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EXPERIMENTAL AND FE ANALYSIS OF ALUMINIUM ALLOY PLASTIC FLOW IN THE FORWARD MICROEXTRUSION PROCESSES

EKSPERYMENTTALNA I NUMERYCZNA ANALIZA PLASTYCZNEGO PŁYNIĘCIA STOPU ALUMINIUM W PROCESACH WSPÓŁBIEŻNEGO MIKROWYCISKANIA

The main aim of the paper is an evaluation of the real impact of a container surface roughness on metal plastic flow in the forward microextrusion process. For the purposes of experiment a specially designed and constructed by authors toolkit was used. Analyzed material was an annealed aluminium wire with 1,7 mm in diameter, with a stress-strain curve defined. Toolkit contains two experimental models of containers and rectangular dies with the same dimensions, differing only in the containers roughness degree. In order to determine the degree of the containers top layers asperities a roughness profiles with using laser microscope were made for each. Punch pressures have been calculated while forward extruding. In the next step the deflection of parallel lines marked at the samples longitudinal sections were analyzed. The extruded samples were submitted to the microhardness testing. Numerical analyses of analogous microextrusion processes have been also conducted. Container surface roughness was modelled as a rigid triangular wave with a zero friction factor at the interface m =0. Punch pressures and shapes of extruded samples flow nets were determined. Conducted investigations revealed the possibility of receiving products with different mechanical properties obtained by the container roughness assorting.

Keywords: Micro Metal Extrusion, Material, Equipment, FEM Simulation

Celem badań było określenie rzeczywistego wpływu stopnia chropowatości powierzchni pojemnika na plastyczne płynięcie metalu w procesie współbieżnego mikrowyciskania pręta metalowego. Do badań użyto zestawu narzędziowego autorskiego projektu oraz wyżarzonego, aluminiowego drutu o średnicy 1,7 mm, dla którego wyznaczono charakterystykę materiałową. Zestaw składa się z dwóch modeli pojemników na wsad i prostokątnych matryc o tych samych wymiarach, różniących się stopniem chropowatości. W celu wyznaczenia stopnia chropowatości warstw wierzchnich pojemników na wsady dla każdego z nich wyznaczono profile z użyciem mikroskopu laserowego. W trakcie przeprowadzania prób współbieżnego wyciskania wyznaczono przebiegi ciśnień na stemplu dla poszczególnych próbek a następnie zarejestrowano deformacje linii równoległych naniesionych na przekrojach wzdłużnych wyciśniętych elementów. Otrzymane próbki poddano testom mikrotwardości. Następnie wykonano numeryczną analizę analogicznych procesów mikrowyciskania. Chropowatość pojemników zamodelowano w formie sztywnej trójkątnej fali z zerowym współczynnikiem tarcia na kontakcie $m = 0$. Wyznaczono kształty siatek deformacyjnych wyciśniętego materiału oraz ciśnienia na stemplach. Przeprowadzone badania ujawniły możliwość wytwarzania wyrobów o różnych właściwościach mechanicznych, uzyskiwanych poprzez dobór określonej chropowatości narzędzia.

1. Introduction

Technological problems of metal forming processes related to microforming can be divided into four groups as in the case of conventional techniques. These are: material, process, tools, machinery and equipment [1]. In addition, next to these issues, in the microscale appear difficulties strongly connected with the same miniaturization and they are present in all four groups.

In the course of the transition from macro to microlevel size effect appears which effect changes the material behaviour during plastic treatment – well described by [2-5]. That effect influences on the microstructure, top layer topography and condition of lubrication, which remain independent of element size and leads to changes in material flow.

Miniaturization influences on such aspects of the processing as forming forces or friction conditions – size effect. The source of its formation can be divided into two groups, for example [6-8]: physical – related to workpiece gabarites and forming forces affecting the process run; structural – caused by the nature of the material structure.

State of art of microextrusion manufacturing methods is well given by [9], where was found that microstructure and the interfacial conditions significant effect on the process characteristics.

For compression tests with use FEM size effect in the surface roughness form was considered as an elliptical and sinusoidal curve with zero friction at the interface [10] or as triangular wave and wave of connected arcs [11]. Thanks to modelling of tools top layers in the form of a rigid wave,

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authors received more realistic interpretations of the friction effect in metal forming at the microscale.

In this paper an influence of size effect in the tool roughness form on material plastic flow in forward microextrusion process is examined. Due to investigations two containers with different roughness have been used. Obtained punch pressures and deformations of engraved on divided samples longitudinal sections parallel lines have been compared. Microhardness tests have been also conducted. FE analyses of analogous microextrusion processes have been conducted. Container surface roughness was modelled in the rigid triangular wave form with a zero contact friction factor. Punch pressures and flow nets were determined.

2. Tools and material

In order to determine an influence of the tool surface roughness degree on the metal plastic flow during forward micro-extrusion process in dry conditions a special toolkit was designed and manufactured [12].

This tool (Fig. 1) contains two experimental models of drilled at the interface of two halves with using EDM containers and rectangular dies with the same dimensions, differing only in the degree of containers roughness. Containers are ϕ = 1,8 mm while dies ϕ = 0,9 mm in diameter (Fig. 2). The toolkit include a piston that presses floating over his face punches.

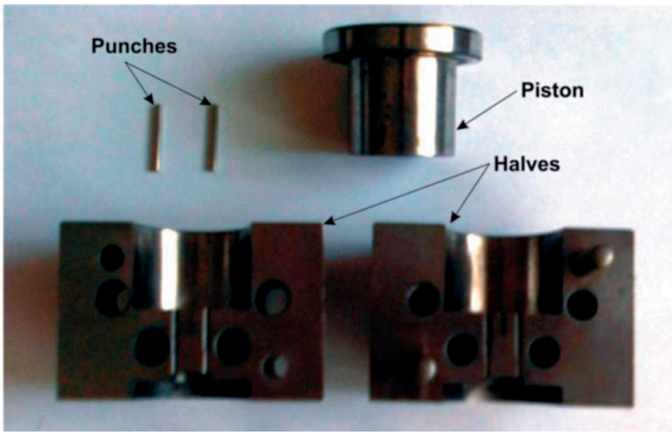
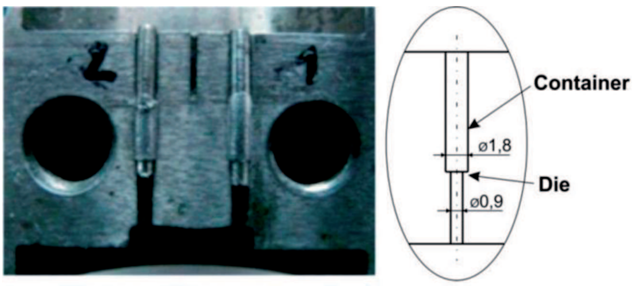


Fig. 1. View of toolkit for the metal rod forward microextrusion



(a) (b)

Fig. 2. Tool for microextrusion: a) view of extruded samples; b) container and die dimensions

In order to determine the containers coarse, the roughness profile has been done for each with using LEXT OLS4000 3D Measuring Laser Microscope and the average roughness parameters Ra have been calculated. As a result of the measurements following values for the roughness parameters was received: Ra = 1,2 μm for the first container (Fig. 3) and Ra = 3,5 μm for the second one (Fig. 4).

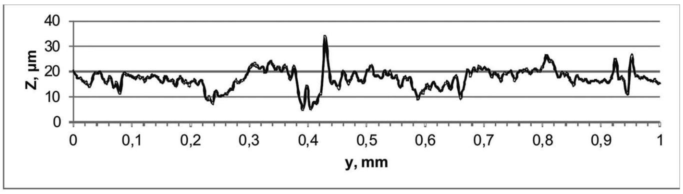


Fig. 3. Roughness profile for the container with Ra = 1,2 μm measured along the axis

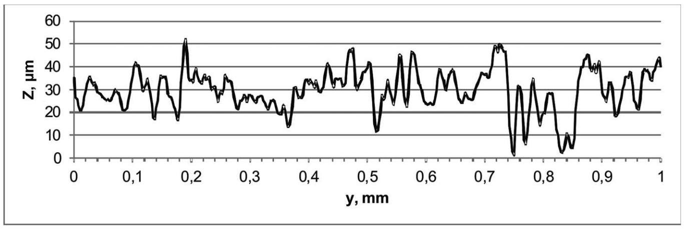
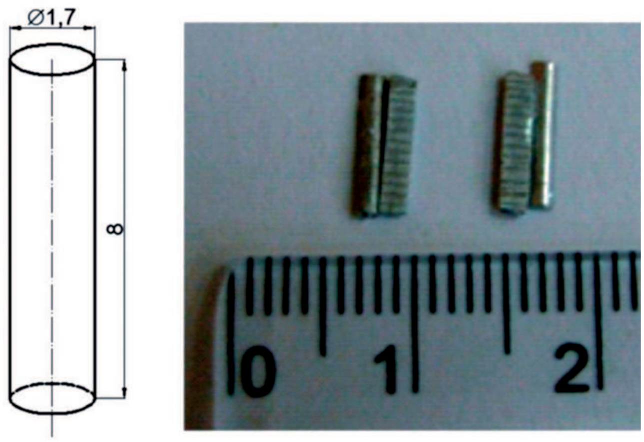


Fig. 4. Roughness profile for the container with Ra = 3,5 μm measured along the axis

An aluminium wire with 1,7 mm in diameter cut on pieces was the material used for test purposes (Fig. 5a). Aluminium was annealed by one hour at 500°C to obtain a homogenous grain structure. Samples divided along the axis were also used in the course of the experiment (Fig. 5b). Transverse parallel lines have been engraved at the longitudinal sections of these samples. Prepared halves were annealed in an identical way as the monolithic ones.



(a) (b)

Fig. 5. Prepared samples: a) shape and dimensions of monolithic samples; b) divided samples with a grid of transverse parallel lines

In order to determine the stress-strain curve of the billet material the compression test has been performed due to possibility of obtaining a larger plastic deformation compared with the tensile one. Fig. 6 illustrates a stress-strain curve of the material obtained during compression test of ten cylindrical samples with d_0 = 1,7 mm in diameter and h_0 = 2,5 mm in height. Yield point of the workpiece material was assumed as σ_p = 35 MPa.

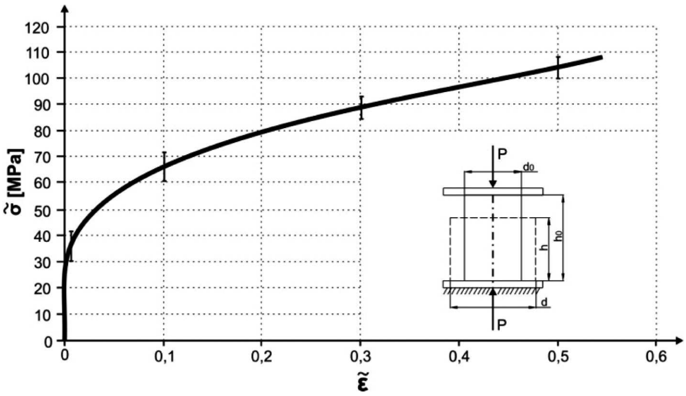


Fig. 6. Stress-strain curve obtained during the compression tests

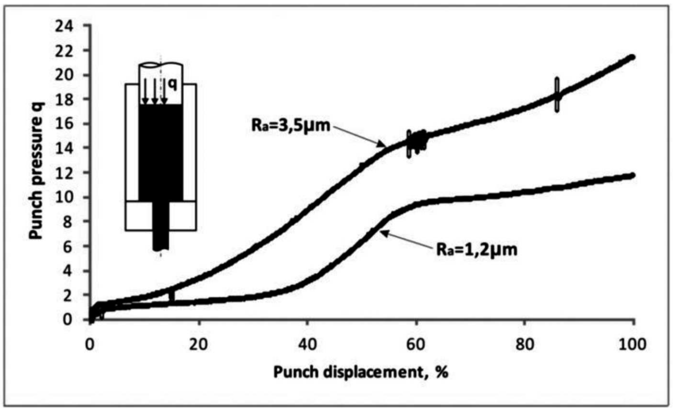


Fig. 9. Dimensionless punch pressures for microextruding of samples in containers with the average roughness parameters Ra = 1,2 μm and Ra = 3,5 μm – test 3

3. Investigation results

Extrusion forces obtained in the course of compression tests are presented in the form of dimensionless punch pressures q (Fig. 7-9) calculated from the following formula: $q = P/S_0/\sigma_p$ where: P – extrusion force, S_0 – initial sample face area before extruding, σ_p – yield point of the billet material. Punch pressures curves clearly illustrate an increase in punch pressure for the container with a higher roughness.

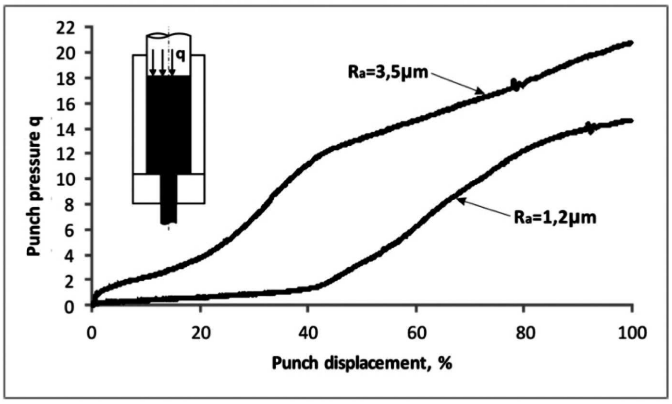


Fig. 7. Dimensionless punch pressures for microextruding of samples in containers with the average roughness parameters Ra = 1,2 μm and Ra = 3,5 μm – test 1

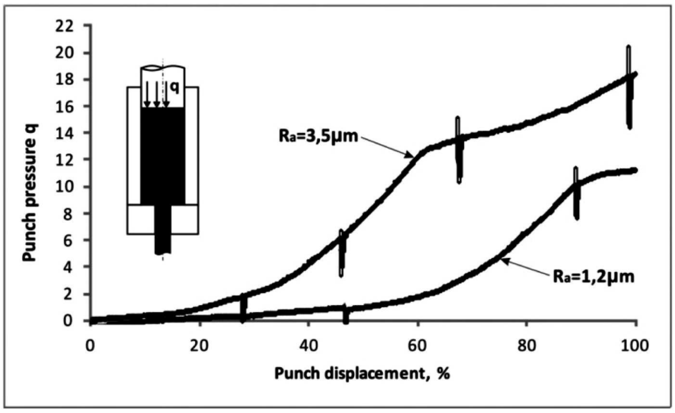


Fig. 8. Dimensionless punch pressures for microextruding of samples in containers with the average roughness parameters Ra = 1,2 μm and Ra = 3,5 μm – test 2

Grids of transverse parallel lines have been greatly obliterated during the treatment, what made it difficult to obtain good quality images. Lines at the upper part of sample being under the influence of the container walls with a lower roughness remain parallel (Fig. 10a). Analogous lines, for a container with a higher roughness, are deflecting (Fig. 10b) in opposite direction to the direction of the material flow. These deflections were formed at the edges of the samples. This phenomenon is clearly caused by a significant degree of the container roughness, which roughness increased the friction at the tool-workpiece interface.

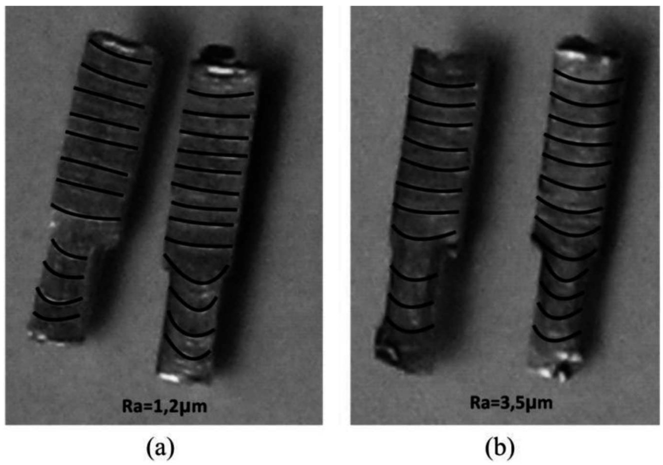
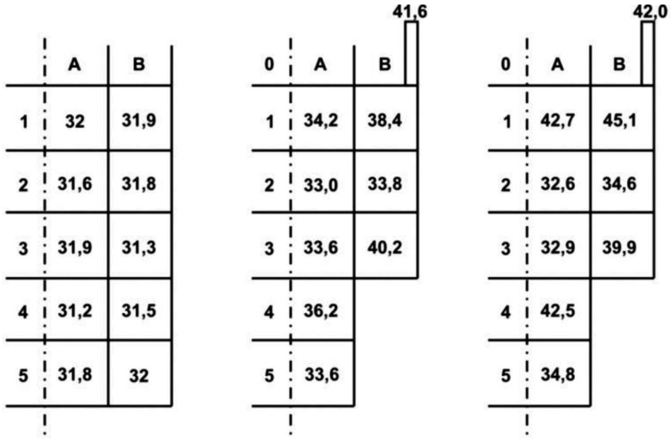


Fig. 10. Divided samples with grids of transverse parallel lines after extrusion in the container with roughness parameter: a) Ra = 1,2 μm; b) Ra = 3,5 μm

In the framework of investigations the microhardness *HV* 0,1 measurements have been carried out. Due to small sizes of samples they were sunk in an artificial resin. Before taking measurements the longitudinal sections of the samples were polished and burnished. Half sections of samples have been divided into squares and three microhardness measurements were taken for each area. Numeric values referred to the squares (Fig. 11) are an arithmetic means of three measurements. In addition the microhardness measurements of outflows from the upper part of extruded samples have been taken.



(a) (b) (c)

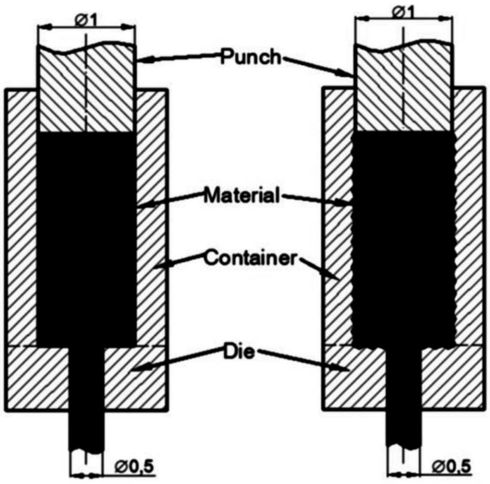
Fig. 11. Micro hardness *HV* 0,1 distribution at the longitudinal half sections of tested samples: a) before extruding b) after extruding in container with Ra = 1,2 μm; c) after extruding in container with Ra = 3,5 μm

In both extruded samples, B2 and B3 squares have a similar value of hardness, what suggesting the presence of dead zones. In these areas deformation of the material was stopped and therefore a permanent hardness was maintained. Important differences in hardness have appeared in A1 and B1 squares of these samples. In the sample extruded in the container with Ra = 3,5μm a significant strengthening in these areas has been occurred with comparison to the corresponding areas of the sample extruded in container with Ra = 1,2 μm. This difference cannot be explained by the presence of the outflows because in both cases they have a similar hardness level. Cause of this phenomenon can be material flow intensification in the vicinity of the container wall with higher roughness, involving the increase in yield point. In both samples there is a clear difference in hardness between their cores and external layers. In both cases, friction at the tool-workpiece interface caused strengthening of samples outer layers. Higher roughness of the container walls influenced also on the increase in hardness of obtained product – squares A4 and A5.

4. Numerical analysis results

In order to determine the influence of container roughness on material flow process while forward micro-extruding the numerical models of containers surfaces roughness have been created. Dimensions of the containers were 1 mm in diameter and right-angled die with 0,5 mm (Fig. 12). These models are two rigid triangular waves obtained in the course of used for the purposes of experimental investigations containers roughness profiles analysis. Roughness waves geometric parameters were determined by using the motives method. In the first case, the wave has motive depth equal to $R = 5\,\mu$m and its length $AR = 17\,\mu$m and represents the roughness parameter Ra = 3,5 μm, while wave with $R = 14\,\mu$m in depth and $AR = 26\,\mu$m in length of the motive is a model of Ra = 1,2 μm (Fig. 13).

Diameters of the modelled containers and dies have been reduced proportionally to the tools used in experimental part of investigations. Relatively large size of the object diameter in relation to small geometric parameters of the tool roughness wave would require using a mesh with number of elements exceeding used software computing capabilities. At the tool–workpiece interface a zero friction shear factor *m* has been given. This assumption gave a possibility to substitute the constant friction by triangle wave. To carry out the simulation processes the commercial code DEFORM 2D was used.



(a) (b)

Fig. 12. Schemes of the forward extruding: a) traditional model; b) model involving roughness of the container walls

(a) (b)

Fig. 13. Modeled parameters of the triangular waves represent: a) Ra = 1,2 μm; b) Ra = 3,5 μm

The billet material was considered as a plastic with the strain hardening defined by the stress-strain curve obtained for the material used in experimental investigation.

Figure 14 show numerical models of forwardly extruded billets with using tools with top layers characterized by rigid triangular waves (Fig. 14a and 14b). Finite element meshes are fine enough to take into account the geometric variability of the being under the effect of containers surfaces roughness material during processing. However, a significant degree of mesh density elongates the time of calculations. Presence of a wave causes deflection of the flow net transverse lines at the longitudinal sections of extruded billets what suggests the material flow intensification with increasing of the container roughness. The higher degree of roughness the greater deformation of the transverse lines (Fig.14c and 14d).

Punch pressures obtained in relationship with varied sizes of roughness waves are shown in Fig. 15. Curves distribution reveals increase of extrusion forces with increasing of the wave geometric parameters. This phenomenon reviles the material hardening intensification with container roughness increasing and confirms conclusions educed from the flow nets distributions.

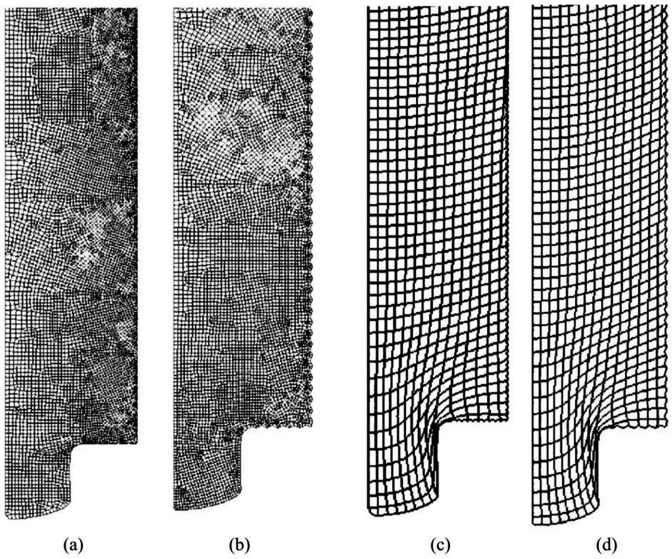


Fig. 14. Material during forward extruding in container with top layer characterized by a triangular wave and $m = 0$ at the interface: a) FE mesh for the $R = 5$ μm and $AR = 17$ μm wave; b) FE mesh for the $R = 14$ μm and $AR = 26$ μm wave; c) flow net for the $R = 5$ μm and $AR = 17$ μm wave; d) flow net for the $R = 14$ μm and $AR = 26$ μm wave

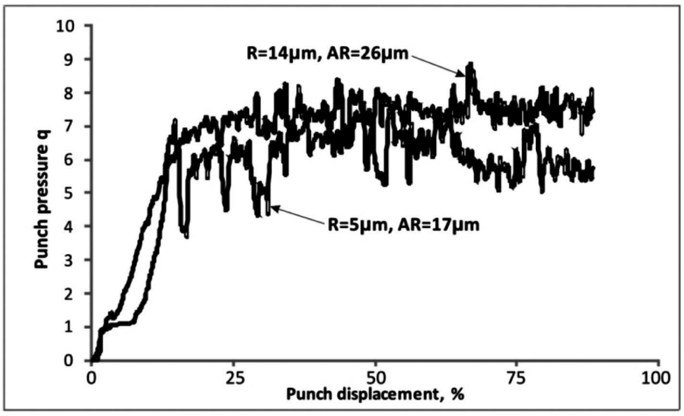


Fig. 15. Influence of triangular waves presence on punch pressures

5. Summary and conclusions

In paper investigation for the influence of tool roughness on material flow during microextruding of the metal rod in dry conditions process is presented. Three micro-extruding attempts of aluminium samples in containers with the average roughness parameters equals Ra = 1,2 μm and Ra = 3,5 μm have been conducted. Increase of the punch pressure with increasing of the container roughness suggests changes in the plastic flow process. Deflections of the transverse parallel lines engraved at the longitudinal sections of samples extruded in the container having a higher roughness indicate a significant increase of the friction forces at the billet-tool contact. Microhardness test showed a significant increase in hardness at the external layers of material adjacent to the containers walls. The material flow intensification, induced by the presence of roughness, caused the increase in yield point in these areas. The container roughness has also influenced on the product strengthening. Numerical investigations confirmed the significant impact of a wave roughness on material flow during microextruding. The higher wave parameters the larger flow net transverse parallel lines deflection. Numerical analysis did not allow achieving punch pressures at the level of those obtained during the experiment. However, the difference in pressures caused by the size of the wave roughness was confirmed. Obtained results presented at work suggest the possibility of the material flow regulate and by this properties of the product in the microextrusion processes by applying tools with a fixed roughness.

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