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Modular tool concept and process design for micro impact extrusion

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ABSTRACT

Micro impact extrusion is an appropriate mass production technology for micro structuring of sheet metal. The technology was applied to form sample geometries consisting of ten precision cavities which are intended to be collets for the form- and force-locked integration of piezo rods for later usage of the sheets as “smart sheet metal”. For reasons of flexibility, a modular tool concept was studied and applied. It allows a flexible arrangement of geometry elements but introduces new aspects which need to be considered. This study investigated the influences of tribological- and process parameters onto the microforming process. Therefore forming experiments were performed with different die coatings (titanium nitride, titanium carbon nitride, amorphous carbon), different lubricants (common oil, forming lubricant and without lubrication), as well as two die materials. In contrast to forming processes with established monolithic die configurations, phenomena like tilted structures and the appearance of unwanted burr were investigated. For creating structures with minimal tolerances, these effects need to be considered. The investigation of the influence of process parameters showed, that the lowest surface roughness was achieved without lubrication. Furthermore low-friction coatings and harder die materials improved the forming results.

1. Introduction

To enhance resource efficiency and performance of structural metal parts integration of functionality plays an important role. Active components such as piezo ceramics, integrated into sheet metal, can be applied for acting and sensing operations in health monitoring systems, as collision sensors or for active vibration- and noise-damping [1–4]. A direct implementation of these functions into sheet metal allows stiffer mechanical coupling of the active material functions to the structural material than an adhesive bonding of sensor or actor patches [4]. The Collaborative Research Centre SFB/TR 39 PT-PIESA is developing mass production technologies and process chains for the fabrication of aluminium piezo composites, which can be used as raw materials for “smart sheet metal” [5,6].

Fig. 1 shows a scheme of a piezo metal module: Ten piezo rods with the dimension of 0.27 mm×0.27 mm×10 mm are integrated into insulated micro cavities with cross sections of 0.30 mm×0.30 mm, arranged in parallel with a pitch of 0.5 mm.

Subsequent contacting of the piezo elements and a locking of the piezo rods by pressing onto the cavity webs will lead to a piezo metal module with sensing and acting functionalities. For functional capability and sensitivity of the fabricated piezo metal module, a tight contact between cavity walls and piezo rods is essential, which places high demands in accuracy on the technology for shaping the cavities. The target of the herein described and evaluated process is the accuracy of these cavities. For their later function a minimum depth of 0.27 mm is necessary, a high flank steepness of the cavity walls and a high uniformity of cavity and web shapes are required. Additionally, to prevent damaging of the brittle piezo rods during the pressing step the surface roughness of the cavity walls and bottoms needs to be very low. To ensure the character of highly productive mass technologies the cavities are intended to be generated by forming. A major indicator of forming processes is the degree of deformation φ which refers to a formed dimension h_1 in relation to its value prior forming h_0:

$$\varphi = \ln\left(\frac{h_1}{h_0}\right) \tag{1}$$

Due to structure dimensions below 1 mm, the process is a microforming process, which requires the consideration of size- or scaling effects including surface effects, e.g. the relation of open and closed lubrication pockets, an increased influence of the material grain size and higher demands onto the hardness and strength of the tool material due to small feature dimensions [7,8]. For conventional forming processes the influences of various process parameters are widely evaluated and well documented. Due to size

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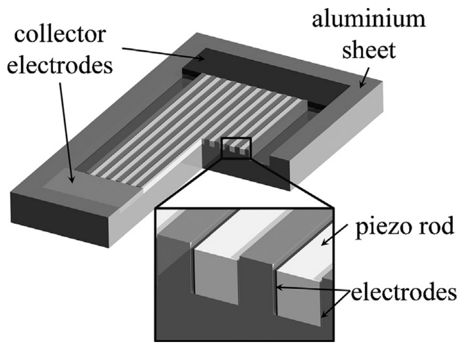

Fig. 1. Microstructured sheet metal with integrated piezo rods.

effects occurring in microforming processes, the entire knowledge and principles could not be transferred from macro to micro scale [7–11]. Tribology is a major issue in all forming processes: besides tool geometry and the material flow curve, the tribological conditions between tool die and workpiece define the necessary forming forces, material flow and tool wear. Especially for the fine micro structures of micro forming tools friction forces can lead to an overload and deformation of the tool. For example, friction conditions depend on specimen size, which can be explained by the open and closed lubricant pockets theory. Within closed lubricant pockets the lubricant is trapped during the forming process. This results in lower forming forces and higher surface roughness values. Whereas open lubricant pockets could not held the lubricant during the process. Open lubricant pockets are located at the border of a part. By scaling down parts, the border area is increasing in relation to the rest of the surface. As a result, the number of open lubricant pockets and the friction coefficient increases for decreasing specimen size [11]. Size effects also have to be considered in other areas of microforming, e.g. in tool design and machine concepts [8,11]. Due to the use of a new modular die, investigation and re-evaluation of the influences of process parameters are required [11].

Advantages of modular dies are high flexibility concerning the formed geometry, cost reduction due to replacing only single parts of the die in case of tool wear as well as lower manufacturing and storage expenditure [12]. Since integrated application of the piezo metal module in structural parts of different size, loads and materials, geometrical flexibility, e.g. concerning the number of the cavities, is an important issue. A modular arrangement of long and short steel sheets was applied as modular tool setup. Two different materials were tested for the single sheets of the modular die: the cold working steel 1.2379 and the high speed steel 1.3343. Beside tool material as parameter, the investigations were focused on die coatings and lubricants. A coating of the steel dies reduces the high adhesive wear which would occur while forming aluminium with pure surfaces of ferrous tools. Titanium nitride (TiN), titanium carbon nitride (TiCN) and an amorphous carbon coating (a-C:H/DLC) were applied onto the steel sheets of the modular die. TiN and TiCN are hard coatings for improving mechanical capabilities, whereas DLC is known for its friction-reducing properties [13]. Due to low adhesion and a higher resistance against abrasive wear, compared to hard coatings (TiN, TiCN), DLC coatings are preferred for optimizing friction conditions [14].

In most macroforming processes a lubricant is applied between tool and workpiece to reduce friction forces. In microforming, the thickness of the lubricant layer is a source of size effects because it is not scalable and diminishes the reproduction accuracy of tool microstructures. Therefore, the impact of lubrication was evaluated by testing two different lubricants in comparison to a dry unlubricated process.

The aim of the paper is to investigate microstructuring of aluminium using a massive forming process in combination with a modular die to generate micro cavities. These structures has to be formed with high demands on precision, regarding uniform cavity depth, flank steepness and other geometric parameters. By using a modular die, i.e. elastic deformation played an important role during the forming process. The first step to improve the micro forming process is the investigation of the influence of different process parameters on the material flow and the generated geometries.

2. Design of experiments

The total area formed is 7.2 mm×14.0 mm and consists of ten primary cavities arranged in parallel and four larger secondary cavities which are arranged parallel and perpendicular to the primary cavities (Fig. 2).

The perpendicular secondary cavities with cross sections of 2.0 mm×0.30 mm are collets for the collector electrodes. The parallel secondary cavities, with cross sections of 1.0 mm×0.50 mm are 0.2 mm deeper than the primary cavities to fulfil the technological function as barrier i.e. to prevent a lateral "outflow" of the formed material. The cavities are formed into 1.5 mm aluminium alloy sheets AL 5182, which is a common material in the automotive industry. Referring to Eq. (1), the degree of deformation φ of the primary cavities was calculated by:

$$\varphi = \ln\left(\frac{h_0 - h_{cav}}{h_0}\right) \tag{2}$$

with h_0 being the initial sheet thickness and h_{cav} being the cavity depth. The modular die concept which was applied for the primary cavities is realized with an alternating arrangement (see Fig. 3) of ten long and thick steel sheets (16.80 mm×0.30 mm×10.00 mm) and eleven shorter and thinner ones (16.50 mm×0.20 mm×10.00 mm). The single die sheets were fixed by four clamps which also form the parallel and perpendicular secondary cavities (Fig. 3). The compositions of the chosen tool materials and selected properties are listed in Table 1.

Titanium nitride (TiN), titanium carbon nitride (TiCN), and amorphous carbon coating (a-C:H/DLC) were applied as coating materials onto the steel sheets of the modular die (see Table 2). The TiN and TiCN coatings were deposited by physical vapour deposition (PVD), the DLC layer with plasma-enhanced chemical vapour deposition (PE-CVD). Two different lubricants were tested (see Table 3) and experiments were conducted without lubricants.

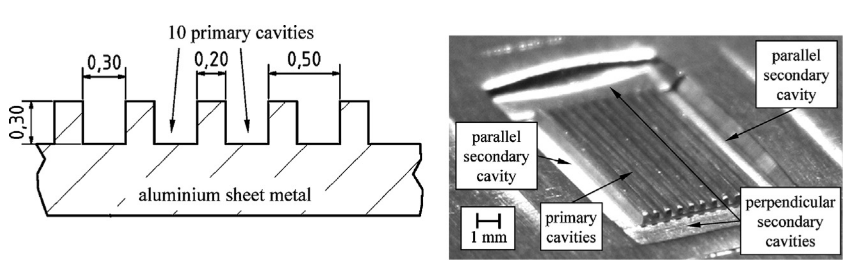

Fig. 2. Cavity dimensions and micro cavities.