Simulation of a Forming Process for Joining a Piezo Aluminium Module

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Abstract: The fabrication of piezo aluminium composite modules for sensor and actor applications with mass production technologies is in the scope of the Collaborative Research Centre SFB/TR 39 PT-PIESA project funded by the German Research Foundation (Deutsche Forschungsgemeinschaft) [1, 2, 3, 4].

After forming of cavities with a width of 0.3 mm into aluminium sheets by micro impact extrusion and the insertion of $0.25 \times 0.25\,\mathrm{mm}^2$ piezo rods, a joining of the rods into the material is necessary. For a minimization of the damping loss from the piezo material to the aluminium sheet, the joining should be done without using any adhesives or intermediate layers. Therefore a strong contact between the two materials should be realized by a forming process. A tool with a flat working face is intended to be pressed onto the element to induce a lateral material flow which clamps the piezo rods. To avoid unnecessary damage or destruction of the piezo rods a simulation of the process was conducted. The stresses in the piezo rods resulting from the forming process were simulated with COMSOL Multiphysics.

Keywords: Micro forming, precision cavities

1 Introduction

Manufacturing of mechanical microparts for sensors and actuators is often done by MEMS technologies. But in certain applications the MEMS processes are too elaborate and expensive for a cost-effective mass production. Furthermore the choice of materials and the range of possible 3D geometries are limited. Forming is a well known process for shaping massive parts and metal sheets for typical mass markets like the automotive industry. Formed parts commonly possess 3D structures and the variety of materials includes metals and plastics. However, the usage of forming technologies for feature sizes below 1 mm is found very rarely. Reasons are the necessary downscaling transformations of the material, geometry, and process parameters from the macro to the micro scale which is not fully understood yet [5, 6].

Therefore the investigation of forming technologies for large area microstructuring of thin aluminium alloy sheets is one focus of the Collaborative Research Centre SFB/TR 39 PT-PIESA of the German Research Foundation "Production Technologies for Light Metal and Fiber Reinforced Composite Based Components with Integrated Piezoceramic Sensors and Actuators" ("Großserienfähige Produktionstechnologien für leichtmetall- und faserverbundbasierte Komponenten mit integrierten Piezosensoren und -aktoren"). The goal of the project is to develop a manufacturing process for the production of metal/piezoceramic composite modules which can be implemented into metal parts, such as metal sheets in cars, and act as vibration sensor or actor basing on the piezoelectric effect.

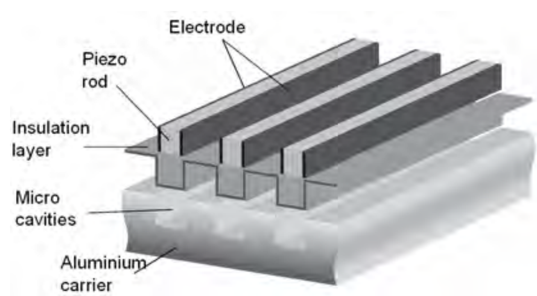

Figure 1: Scheme of metal-based piezo module.

Figure 1 depicts the scheme of the metal-based piezo module. Thin piezo rods are integrated periodically into cavities of light metal sheets. With a forming process (discussed elsewhere [1, 2]) cavities of 0.3 mm width are embossed into ca. 1 mm thick aluminium alloy sheets. Piezo rods with a squared crosssectional area ($0.25 \times 0.25\,\text{mm}^2$) are inserted into the cavities.

For a form closure of the piezo rods into the cavities a second forming process is conducted by using a flat surface stamp which is pressed onto the cavity walls which are significantly higher than the piezo rods [4]. A module with inserted piezo rods before the joining step is shown in Figure 2.

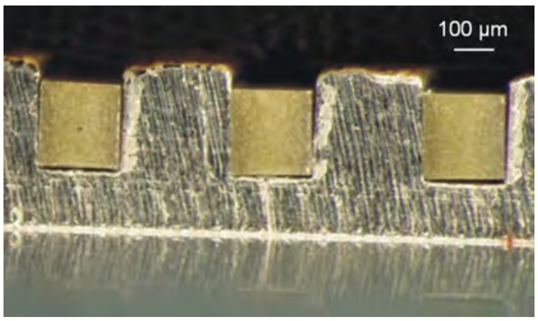

Figure 2: Inserted piezo rods before the joining step.

However, after getting a flat surface of the element, further pressure will lead to a stronger bond between aluminium carrier and the piezo rods. But this step should be done very thoroughly to avoid a damage of the piezo material. Therefore, a FEM simulation of this process step was conducted.

2 FEM Implementation

For the simulation, COMSOL Application Mode "Plane Stress" was used. The created 2D model bases on the geometry of the real module. A half cavity (125 µm width) and a half cavity wall (125 µm width) represent the single segment of the periodic module. Left and right wall were set as symmetry planes. Sheet thickness ranges from 1.18 mm on the cavity bottom to 1.4 mm maximum. Cavity length was set to 10 mm. One piezo rod is inserted form-locked into the cavity.

The forming step is realized by a prescribed displacement of 30 µm of the upper boundaries in 1 µm steps which leads to an average pressure of 743 MPa after 30 µm stroke onto the segment.

As carrier material the aluminum alloy AlMg4.5Mn0.4 (UNS A95182) was chosen which is a common sheet metal in automotive applications. It was considered as elasto-plastic material. Non-polarized PZT was applied for the piezo rod and considered isotropically. Insulation layer and electrodes are omitted in the model.

The mesh was generated using the "Extra Fine" option and it consists of 1170 triangular elements.

3 Results and Discussion

Figure 3 shows the von Mises stress in the simulated module segment and a detailed view onto the piezo rod. The stress in the piezo material is much higher than in the aluminium carrier because the carrier reduces its stress by plastic deformation. A stress concentration occurs in the lower corner of the piezo rod.

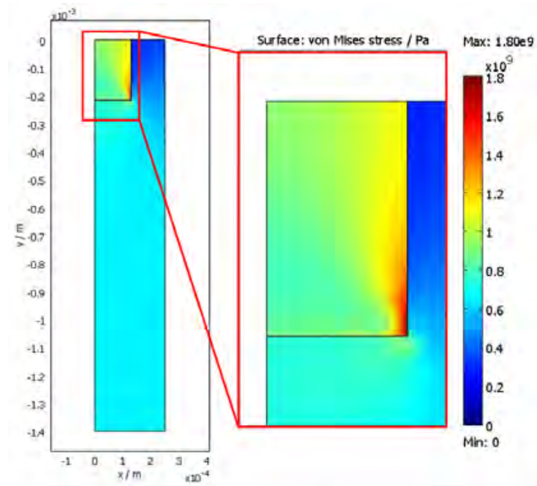

Figure 3: Von Mises stress in the simulated module segment.

In Figure 4 the von Mises stress is plotted over the vertical edge of the piezo rod. With an increasing stroke the stress increases and the maximum stress is located for every stroke in the corner of the piezo rod.

The simulation results show that a forming-induced mechanical damage of the module occurs "invisibly". A visual check of the module's surface is not sufficient to find cracks developed from mechanical stresses. Therefore cut images of experimental samples were prepared. In Figure 5, a lateral cut through a metal-based piezo module is shown. The joining of the displayed piezo rod into the cavity was performed with a pressure of 600 MPa which is according to a 23 µm stroke in the FEM model. A maximum stress of

1360 MPa in the piezo material is predicted by the the simulation for this applied load. Regarding the compressive strength of the piezo material of 600 MPa [7] the cracks in the corners (marked by red circles) are allegeable.

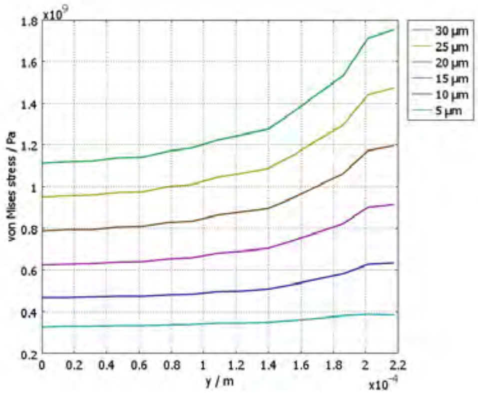

Figure 4: Von Mises stress of the vertical edge of the piezo rod with the forming stroke (5 to 30 µm) as parameter.

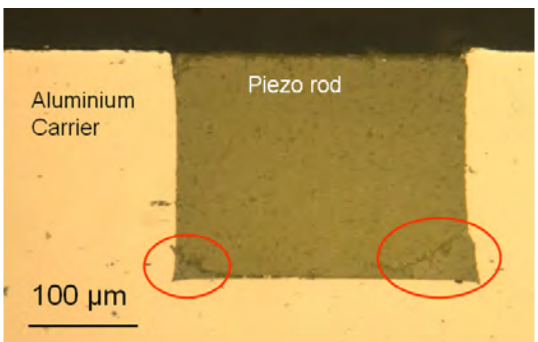

Figure 5: Lateral cut through a module with inserted piezo module.

However, a quantification of the necessary forming stroke or pressure is hardy possible. The FEM model assumes sharp corners and edges and a perfect filling of the piezo rod from the beginning. In reality, carrier and piezo rods are subjected to geometric tolerances, and the forming step which closes the filling gaps leaves no perfectly straight and even surfaces.

Fillets or chamfers at the piezo rod or an undercut at the cavity walls would dislocate and reduce the maximum stress. But this would require additional manufacturing steps and/or other manufacturing technologies which is not intended to be done.

4 Conclusion

With a FEM simulation in COMSOL Multiphysics the stresses appearing in a metal-based piezo module due to manufacturing processes were evaluated. It was found out that stress-induced damages at the integrated piezo rods will not be visible since the cracks are not appearing at the module's surface. The variation of the shape of the cavities will be evaluated for decreasing the load on the piezo rod.

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