Deformations in micro extrusion of metals

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Abstract

Production technologies of small dimensions metallic elements are known for a long time. They are produced by machining methods: turning, milling, polishing. Recently, methods for manufacturing small details by forming are developed – microforming. This process is characterized by the high dimensions accuracy and the surface smoothness of received items and the high production rate. When a forming process is scaled down to micro dimensions, the microstructure of the workpiece, the surface topology of the workpiece and that of the tooling remain unchanged. Size effect is appearing. This paper analyses specifications of a metal extrusion in micro scale. To determine the impact of the tool surface roughness on deformation process the numerical model of roughness as triangle wave were developed. In paper the influence of the wave presence on the material flow is described. Impact of the forming conditions on extrusion forces there is also characterized.

Keywords: mechanical property; micro extrusion; rough friction, FEM simulation

1. Introduction

Trend to miniaturization of everyday devices increases industry demand for miniature parts. Metal production technologies for small dimensions elements are known for a long time. They are produced by machining methods: turning, milling, polishing. However the rapid increase, in the last two decades, of demand for small and handy devices, induced engineers to search for new, unknown methods of microparts manufacturing or to adapt traditional ones to the requirements and standards of miniaturization.

One example of adopted technology is the production of small parts by forming – microforming. This process is characterized by the high dimensions accuracy and the surface smoothness of received items and the high production rate, what makes it to be a good alternative to machining. Excepting benefits there are also some limitations, for example: limited forming possibilities of the treated material and narrow shapes range of obtained details.

Forming of metals and thus microforming of metals can be divided in three sections: massive forming, sheet metal forming and profile forming. In this work mechanics of extruding at micro scale is considered compared to traditional, widely developed extrusion. Extruded microelements have an application in the medical, electronic or military industry. Typical examples for such parts are pins for IC-caries, sockets, fasteners, micro-screws, lead frames, and any kind of connecting element (fig. 1) [2].

When a forming process is scaled down to micrometres, the workpiece microstructure, the workpiece surface topology and that of the tooling remain unchanged [3]. The material cannot be considered as a continuum, due to the fact, that large share of its volume is occupied by an individual grain. Thus, the microforming process limitations are largely influenced by the workpiece dimensions, and this is commonly referred to the size effect.
The primary problem connected with microforming is the so-called "size effect" resulted from same miniaturization [4]. This effect distinguishes described process from conventional methods of metal forming in macro scale and significantly affects the possibilities and limitations of this technology. Size effect formation sources can be divided into two groups [5]: physical – related to overall dimensions of the workpiece and the forces affecting the process; structural – induced by the material microstructure.

Metal deformation processes in small scale are characterized by high workpiece surface to volume ratio [6,7]. A relatively large area acts an important role during treatment. Increased influence on the process has therefore the friction on the billet-tool interface. It is started to be important the tool and the workpiece roughness degree, leading to the disclosure of the activity of new material forces, new structures and a new schemas of deformations.

Authors of [8] performed a numerical simulation of the ring compression. The initial dimensions of the ring were: \(d_o = 6\,\text{mm}, d_i = 3\,\text{mm}, h = 2\,\text{mm}\). In order to take into account size effect, the tool surface was modeled with an elliptical and sinusoidal curve and zero friction as shown in Fig 2. The calibration curve was determined from the relation \(m = f(a,t)\). Combining \(a\) and \(t\), the average roughness (arithmetical average height) \(R_a\) was derived.

To determine the influence of tool roughness on metal deformations while micro extruding, the numerical model of surfaces roughness for container and die for rod forward extrusion has been created. The dimensions of the container were \(1\,\text{mm}\) in diameter and right-angled die with \(1/2\) diameter reduction (fig. 3). This model is the triangular wave in two variants. In the first case its height \(h = 10\,\mu\text{m}\) and length \(\lambda = 40\,\mu\text{m}\) represents the average height of asperities \(R_a = 2.5\). In the second, height \(h = 5\,\mu\text{m}\) and length \(\lambda = 20\,\mu\text{m}\) – the average height \(R_a = 1.25\) (fig. 4).

### 2. Investigation procedure

#### 2.1. Tool roughness

Qualitative distribution of friction and its quantitative parameters directly influence on the size effect which effect, in distinction to traditional macro forming, causes here different deformations schemes of the treated metal. This article presents the methodology of numerical modeling of the tool-workpiece interface geometry with use a triangular wave. The wave represents a surface roughness degree of tool for metal rods extruding. At work the impact of the above mentioned wave on the image of material deformation while forming has been examined. A dependence of extrusion forces from the size of asperities there is also described.
2.2. Assumptions

Axisymmetric geometry of the investigated processes, allows considering one half of the billet, reducing calculating time this way. To carry out the simulation processes, DEFORM software was used. The billet material was considered as a plastic with the strain hardening defined on fig. 5. The mesh of the billet was fine enough to take into account all the asperities of the interface. As well as die, container and punch were treated as a rigid.

Fig. 5. Stress-strain curve of the workpiece material

At the interface a rough layer of a tool–workpiece, a zero friction shear factor \( m \) has been given. This assumption gave a possibility to substitute the conventional constant friction by the triangle wave. In that case, resistance of the rigid asperity to billet movement was treated as a friction.

2.3. Study results

In order to illustrate the influence of tool roughness on the deformation process while metal rod micro extruding three numerical simulation has been carried out. In the first case flat material-tool contact surface with a constant friction factor \( m = 0.12 \) has been modeled – traditional extrusion without considering the effect of roughness. Another two cases are contact surfaces shaped by triangle wave (fig. 4) representing the roughness of the container and die with a friction factor \( m = 0 \) – extrusion including size effect.

The presence of the roughness wave clearly affects on the rotation angle of mesh nodes (fig. 6). Strain value is growing with increasing of triangles height in vicinity of the wave (fig. 6b and 6c). Especially distinct deformation increase is observed in the vicinity of the wave. The flat tool extrusion model with constant friction factor \( m \) does not reveal such symptoms. Strain appears only in the die (fig. 6a).

Extruded samples flow net view confirmed lack of material deformation in the container with a flat wall (fig. 7a). While the presence of roughness wave raises a deflection of the flow net cross lines at the longitudinal section of the container. The higher the roughness degree, the greater deflection level of the net cross lines (fig. 7b and 7c).
Dependence of obtained extrusion forces from the size of asperities are presented on fig. 8. For comparison, loading curve received during the extruding in the flat container with a constant friction factor $m = 0.12$ (without wave model) there is situated. Distribution of the extrusion loading curves clearly indicates growth of forces with increasing wave parameters.

Fig. 7. Flow net of extruded metal rods with a interface characterized by: a) constant friction factor $m = 0.12$; b) triangular wave $h = 5 \mu m$ and $\lambda = 20 \mu m$; c) triangular wave $h = 10 \mu m$ and $\lambda = 40 \mu m$

4. Conclusions

Growth of roughness importance in micro scale causes changes in material flow while plastic treatment compared to traditional macro forming, where influence of roughness on the process is relatively small. During the metal rod micro extruding simulation with container and die top layers characterized by the triangular wave, the highest strain level has occurred in the vicinity of the wave. However changes in flow caused by the presence of the wave penetrate into the depth of the material. Above characteristic phenomena leads to an irregular metal flow in a whole sample volume, which is not observed while extruding in the tool with flat walls and with defined friction factor. With increasing wave parameters increases the level of distortion.

The value of extrusion forces increases concurrently. That increment may be explained by the hardening of the deformed material under roughness impact. This phenomenon does not occur at traditional macro extrusion and may be treated as a size effect, which directly influence on the deforming processes in micro scale.

References