The friction in rod forward and backward micro extrusion

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Received: 26.02.2010; accepted in revised form: 30.03.2010

Abstract

Micro parts are increasingly applied in industry because of the trend to miniaturization every day devices. Microforming is a method of manufacturing metal micro elements using a plastic treatment. This kind of production ensures high productivity, shapes and dimensions repeatability and good surface quality. Size effect connected with small dimensions affects changes in treatment processes of micro parts. While forming in micro scale, surface roughness is size independent and does not decrease with decreasing detail dimensions. The article presents schemas for forward and backward extrusion of metal rods. Using FEM, tool’s roughness as a triangle wave has been assumed, taking into account thereby size effect. Influence of roughness on extrusion forces by comparison with traditional flat tools and constant friction shear factor \( m \) has been specified. Impact of roughness caused growth of extrusion forces while forward extruding. On the contrary, backward extrusion ensured stable required forces, regardless of a surface structure.

Key words: Mechanical property; Microforming; Micro extrusion; Friction; FEM simulation;

1. Introduction

Extrusion processes of metal in macro scale were analyzed from the beginning of the 19th century using different procedures. These were at first mainly experimental methods. Recently, the theoretical aspect of this process has been intensively developed. The plastic effects, caused by a large deformations, are described by the yield plastic theory equations [1, 2]. However, there is still lack of their solutions. A finite element method, currently used, helps to obtain a lot of numerical results, however, its credibility must be verified with using complex and costly experiments. Theory of macro extrusion is developed by a wide number of scientific centers in the world and it matters regarding to the importance of this process in materials boring less treatment.

In the last decade, dynamic development of extrusion technologies advert on mechanics of metals deformation in micro scale. Actual trend to miniaturization of everyday devices, causes increase of industry demand for miniature components (fig.1). However, reducing dimensions of extruded objects leads to much of peculiar phenomena, did not occur in traditional metal forming processes in macro scale. Size effect, associated with the miniaturization, causes disclosure of the activity of a new forces, new material structures and new deformation schemas.

Fig. 1. Application of metallic micro parts [3].
Micro extrusion is a technology of making parts (two dimensions less than one millimeter [4]) which is derived from traditional macro forming. However, some aspects of the process such as the homogeneity of the material or friction conditions, known and verified so far, appear to be not verifiable for plastic treatment in reduced scale.

The basic problem in micro forming is so called size effect consequential from the same miniaturization. This effect, distinguishes that process from conventional metal forming methods in macro scale and significantly affects the possibilities and limitations of this technology. It causes the changes in the deformation dynamics, does not occur while traditional processes of deformation. Size effect is caused by increase of parameters significance in micro scale, neglected in conventional extrusion processes, because of their negligible influence in that case. Regarding micro forming, parameters such as number and size of grains, workpiece and tool roughness level, adhesion forces and intermolecular Van der Waals forces occurred at the interface are getting importance.

The grain size of metal is located within specified limits, and it can’t be freely decreased as dimensions of manufactured items. Fig.4 shows a sample of extrusion of polycrystalline and amorphous materials into V-grooves width 1 and 2µm. For the purpose of the experiment aluminum alloys with different grain sizes and amorphous alloy Zr55Al10Cu30Ni5 has been used. Amorphous material appeared much more formability than polycrystalline one [5]. Too large size of material grains, deformed in micro scale, leads to its irregular flow, which causes a lack of manufactured parts shapes repeatability.

In the process of micro extrusion, surface roughness is part size independent and do not decreases with decreasing detail dimensions [6]. The main purpose of the article is to define the container and die roughness impact on pressing forces. The analysis has been made by comparing backward and forward rod extrusion, carried out with and without use of roughness triangle wave model.

2. Procedure of experiment

Growth of tool roughness significance related to sizes reduction compared with the corresponding macro processes, causes changes in friction conditions while processing.

To illustrate quantitative influence of impact of friction forces in micro scale on deformation forces, four numerical rod extruding models has been used, with 1mm rod in diameter and right-angled die 0,5mm in diameter. In the first case it was forward extrusion (fig.3a) and backward one in the second — material flows through a hole in the punch (fig.3b). These models has reflected traditional material deformation processes without taking into account the size effect, caused by impact of roughness. At the interface workpiece – tool, the constant friction factor \( m = 0.12 \) have been given.

![Fig. 3. Layout of metal rod extruding; a) forward extrusion, b) backward extrusion](image)

Following, analogous two processes were designed with taking into account size effect – micro extrusion (fig.4). Top container and die layers has been modeled in the form of a triangle wave – \( h = 10\mu m \) in height and \( \lambda = 40\mu m \) wave length (fig.5). This way, the model of mean tool roughness characterized by parameter \( R_{\text{a}} = 2,5\mu m \) has been obtained.

![Fig. 4. Tools models for micro extrusion of rods involved the roughness as a triangle wave form; a) forward extrusion, b) backward extrusion](image)
Fig. 5. Die and container surface triangular wave parameters

Axisymmetric geometry of the investigated processes, allows considering one half of the billet, reducing calculation 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.6. 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. 6. 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 observe a flow of a extruded material along triangle roughness wave without conventional friction disturbance. In that case, resistance of the rigid asperity to billet movement was treated as a friction.

3. Results and discussion

Extrusion forces obtained for forward and backward rod extrusion in flat container with a right-angled die with constant shear friction factor \( m = 0.12 \), are similar (fig.7). The loading curve for forward extrusion is decreasing while processing, which is caused by reducing interface area between the container and workpiece. The backward extrusion loading curve suggests lack of friction impact in the vicinity of the container.

Fig. 7. Comparison of rod forward and backward extrusion loading curves with constant friction shear factor \( m = 0.12 \)

Next two simulation processes for forward and backward extrusion have been conducted using a tool with surface characterized by the triangular wave. As it is showed on fig.8, extrusion loading curve for forward extrusion revealed a distinct growth of deformation forces comparing to backward one. Despite zero interface friction factor, while forward extrusion, the roughness wave causes significant growth of a movement inhibitory forces. On the contrary, backward extrusion assure state level of a needed deformation forces, without taking into account a surface texture. Extrusion forces, in this case, cause pressing of the material in to a wave valleys and does not affect a displacement of a billet along the container triangular surface.

Fig. 8. Comparison of rod forward and backward micro extrusion loading curves with influence of triangular wave \( h=10\mu m \) and \( \lambda=40\mu m \)

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**Archives of Foundry Engineering** Volume 10, Special Issue 1/2010, 447-450
4. Conclusions

The increase of a roughness significance in micro scale, distinctly influences on the growth of a deformation forces. During metal rods extrusion this kind of size effect can be reduced by using a backward extrusion method. Deformed material does not move along asperities of the container. Friction forces affects only at the die – workpiece interface. Elimination of material movement in the vicinity of container asperities prevents from extrusion forces growth. Reduction of a friction forces has a particular meaning when specifying bearing parameters of micro extrusion tools with a small number of parts of small dimensions.

This relationship will be especially distinct while fine-grained material plastic treatment. Small grains will be easily flow into the valleys of tool roughness. Material with coarse grains will be less sensitive on a tool roughness texture. Too large size of grains of a deformed material makes straiten to assuring repeatability of the produced micro details shapes.

The simulation results presented in article should be confirmed experimentally using materials with a different grain sizes.

References