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Flexible tooling for vibration-assisted microforming

W. Presz [a,*], B. Andersen [b]
[a] Institute of Materials Processing, Warsaw University of Technology, Narbutta 85, 02-524 Warsaw, Poland
[b] Noliac A/S, Hejreskovvej 18, 3490 Kvistgaard, Denmark
* Corresponding author: E-mail address: w.presz@wip.pw.edu.pl

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Analysis and modelling

ABSTRACT

Purpose: Miniaturisation generates necessity of micro-parts production. Micro-scale means closer tolerances and better surface roughness. These requirements can be achieved with metal forming processes but under high pressure and sufficient relative sliding distance between tool and workpiece surface. It makes such a process proven to galling. This tendency increases with diminishing of component dimensions. It means that retarding undesirable surface phenomena with special regard to galling becomes a critical factor for microforming. Literature search and previous investigations shows that implementation of vibrations might be a solution for limitation of galling tendency in microforming.
Design/methodology/approach: The group of so called "reference micro-components" has been chosen as an representation of micro-products. For these parts with FEM basic processes parameters were found. The tooling system for vibration assisted microforming of referenced parts has been designed. Vibrations are performed with vibrators based on stacked ceramic multilayer technology assuring accurate frequency and amplitude control.
Findings: The method based on static and dynamic analytical and FEM calculations of proper design of vibration assisted flexible tooling with piezo-vibrators has been found.
Research limitations/implications: Proposed reference micro-components and designed system can be used for investigations of technological parameters for utilisations of microforming.
Practical implications: Flexible laboratory system is designed to manufacture a wide range of micro-components using tools vibrations for improving quality of products. After laboratory investigations it is attended to design industrial system working on same principles.
Originality/value: Designed within this project flexible tooling for low frequency vibration assisted microforming seems to be original according to literature investigations.
Keywords: Plastic forming; Microforming; Vibrations; Flexible tooling

1. Introduction

Miniaturization of products in the electronics industry results a need for smaller and smaller metallic parts. Diminishing sizes requires improvement of dimensional accuracy and surface smoothness. Microforming processes carried out at sufficiently high contact pressure and large relative movement at the material-tool interface assure these requirements: narrow dimensional tolerances and a very low surface roughness [1], especially using ultra fine grained [2] or nano-materials. However, these conditions are perfect for the occurrence of a very dangerous surface phenomenon - galling. Unfortunately, diminishing the objects size to a range of microforming, increases the risk of galling because of worse lubrication conditions [3]. It means that retarding undesirable surface phenomena with special regard to galling becomes a critical factor in microforming processes deciding about successful implementation of this technology. Based on the literature reports, it appears that adding vibrations to metal forming processes could be a promising solution for surface phenomena problems.

2. Vibrations in metal forming

The first application of vibrations during deformation of metals was reported by Garskij and Efromov [4] in 1953. Two years later Blaha and Langekert [5] used ultrasonic vibrations in tensile tests of a Zink monocristal. Since that time in laboratories all over the World many investigations of plastic forming with a help of vibrations have been performed. Although there is no uniform opinion about mechanisms of mainly advantageous phenomena observed during processes with a help of vibrations. So far industrial applications mainly regard to wires and tubes drawing with ultrasonic waves of tools [6,7,8].

There was observed significant drop of process force and surface quality improvement. Only few works refer to other metal forming processes and the low frequency vibrations - under 1kH, but also in this area some positive effects were observed [9,10].

Although long history of laboratory investigations which shown profitable influence of vibrations on course of plastic deformations there were hardly reported any spectacular industrial uses. The reason of so limited industrial applications seems: large energetic expense and high costs of setting in vibrations of heavy tools which usually used in metal forming. These troubles because of small masses of products in principle do not refer to microforming. It means than, that this technology can perhaps be at last the sector, in which vibrations will be find economically well-founded and have finally industrial use. A dominating opinion is that the influence of vibrations on metal forming processes can be considered in two areas. First, the so-called *volume effect* [5] links lowering of yield stress with the influence of vibrations on the dislocation movement. Second, the so-called *surface effect* [11, 12, 13] explains lowering of the effective coefficient of friction by a periodic reduction in the contact area and/or periodic changes of direction of the friction force vector. ***This effect (surface effect) seems to be quite good theoretically supported and has been chosen as a dominant and goal phenomena within this project.***

As it was already pointed the contact problems are very critical in metal forming because of a very high pressure and increasing of contact surface and temperature that favors adhesions and galling. With scaling down dimensions of products the contribution of surface phenomena increases since surface to volume factor increases. It makes application of surface effect of vibrations especially suitable to micro-forming processes. In the so far utilizations diminishing of positive effect of vibrations was observed with lowering of vibrations amplitude [14]. On the other hand amplitude increasing results with increasing of technical complication and might lead to serious technical problems. A sort of compromise must be than achieve during system design. Within this project the relative surface movement has been assumed within a range of 25-50 µm [15] This assumption has a back ground coming out of a typical industrial tool surface constitution because precise grinding to the surface roughness about Ra = 0.32 µm results distance between asperities about 25-50 µm.

3. Type of vibrations

Surface effect can be observed only if occurs changes in relative movement of areas being in contact during metal forming process. Practically it means reversing of sliding direction of material on a tool surface or temporary loosing of contact between them. It can be obtain by vibration in two main ways. First, standing waves in tools [6] that cause complicated usually 3D periodic deformation of tool resulting local surface movement – points of tool are moving on different ways. Second, periodic movement of tool without its deformation – points of tool are moving on the same ways [7,9]. First method is based on propagation waves inside tool in resonant conditions to obtain possible high amplitude. Since self frequency of tool is usually very high obviously occurs problems with relative movement amplitude. Additionally along the work piece deformation self frequency of vibration system which consists of tool work piece is changing. This change draws correction of excitation frequency to keep in resonant range. It makes whale system rather complicated and certainly not flexible – different work piece shape or volume would need totally different resonant excitations. The second type of vibration or excitations is usually called *direct vibration or excitation*. ***In this project vibrations are utilized in the meaning of direct excitation of tools that limits vibration frequency to relative low values – less than 1kHz.***

In general metal forming manufacturing system consists of three main parts: 1 moving tool – mainly punch that is in “forming contact” with work piece, 2 stable tool – die that is in “forming contact” with work piece, 3 blank holder or ejector - exists only in some cases. Defining coordinates system as it is shown in Fig.2 it is possible to apply direct vibrations to each part (punch , die and blank holder) in 6 ways: 3 translations T_x, T_y, T_z and 3 rotations R_x, R_y and R_z. It makes quite a big amount of theoretically possible design variants. Most probably all of them would be able to successfully support forming processes with vibrations, but not all of them are at the same level of construction difficulties. In this project only two longitudinal translations have been chosen: one for moving tool and one for stable tool.

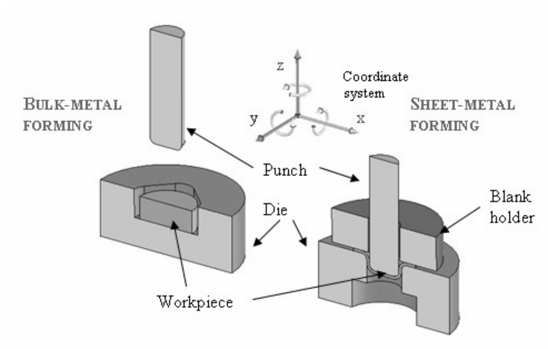

Fig. 1. Scheme of metal forming processes

4. Reference micro-parts

There was specified a group of micro-components to manufacturing of which system is dedicated. These parts called “reference parts” cover main groups of metal forming components and can be used for analysis technological and design problems in microforming. Technical drawings of these parts are shown in Fig.2. In Table 1 are collected some basic information about reference parts and their manufacturing processes also treated as “reference processes”.

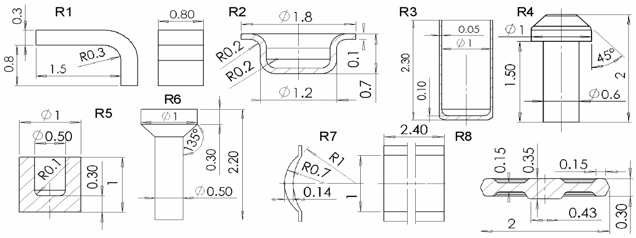

Fig. 2. Dimensions of reference parts: R1-R8

Table 1.
Reference micro-parts

Initial Shape								
Process Type	Bending	Deep Drawing	Ironing	Upsetting	Backward Extrusion	Forward Extrusion	Closed-die Forging	Closed-die Forging
Final shape	R1	R2	R3	R4	R5	R6	R8	R7
Volume mm^3	0.57765	0.41732	0.46972	0.73500	0.65102	0.67413	0.66760	0.31582
Mass [mg]								
Al.	1.56	1.13	1.27	1.98	1.76	1.82	1.80	0.85
Cu - alloy	4.86	3.51	3.95	6.18	5.48	5.67	5.61	2.66
Steel	4.56	3.30	3.71	5.81	5.14	5.33	5.27	2.49

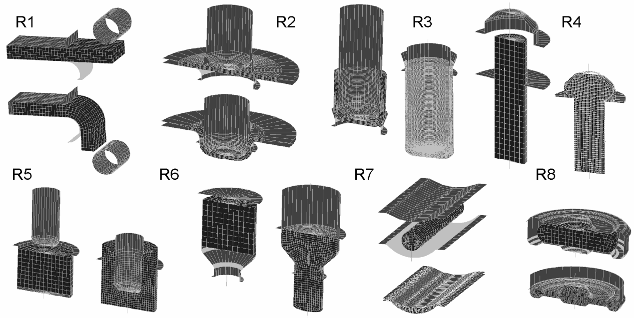

Fig. 3. Initial and final states of reference processes (FEM)

5. FEM simulation

All reference microforming processes were simulated with FEM MSC-Marc code under 2d conditions for rigid tool and coulomb friction assuming friction coefficient μ =0.1 (Fig.3). Two very different materials were taken: rather soft Al 98 % and pretty hard alloy steel XCrNiMoTi18. At this stage of analysis the main goal of simulation was to find process forces because of they strong impact on vibrators design. Contact pressure distribution and relative material movement were this way also obtained. Comparison of process forces is shown in table 2. In case of some forging processes forces increase rapidly in the final stage of deformation. For a better description there are two forces expressed in the table 2: so called "stable" force – process force just before rapid increase and the top force. It is explained in Fig.4. In forging processes top force becomes so high as a result of flash formation and narrow corners filling. In case of component R8 very high force is obtained because of three main reasons: 1. relative big cross section area of this component, 2. not optimal material flow in the final stage of process, 3. high flatness that increases the negative role of friction.

Table 2.
Process forces

Reference process	Micro-process force [N]			
	Al		Steel	
	Stable	Top	Stable	Top
R1 Bending	12	12	58	58
R2 Deep drawing	8	7.6	50	50
R3 Ironing	27	27	195	198
R4 Heading (closed)	118	180	874	1160
R5 Backward cup extr.	75	75	570	570
R6 Forward bar extr.	76	76	572	572
R7 Closed-die forging	21	83	231	693
R8 Closed-die forging (disc)	250	350	1500	2300

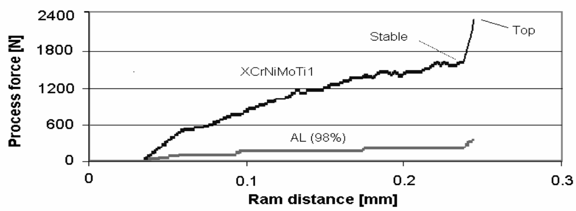

Fig. 4. Process force for reference process R8 (FEM)

Assuming the maximal working force at the level of 1000 N size of the part R8 must be reduced. For the high strength work piece material, XCrNiMoTi18 steel with the yield stress about 350 MPa, disc diameter can not accede 1.2 mm.

6. Tooling design

The principle of flexible tooling is shown in fig.5. System consists of two piezoelectric vibrators: moving vibrator *1* and stable one *2* mounted in the frame *3*. Vibrating heads *4* and *5* are exciting to longitudinal vibrations with stacked ceramic multilayer actuators *6* and *7*. Heads are connected with upper vibrating tool *8* and lower vibrating tool/ejector *9*. Shanks of vibrating tools have standard ends for stable joining with vibrating heads. For convenient manufacturing and maintaining they are relative big - 3 mm in diameter. Vibrating tools ends are much smaller and have shapes depending on micro product geometry. Both vibrating tools are guided in the tool block *10*. Vibrators are based on the stacked multilayer PZT ceramics [16]. This technology can be used for relative long distance movements [17]. Piezo-stack is placed inside housing (fig.6). On the both sides stack have ball joints to prevent bending load. At the starting point, fig. 6b, a time t = 0 means left - A position and starting movement to the right. At this position spring is already pre-stressed from its position 0 to position x_0 thus the working range for spring is x_0 to x_0+2A. The slider is moving from -A to A position. For certain conditions because of inertial forces it is possible that transducer will loose a contact, as it is shown in fig. 6b. Such situation is certainly not acceptable because of high sensitivity of transducer for tensile stresses.

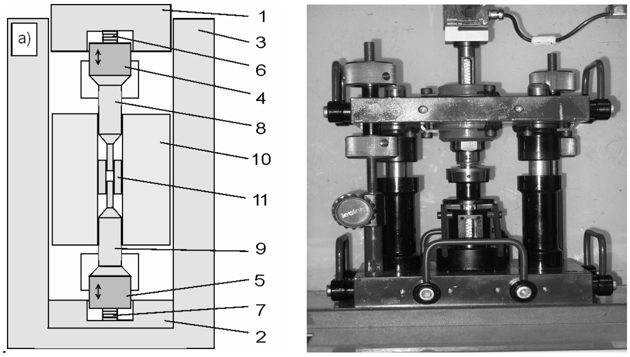

Fig. 5. Flexible tooling (details in text)

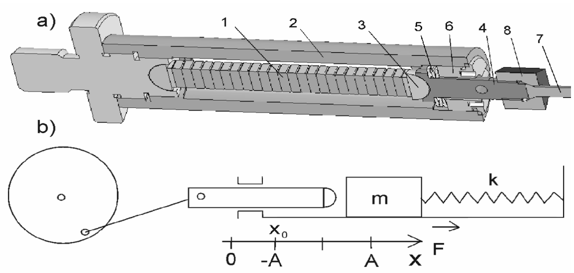

Fig. 6. Piezoelectric vibrator: a) technical drawing: 1- piezo-stack, 2- housing, 3- ball joint, 4- head, 5- pre-stressing springs, 6- bolt, 7- tool, b) mechanical scheme

It implicates a constant need of positive contact load of transducer. The final load on piezo-stack is shown in the fig. 7. Calculations were performed for frequency: 100 Hz, process force 570 N, stroke 50 um, friction force 100 N, effective moving mass 6 g. Maximal force is 707 [N] for the threshold value of k (calculated under no loosing contact condition) 350 N/mm. According to above analysis stacks dimensions 6x6x50 mm have been chosen.

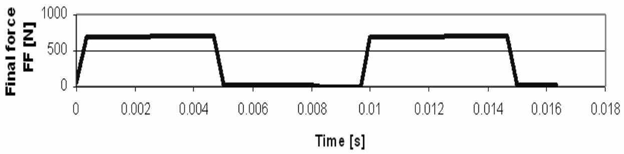

Fig. 7. Calculated force flow acting on piezo-stack during vibrating assisted microforming with frequency 100 Hz

7. Conclusions

- A group of reference parts for microforming have been proposed for experimental and FEM analysis of these type of technology.
- Principle of designed *flexible tooling* is assisting of micro forming operations with low frequency (under 1kH) longitudinal direct vibrations of tools.
- Designed system consists of two vibrators acting on the work piece from the top and the bottom.
- According to theoretical analysis stacked ceramic multilayer actuators with dimensions of 6x6x50 mm are suitable for vibration assisted microforming.
- Designed flexible system is able to cover vibration assisted manufacturing of all referenced parts.

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