First International Conference on Multi-Material Micro Manufacture 29: 143-146.
9. **Cao, J.; Krishnan, N.; Wang, Z.; Lu, H.; Liu, W. K.; Swanson, A.** 2004. Microforming: experimental investigation of the extrusion process for micropins and its numerical simulation using RKEM, Journal of Manufacturing Science and Engineering 126(4): 642-652. http://dx.doi.org/10.1115/1.1813468.
10. **Arentoft, M.; Bruschi, S.; Ghiotti, A.; Paldan, N.A.; Holstein, J.V.** 2008. Microforming of lightweight metals in warm conditions, International Journal of Material Forming 1(1): 435-438. http://dx.doi.org/10.1007/s12289-008-0088-y.
11. **Rosochowski, A.; Presz W.; Olejnik, L.; Richert, M.** 2007. Micro-extrusion of ultra-fine grained aluminium, The International Journal of Advanced Manufacturing Technology 33(1-2): 137-146. http://dx.doi.org/10.1007/s00170-007-0955-6.
12. **Geißdörfer, S.; Rosochowski, A.; Olejnik, L.; Engel, U.; Richert, M.** 2008. Micro-extrusion of ultrafine grained copper, International journal of material forming 1(1): 455-458. http://dx.doi.org/10.1007/s12289-008-0093-1.

K. Mogielnicki, J. Piwnik

INFLUENCE OF DEFORMATION ON METAL STRUCTURE IN THE FORWARD MICROEXTRUSION PROCESS

S u m m a r y

Investigation results presented in the work relate to the impact of tool roughness on the material plastic flow during forward microextruding of metal. Investigation process consists of the experimental and numerical parts. In the experimental one, forward microextrusion of annealed material using the toolkit author's copyright project was performed. The tests were conducted to compare deformation of the material extruded in containers with different roughness. As a result, obtained images of deformed material structures are presented and compared. Numerical part relates to simulations of analogous microextrusion processes conducted using DEFORM software. Tool roughness was modeled in the form of rigid triangular waves, whose geometric parameters were based on the roughness profiles obtained for the experimental tools. Depth and length of the triangular elements were determined using the motives method. Distribution fields of the effective stress, strain and the flow velocities are presented and compared. Based on obtained data, concept of determining of the parameter which can help to define the appearance of structural size effect resulting from the influence of container roughness is also presented.

Keywords: microextrusion, tool roughness, material structure, FE analysis.

Received January 22, 2015
Accepted March 17, 2015