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Simulation of a modular Die Stamp for Micro Impact Extrusion

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Abstract: Micro impact extrusion is investigated at Chemnitz University of Technology as a potential procedure for large area machining of micro cavities within the scope of the SFB/Transregio 39 PT-PIESA of the German Research Foundation [1, 2, 3]. Applying impact extrusion micro forming is done by material flow opposite to the effective direction of the force into the structure of the tool. Therefore no structured lower die plates are necessary, but high forming forces are required. Figure 1 shows a scheme of the tool system developed at Chemnitz UT. In this tool system modular micro stamps can be implemented, which consist of several single stamp elements.

In this study COMSOL Multiphysics is used to analyze the stress in such modular tool stamps. The results help to redesign the stamp after first experimental investigations.

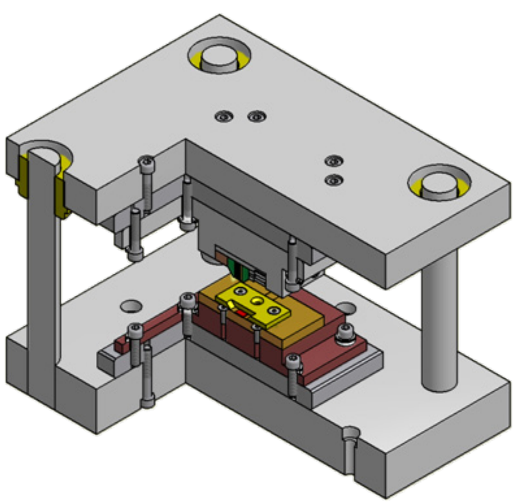

Figure 1: Scheme of the tool system for micro impact extrusion

Keywords: Micro forming, impact extrusion, precision cavities, SFB/Transregio 39 PT-PIESA

1 Introduction

On account of the progressive technical development primarily in the area of microsystem and precision technologies, metallic smallest parts, whose structural dimensions constitute a few millimeters down to some micrometers, are needed in high numbers of pieces. The development of suitable forming technologies is necessary for a competitive production of such miniaturized metallic components. Beside procedures for the production of smallest parts techniques which allow a defined microstructuring on big surfaces are requested increasingly.

Therefore the Collaborative Research Centre SFB/TR 39 of the German Research Foundation „Großserienfähige Produktionstechnologien für leichtmetall- und faserverbundbasierte Komponenten mit integrierten Piezosensoren und -aktoren“ (High-Volume Production-Compatible Production Technologies for Lightmetal and Fiber Composite-Based Components with Integrated Piezo Sensors and Actuators) works among other topics on the investigation of technologies for large area microstructuring of aluminium alloy thin sheets. Figure 2 shows a scheme of a piezo-fiber metal module exemplary. To manufacture this module cavities should be embossed on a metallic carrier material where piezo-elements can be inserted and joined.

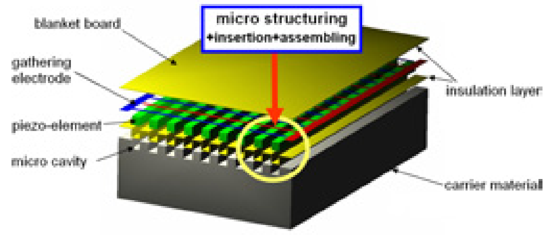

Figure 2: Scheme of a metal-based piezo module

The known laws for macro scale forming technology are the basis for the development of new technologies in micromachining. In addition different works on forming technologies for components with a size of some millimeters show that the know-how of conventional forming procedures cannot be transferred easily from the macro into the micro scale. In particular frictional effects have, with respect to the rising relation of surface to volume, a major influence on the forming process [4, 5, 6]. Not at least down-scaling effects of different process parameters like material, tool and machine are content of scientific investigations [7].

Starting from this point investigations were performed at Chemnitz UT for material flow and the development of a suitable tool for micro impact extrusion of aluminium alloy sheets. Firstly the application shown in figure 2 was defined as model geometry consisting of micro cavities arranged on a surface with a dimension of 10 x 0,3 x 0,3 mm^3. The pitch between neighbouring cavities is 0,5 mm with a resulting web width of 0,2 mm.

With regard to potential applications in automotive industry two typical aluminium alloys (AlMg4.5Mn0.4 and ALSi1,2Mg0,4) were chosen as carrier material. The plate thickness was defined with approximately 1 mm.

2 Impact extrusion for plane microstructuring

Main focus of the topical work are investigations on the conventional impact extrusion technology, especially for the assembly of precision cavities in thin plates of aluminium. In impact extrusion the plastic deformation of the work piece material is achieved by high pressure on blanks within special tool systems. The high pressure forces the material to flow in the form determined by the geometry of the tool stamp.

In case of reverse impact extrusion material flows oppositely to the stamp movement into the canals of the stamp and forms the cavities. Therefore an increase of the metal thickness ($d_0 < d_e$) in the area of the deformation has to be expected as result of the material flow in opposite direction to the forming force.

The material flow is illustrated in figure 3. It's obvious that the most intensive deformation of the material occurs in the area between the marked lines ABC and DEF. It decreases in direction of the sheet ground. If the metal thickness below the formed canals remains big enough these areas are not deformed.

In addition the material below the surface of the stamp is transformed only slightly because of the friction between die and work piece which impedes a lateral material flow. Furthermore, if the material has started to flow into the gap, nearly no more forming takes place and the material is only pushed upwards.

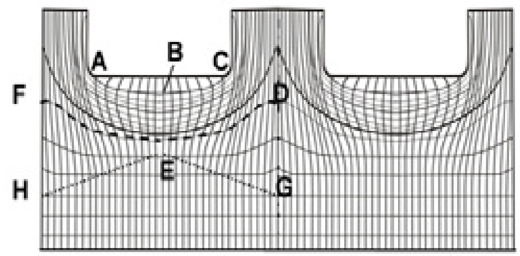

Figure 3: Sketch of the material flow with the reverse extrusion moulding of canal-web-structures

The design of an impact extrusion process leads to high demands on die systems, material and hardness of stamps especially for the creation of suitable material flow [8]. Basis for the development of the forming die and the process design are the mentioned reference structure, the legitimacies known in macro scale laws and the relevant material parameters of the selected aluminium alloys. The latter were determined for both aluminium alloys with a conventional tension and compression test.

To mould the cavities entirely very high forces are necessary. For a single cavity approximately 3700 N are needed [1]. Referred to the dimensions of the cavities a pressure of approximate 1200 $\mathrm{N/mm}^2$ results. Based on these calculations and the defined specifications the die stamp was designed.

3 Simulation and design of the modular forming stamp

The die system shown in figure 1 is incorporated in a die set. Sheet-specimens can be fixed by a blank holder on a substrate support. Warping of the test body is prevented by the clamping during the forming process.

On the guide plate of the die set the modular forming stamp is mounted. The stamp structure can be configured modular and can be adjusted for the respective experiment by an arrangement of form elements. The single elements are centered by a distance piece and braced by means of a wedge system. So several stamp parameters for example hardness, surface structure, surface roughness or coatings for one ore more form elements can be varied by exchanging the elements without making a complete new stamp. Not at least all die elements can be disassembled after the experiments for an analysis of wear behavior.

For first experimental investigations on micro impact extrusion the reference structure of the stamp was realized by lined up hardened steel panels made of 1.2379 with different lengths (17,0 mm & 16,7 mm) and widths (0,3 mm & 0,2 mm). Because of the known strong adhesion of aluminium in cold forming processes [9], the segments are coated with titanium nitride to decrease the friction and hence resulting reweldings. The negative trench-web-structure is generated by an alternating arrangement of long and short steel elements.

The experimental investigations were performed with a stamp which consists of three long and five short elements. The stamp is shown in figure 4. A total forming force of 9 kN was applied.

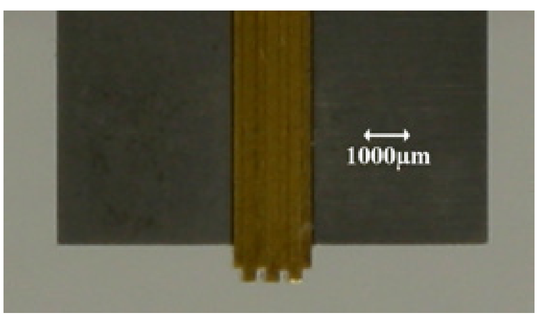

Figure 4: Photo of the modular stamp with 3 long and 5 short sheets

The result of the impact extrusion experiments is shown in figure 5. It's obvious that a material flow in lateral direction to the force takes places and that the flanks of the cavities are not vertically formed. In addition secondary mouldings can be found on top of the inner webs. Deductive the results were not acceptable.

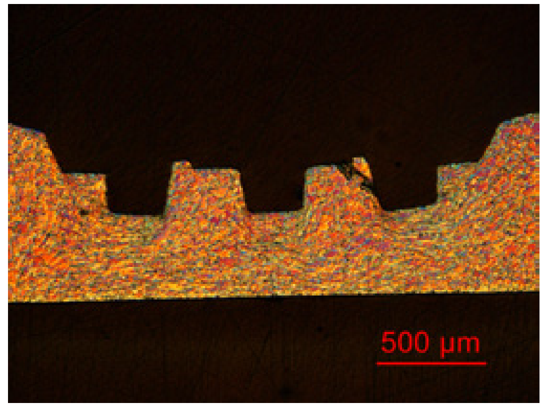

Figure 5: Result of impact extrusion with 3 long and 5 short sheets

To get a closer look on the reasons especially for the slant flanks and the secondary mouldings COMSOL Multiphysics was used to simulate the stress in the applied stamp. A main result of the simulation is shown in figure 6.

In the model all subdomains were defined as the used 1.2379 by help of the COMSOL Material Library. On the upper boundaries the total force of 9 kN was used to define the distributed load. Referred to the dimensions of the cavities a pressure of approximate 1000 N/mm^2 results. The three boundaries on the bottom of the three long sheets are fixed, while all other boundaries are free.

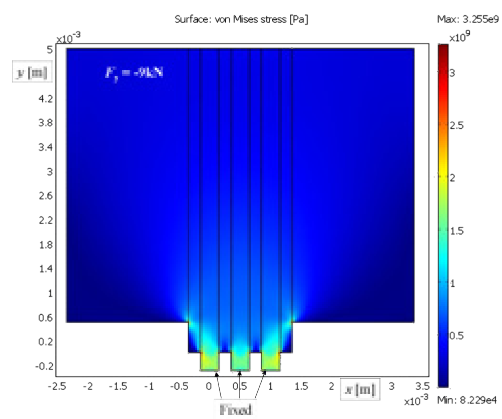

Figure 6: Simulation of the modular stamp with 3 long and 5 short sheets

It can be derived from the simulation, that the von Mises stress in the long sheets is higher than the maximal compressive stress of 1.2379 which is 3000 N/mm^2 [10]. So an elastic and plastic deformation of the stamp elements can be verified as the reason for the slant flanks and the secondary mouldings.

To reduce the stress in the elements two modifications for the stamp were tested using COMSOL Multiphysics. Firstly a reduction of the free length of the sheets from 800 µm to 300 µm was investigated. Secondly clamping jaws on both sides of the stamp were implemented. The clamping jaws were defined to be 200 µm longer than the structuring elements.

The clamping jaws have two main functions. First function is an improvement of the clamping of the stamp elements. In addition the lateral material flow should be reduced because the jaws are sinked into the material prior to the stamp. The main result of the simulation of the redesigned stamp is shown in figure 7.

The definitions of subdomains and boundaries are similar to the first model. To improve the material flow in the stamp the pressure referred to the dimensions of the cavities was increased to 1500 N/mm^2. That means a total forming force of 90 kN. It can be found, that the von Mises stress in the sheets is, despite the increased pressure, reduced to a value of about 2000 N/mm^2.

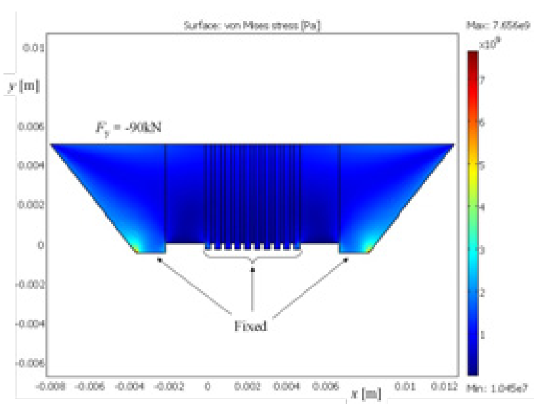

Figure 7: Simulation of the modular stamp with clamping jaws, 10 long and 9 short sheets

After the simulation the redesigned stamp was realized. A photo of the stamp is shown in figure 8. All in all the new stamp has fulfilled the expected improvements. The results which were achived using the redesigned modular stamp with clamping jaws, 10 long and 9 short sheets are presented in the next section.

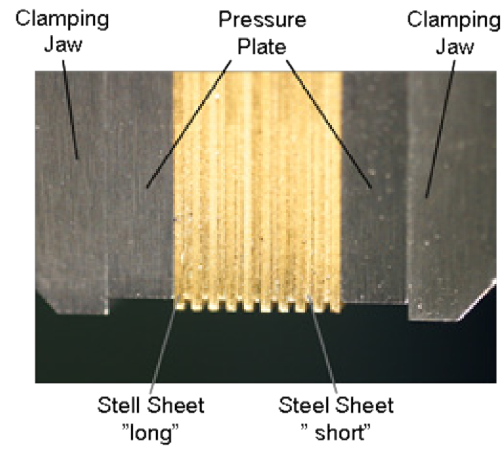

Figure 8: Photo of the modular stamp with clamping jaws, 10 long and 9 short sheets

4 Impact extrusion as a potential micro manufacturing procedure

After the successful design of the tool stamp several experimental investigation on micro impact extrusion were performed. By help of forming 10 neighbouring cavities the suitability of the technology for a large area forming of microstructures had to be verified. Furthermore a lot of process parameters for the procedure and the mould design should be found out.

The experimental studies for impact extrusion were carried out in sheets of the aluminium magnesium alloy AlMg4.5Mn0.4 with thicknesses in a range of 0,8 to 1,5 mm. The process forces were determined experimentally as function of the metal thickness. Therefor the force was varied in a range from 10 to 90 kN with a step width of 10 kN.

In addition investigations for the reproducibility of the forming results were performed with the maximum forming force of 90 kN. Five attempts were carried out on every metal thickness.

Figure 9 shows as one main result the formed micro cavities in aluminium sheets with a thickness of 0,8 mm. The maximum force of 90 kN was applied.

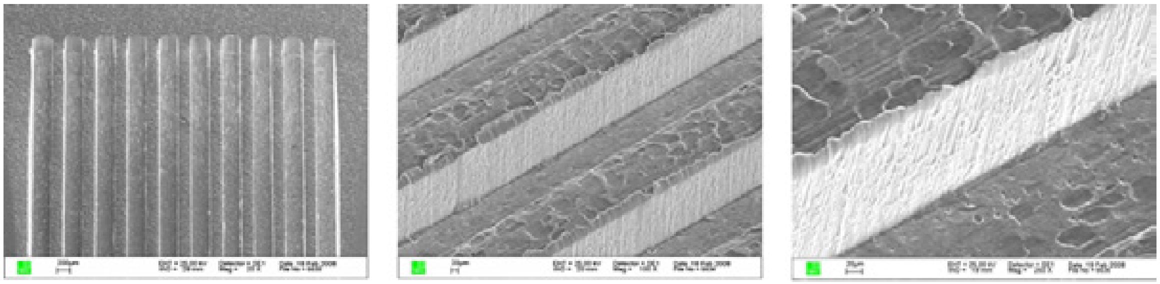

Figure 9: Micro cavities in aluminium sheet with a thickness of 0,8 mm

The SEM images show a steady spreading of the structure over the whole treatment area. In comparison to the experiments with the first stamp construction (figure 5) secondary mouldings can not be found on the top of the inner webs. The flanks of the webs are characterized by a high degree of steepness and directness. Looking at the edges of the webs, a slight feathering can be found. Furthermore it can be seen that the top side of the webs has a surface curvature and the surface structure of the rolled and structured basic material is obvious. Consequently no contact between tool and work piece and therefore no entire forming out has taken place in this area. This shows that the forming force determined by the known rules of the macro forming technology is not dimensioned high enough. A possible reason for the raised need of force is friction between tool flank and work piece material.

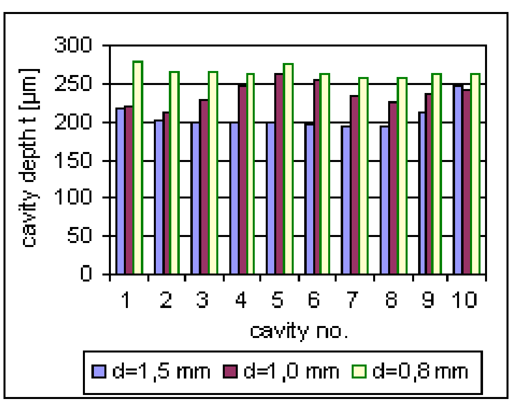

Figure 10: Cavity depth as a function of the position of the cavity and the thickness (d) of the sheet with the same stamping force

To analyze the precision of the technology the geometry-describing parameters depth and width of the cavities as well as those of the webs were determined. The depths are charted in figure 10 as function of the thickness of the sheet and the position of the cavity. The cavities are numbered serially from the left to the right side. The results show that the attainable structural depths are dependent on the thickness of the sheets. The depths are varying in a range from 0,195 to 0,270 mm.

It appears that the cavity is deeper, the more thinly the basic material is. Furthermore it can be detected that nearly same deepnesses can be achieved with the thinnest sheet over the whole structured area. In comparison a dependence on the position of the cavity is recognizable moreover with the thicker work pieces. It is recognizable that with the 1,0 mm sheet the median cavities are clearly deeper than outer ones. So it seems that material flow in the internal region is better than in the outer caused by the internal stress condition.

In comparison outer cavities are stronger coined with the 1,5 mm plate. This points out to the fact that the material in the center area is pushed in direction of the work piece ground on account of the internal tension relations.

From the measured geometrical dimensions a relation could be derived for the form filling and other characteristic parameters. In spite of the limited press capacity form fillings up to 90% with the sheets of a thickness of 0,8 mm and 1,0 mm as well as 72% with the sheets of a thickness of 1.5 mm were achieved. For an assessment of material flow the relevant characteristics parameters for the procedure flow ration and stamp ration were determined.

Figure 11 illustrates the distribution of these rations for the several sheet thicknesses. For comparison the original sheet thickness is marked red. Significant is the increasing thickness of both thinner sheets. However, no change of the sheet thickness is detectable with the 1,5 mm sheet plate after the shaping.

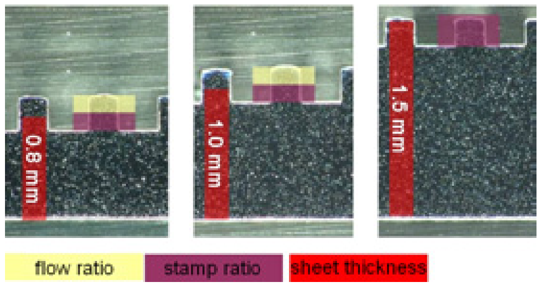

Figure 11: Graphic exposition of the stamp ratio and flow ratio as a function of the sheet thickness

Deductive the internal tension relations in the thinner sheet plates are so advantageous that the material is forced to flow contrary to the active direction of the force into the flow gap of the stamp. The relation between flow ratio and stamping ratio is about 50% referring to the generated structural depth. Because of the relation between flow gap and width of the stamp segment which is 2:3 it results that more material is edged out below the stamp than flows into the flow gap. Out of this follows, that a particular material part is pushed crosswise or in the direction of the blank's ground.

5 Conclusion

In this study COMSOL Multiphysics was used to redesign a modular tool stamp for micro impact extrusion. The results applying this stamp indicate the potential of impact extrusion for plane forming of micro cavities. The investigations show that by means of impact extrusion a large area and reproduceable structural forming with a high degree of precision can be achieved. In future COMSOL Multiphysics should be used at Chemnitz UT, in addition to the stamp design, to simulate the forming process for micro impact extrusion and other micro forming procedures.

6 Acknowledgment

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Literatur

[1] A. Schubert, R. Pohl. Untersuchungen zur umformtechnischen Herstellung von Präzisionskavitäten in Aluminiumwerkstoffen. *In R. Neugebauer: Tagungsband zum 1. Wissenschaftlichen Symposium des SFB/Transregio 39, Technische Universität Chemnitz*, 2007.

[2] A. Schubert, R. Pohl. Fliesspressen von Mikrostrukturen - Umformtechnische Herstellung von Mikrokavitäten in Aluminiumfeinblechen mittels Fliesspressen. *wt Werkstattstechnik online Jahrgang 98*, 10:855–859, 2008.

[3] A. Schubert, R. Pohl. Mikrostrukturierung von Al-Blechen mittels Durchsetzen - Werkzeuggestaltung und experimentelle Bewertung. *In R. Neugebauer: Tagungsband zum 2. Wissenschaftlichen Symposium des SFB/Transregio 39, Technische Universität Chemnitz*, 2009.

[4] N. Tiesler. *Grundlegende Untersuchungen zum Fliesspressen metallischer Kleinstteile*. Meisenbach Verlag GmbH, Bamberg, 2002. ISBN 3-87525-175-X.

[5] Jenn-Terng Gau. An experimetal study on size effect on flow stress and formability of aluminium and brass for microforming. *Journal of Materials Processing Technology*, 184:42–46, 2007.

[6] A. Messner. *Kaltmassivumformung metallischer Kleinstteile - Werkstoffverhalten, Wirkflächenreibung, Prozessauslegung*. Meisenbach Verlag GmbH, Bamberg, 1998. ISBN 3-87525-100-8.

[7] R. Eckstein U. Engel. Microforming - from basic research to its realization. *Journal of Materials Processing Technology*, 125-126:35–44, 2002.

[8] H. Tschätsch. *Praxis der Umformtechnik*. Vieweg Verlag, Wiesbaden, 2005. ISBN 3-8348-0038-4.

[9] P. Groche, G. Nitzsche. Temperatureinfluss auf den Adhäsionsverschleiss beim Umformen von Aluminiumblechen. *Materialwissenschaft und Werkstofftechnik*, 35:461–466, 2004.

[10] K. Lange. *Umformtechnik Handbuch für Industrie und Wissenschaft, Band 2: Massivumformung*. Sprigner-Verlag, Berlin, 1988. ISBN 3-540-17709-4.