# Piezo driven prestressing of die-system for microforming of metal components

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ABSTRACT: In micro forming, the increased surface to volume ratio makes ejection of an extruded component to an often complicated process. The aim of this work has been to demonstrate the possibility to reduce the force required to eject the component, by controlled pre-stressing of the die, before, during and after the forming process. The level of required prestress has been evaluated by FE analysis of the interaction between the forming process and the elastic deflection of the tool-system. A test rig has been designed containing four piezo actuators mounted symmetrically around the circumference of the die cavity. Mechanical amplification has been used to increase the pressure created by the piezo actuator to reach the level required for prestressing of a bulk forming tool.

Key words: Microforming, prestressing, ejection, piezo-actuators

## 1 INTRODUCTION

The trend in miniaturization of industrial products has lead to a large increase in the demand for small metallic parts manufactured by forming processes. The production of these components is effected by a detrimental phenomenon known as the size effect [1]. The size effects is represented by mainly 2 effects. One is the grain size to size of component ratio. The limited number of grains will influence the rheological data for the materials. Depending on the process the apparent flow stress can be increased (close die forming) or decreased (open forming) [1]. The other effect caused by down-scaling is related to the topography of die and workpiece, where the surface roughness is kept constant. Hereby the tribological conditions are worse and the influence higher compared to conventional processes. Experimental results have shown a significant increase in the forming force for close die forging and an even larger increase in the forge required for ejecting the finished component from the die [2]. This phenomenon is due to the increased surface to volume ratio which prevails in micro forming.

Especially for processes with large internal pressures and relatively large workpiece-tool contact area, like extrusion, the poor tribological conditions may create problems when ejecting the component. For conventional cold forging, the strength of the extruded pin can resist the required ejector force, whereas for micro forming of pins down to 0.3 mm, the ejector or extruded part may collapse. The maximum acceptable ejecting force will be less than 20 N for such a component. In figure 1, a forward extruded component with a shaft of 0.8mm and an extruded pin at 0.3 mm is shown together with a number of collapsed ejectors.

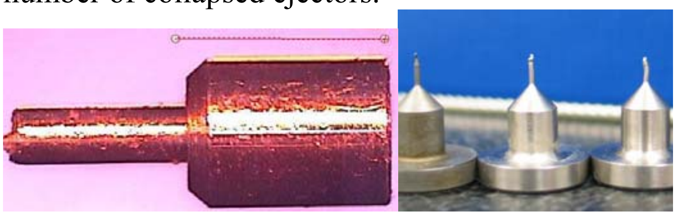

Fig. 1 Extruded silver pin from 0.8 to 0.3 mm and a number of collapsed ejectors

The force required to eject the component from the die depends on the tribological conditions combined with the radial pressure between die and component due to elastic deflections remaining after the punch is withdrawn from the die. The objective of this work is to ease the ejection of the micro formed component by controlling the prestressing of the container before, during and after the forming process. The stress level will be controlled by a number of piezo actuators acting at the outside of the container. By heavy prestressing during the process followed by a release of the prestressing unit, it is expected that a spring back in the size of microns will reduce the stresses and ease the ejection.

## 2 THE TOOL CONCEPT

Prestressing of cold forming dies is conventionally performed by applying a radial compressive pressure to the outer surface of the die, using a number of stress rings [3]. In the work reported here, these steel rings are substituted by four multilayer piezo actuators mounted radially around the circumference of the die as shown on figure 2, and the conventional circular die is substituted by a square die to ensure maximum contact pressure across the surface between the actuator and the die, even after elastic deformation of the outer surface of the die. The four piezo actuators are mounted in an outer steel ring to constrain them axially, and to make it possible to preload the piezo actuators to reduce the effect of manufacturing inaccuracies and surface roughness of the parts. The prestressing tool is mounted on a compression/tension loadcell which allows for the measurement of the forming- and ejection force.

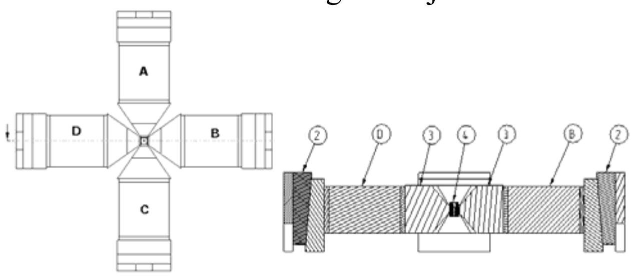


Fig. 2 Top view and cross section of piezo based pre-stressing unit, with only actuator assembly and die shown.

## 3 NUMERICAL SIMULATION

The tool system is designed for rod extrusion of a AA6062 from Ø0.5mm down to Ø0.3 mm. The strength of the extruded part is so low, that conventional ejection systems will cause problems as described in the introduction and in figure 1. The process is simulated by the commercial FE code Deform 2D and consists of 3 objects. The die is simulated as elastic and the billet as elasto-plastic. The prestress pressure is applied as a pressure boundary condition on the outer surface of the die. The die is simulated as axi-symmetic in the 2D simulation, but the elastic deformation of the die has been verified by 3D simulations of a square die.

At figure 3, the billet is shown together with the formed component. A red spot on the die surface mark the trackpoint which is used in figure 4 for analysis of the conditions at the inside of the die insert.

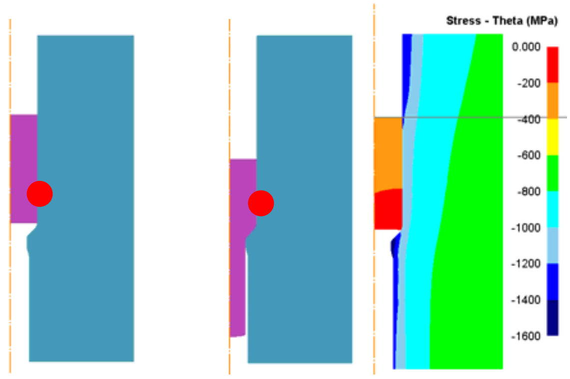


Figure 3 2D simulation of the extrusion process, with a red mark at the point of the contact analysis on the inside die surface. Initial condition (left), finished extrusion (middle) , Hoop stress in the die under prestress (right)

In the first phase, the billet is positioned inside the container and the piezo actuators are activated. Hereby the die insert contracts. In this model, the diameter of the billet and die insert are initially identical, and an internal pressure is therefore created. At a certain point, the pressure reaches the flow stress of the billet and a deformation will occur, the hoop stress in this situation is shown on figure 3 (right). The second phase is the forming process. The punch is moving downwards whereby the internal pressure will increase and the die insert will expand. At figure 4, the blue curve shows the normal pressure, which during the process reaches app. 310 MPa. The green curve represent the inside diameter of the die insert, where the expansion of the die insert during the forming process, can be identified as a small positive step of the curve.

The third phase is the one where the process benefits from the controlled pre-stressing device. The punch is withdrawn and the piezo actuators are de-activated. Hereby the die insert expands to the initial diameter, as shown in figure 4. The interesting part is the internal pressure in the reference point, which during the un-loading phase becomes zero. This indicate that there will be a gap between the formed component and the container after un-loading. Hereby a significant reduction in the ejection force must be expected.

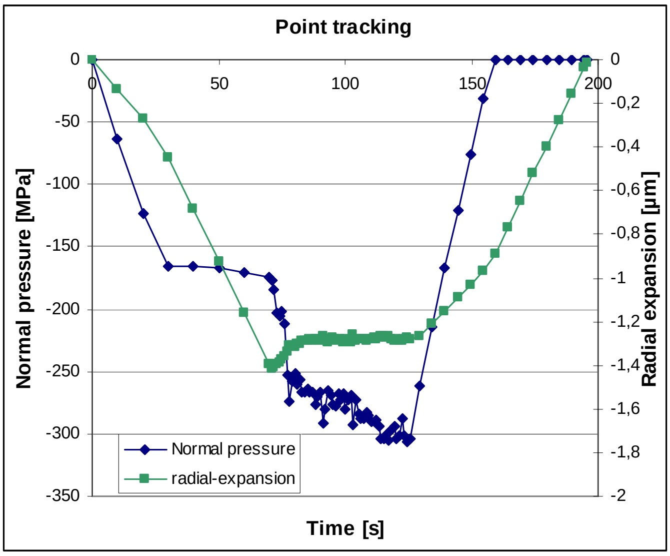


Fig. 4 Internal pressure and radial displacement of container wall for a rod extrusion using the piezo pre-stressing device.

## 4 DESIGN OF THE PRE-STRESSING UNIT

A high performance piezo actuator can provide app. 45 MPa blocking pressure in continuous operation, whereas the pressure required to prestress the die is more than a magnitude larger, the design criteria used in this application being 700MPa. Directly applying the piezo force to the surface of the container will therefore lead to failure in the piezo ceramic material or too low preload pressure. The solution is to concentrate the pressure generated by the piezo ceramic actuator on the outer surface of the die. Any clearances in the actuator assembly needs to be removed, to allow the piezo ceramics, to operate at maximum capacity. A double wedge shaped carbide element is therefore mounted between piezo ceramics and the base allowing a flexible initial pre-stressing of the ceramics. The pressure from a piezo stack 15*10 mm in cross-section is acting on a 1.9 x 2.2 mm surface as shown in figure 5. Hereby the pressure is increased by a theoretical factor of 35.9.

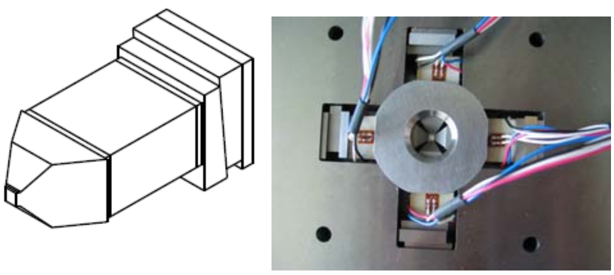

Fig. 5 15x10mm piezo actuator assembly with mechanical amplifier(left) and the die insert (2 x 2 mm) mounted in the prestressing unit

A test die for verification of the prestress has been designed as a 2x2x3mm cube with a bore of 0.5mm. The free strain of a high performance piezo actuators are in the size of 0.17% of the length of the stack. A 16 mm stack, with an active length of 14mm, will therefore, in an un-loaded condition, expand app. 23 µm. but has no displacement when loaded to the maximum pressure of 45MPa. A design pressure of 22 MPa was chosen as the working point to ensure sufficient stroke at the required pressure. The required length of the actuators was calculated, based on the elastic deflection of the outer ring, the wedge assembly and the pressure amplifier, together with the working stroke at the surface of the die, which was calculated as 3µm when subjected to a pressure of 700MPa.

An iterative approach based on FE simulation of the stiffness of the system was used and the optimal design was found to be a 16mm long actuator, pressure amplifiers made from tungstencarbide to reduce the elastic loss at the point of contact between the amplifier and the die, and an outer ring with a diameter of 160mm.

To validate the expansion of the piezo stacks, strain gauges were glued on the stacks, which enable monitoring of the system. In addition, the last layer of the piezo actuator was wired independently to either be used for additional displacement when a voltage was applied, or used as force sensor when connected to a charge amplifier. At figure 6 and 7, the piezo based pre-stressing device is shown.

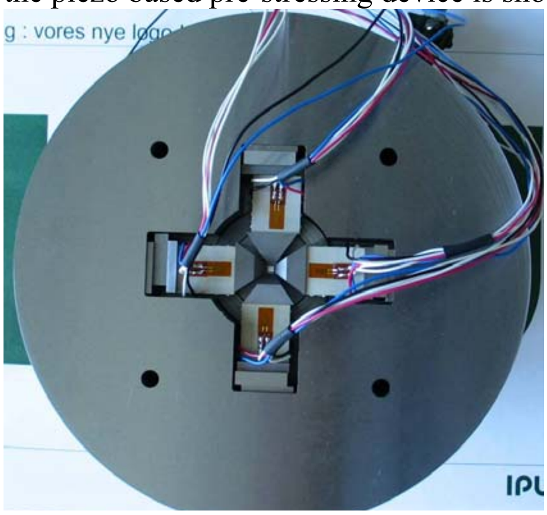

Fig.6 Top view of the piezo based pre-stressing unit, shown with the cover plate removed.

The system is designed for forming on the mini press available at IPU [2], where the punch is aligned by the inner surface of the die.

The lower part of the die is supported by an additional tool element, which is also used to guide the ejector. The die and the supporting element are not constrained in the horizontal plane, but allowed to move as the force balance between the piezo actuators dictate.

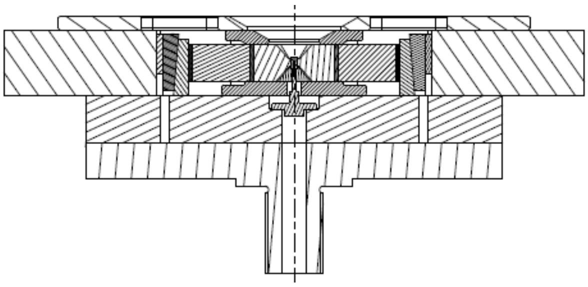

Fig.7 Cross section of the assembled piezo prestress tool

The movement of the actuators is controlled in pairs, i. e. the two x-actuators and the two y-actuators each share a voltage supply. This allows for a simple electronic setup, where two analogue outputs ranging from 0-10 volts, from a computer running Labview are amplified by a fixed amount. The design voltage is 200V, but the amplifier allows twice as much if testing at extreme conditions are needed.

## 5 SIMULATION OF EJECTION FORCE

2D simulations of the effect of the reduced prestress during the ejection phase have been carried out for a normal pressure at 25, 50 and 100 MPa. A Coulomb friction of $\mu$=0.2 has been used to model the interface between the component and the die, instead of the shear friction with m=0.2 used to model the extrusion process. In figure 8, the velocity of the nodes for an internal pressure of 50MPa and 100MPa is shown. It can be seen, that the part can be ejected at 50MPa but collapse at 100MPa. The collapse force is 14.5 N and the part is ejected at 13N for 50MPa and 12 N at 25MPa.

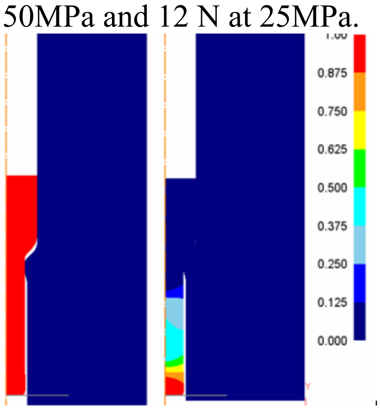


Fig.8 The velocity of the nodes during simulation of the ejection of the formed component. Successful ejection at an internal normal pressure of 50MPa (left), upsetting of the extruded part at an internal pressure of 100MPa (right)

The ejection force is not reduced as much as the normal pressure in the contact point. This is due to a zone with high pressure at the dieland, which is created by a slightly elastic compression of the extruded part. This phenomenon appear even for a successful ejection of the component.

## 6 CONCLUSIONS

An active tool system for cold forming of micro components with variable prestress during the process has been designed, taking into account possible manufacturing inaccuracies. The expected performance of the system has been demonstrated by FEM simulations of the interaction between the peizo actuators and the tool components, and through simulation of the forming and ejection process under different prestress conditions.
The tool system has been manufactured and allows control of the prestress of the die before, during and after forming of the component. Remove the prestress of the active tool during the ejection part of the process has shown to reduce the required ejection force in experiments [2] and in FE simulations. The tool allows for the possibility to apply slow radial vibration during the forming process which could prove beneficial in reducing the forming force. Experimental verification of the simulation results shown here will be carried out in the future.

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