Influence of Different Tool Materials, Coatings and Lubricants onto Shape Accuracy during Micro Impact Extrusion

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Abstract

In this paper the impact of different tool materials, tool coatings, and lubricants onto the micro forming process of micro cavities is investigated. As tool materials two different hardened steels were used for the forming die. To lower the friction and adhesion between forming tool and aluminium substrate three coatings TiN (titanium nitride), TiCN (titanium carbon nitride), and DLC (diamond like carbon) were tested. Furthermore, the influences of different lubricants were studied. Geometric parameters and surface quality were judged by laser microscopy and SEM images of metallographic sections.

1 Introduction

Within the Collaborative Research Centre CRC/Transregio 39 PT-PIESA of the German Research Foundation (DFG) the main topic is to develop mass production technologies to fabricate aluminium composite modules for sensor and actuator applications. Therefore high precision cavities are formed into aluminium sheets by a mass-production compatible micro impact extrusion process which has high potential to manufacture small, precise structures [1, 2].

In micro forming, size effects play an important role. For example, this includes surface effects (lubrication pockets), an increased influence of the grain size of the substrate material, and higher demands onto the hardness and strength of the tool material due to small feature sizes [3, 4]. The impact of these parameters cannot be transferred out of well understood macro-forming processes and knowledge, but has to be evaluated for microforming.

2 Design of Experiments

In this study micro cavities, shown in figure 1 a) and 1 b), were used for the investigations. The structure consists of ten micro cavities with nominal cavity width and depth of 300 µm, which results in a forming aspect ratio of 1. The pitch between two cavities is 500 µm. A 200 kN precision forming press was used to microstructure the 50 × 50 mm^2 workpieces, made of 1.5 mm thick aluminium AL 5182 alloy sheets.

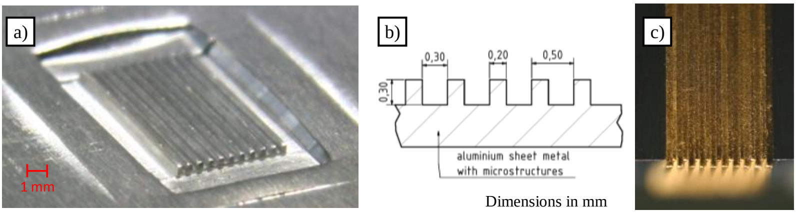

Figure 1: Micro cavities, cavity dimensions and modular die

The applied modular forming die is composed of ten long (16.8 × 0.3 mm^2) and eleven short (16.5 × 0.2 mm^2) steel sheets, which are arranged alternately beneath each other (figure 1 c). Within these investigations two different hardened steels (1.2379 and 1.3343) were used (table 1).

Table 1: Used die materials

Material number	Composition	Young's modulus	Hardness
1.2379	1.55 % C, 12.00 % Cr, 0.70 % Mo, 1.00 % V	215 MPa	60+2 HRC
1.3343	0.90 % C, 4.00 % Cr, 5.00 % Mo, 1.90 % V, 6.40 W	224 MPa	64+2 HRC

For reducing abrasion between tool and workpiece, low friction coatings were applied onto the steel sheets. Experiments were performed using titanium nitride (TiN). This often used coating material was compared to titanium carbon nitride (TiCN) and a diamond like carbon (DLC) coating (table 2).

Table 2: Used coatings

Coating	Friction coefficient against metal parts [5]	Micro hardness
Titanium nitride (TiN)	µ = 0.6	25 GPa
Titanium carbon nitride (TiCN)	µ = 0.2	35 GPa
Diamond like carbon (DLC)	µ = 0.1 to 0.2	20 to 30 GPa

A second possibility to lower friction and prevent galling of the die, is the use of lubricants. A commercially available motor oil (oil 1) and a special forming lubricant (oil 2) were tested in comparison to unlubricated specimens (table 3).

Table 3: Used lubricants

Oil	name	Viscosity at 40 °C	Density at 15 °C	Flashpoint
1	Castrol Edge motor oil 5W30	70 mm^2/s	851.3 kg/m^3	202 °C
2	Fuchs Plantoform MBO 2797	49 mm^2/s	921.0 kg/m^3	304 °C

The forming process was realized by applying a constant stamp velocity of 5 mm/min at punching forces between 70 kN and 120 kN. The formed test samples were characterized using an optical measurement system (Nikon MM400, calibrated, x-,y-,z-axis resolution of 0.1 µm) for geometric parameters (cavity width, depth, and web width), a Keyence laser microscope (VK 9700, calibrated with a z-axis calibration standard and a maximal z-axis resolution of 1 nm) for roughness measurements and metallographic cross sectional samples to investigate the material flow.

3 Results and Discussion

First forming tests were carried out for the 1.2379 steel type and a variation of die coatings. Figure 2 shows the dependence of the cavity depth onto the punching force with the coating material as parameter.

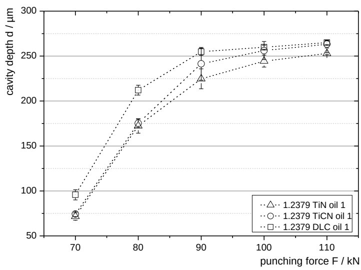

Figure 2: Cavity depth as function of punching force and die coatings

For increasing punching forces a degressive increase of the cavity depths can be observed. With a DLC coating the deepest cavities were achieved. For example, at a punching force of 80 kN the cavity depth (212 µm) is 23 % deeper than for TiN (172 µm) or TiCN (175 µm) coatings. An explanation for this could be the lower friction coefficient for DLC compared to TiCN and TiN. Based on this, the forming process starts at lower punching forces, due to the lower resistance to forming between die and workpiece. With the combination of 1.2379 die sheets and DLC coatings the best forming results in this experiments series with a maximum cavity depth of d = 265 µm were reached.

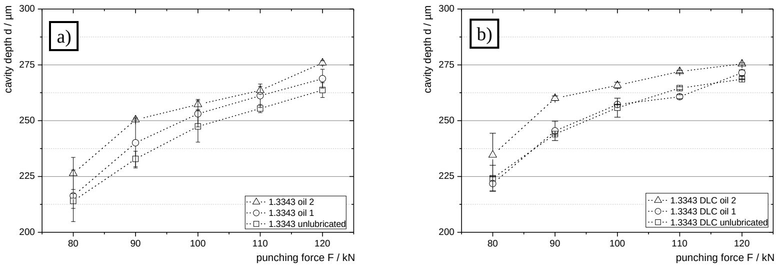

Figure 3: Cavity depth as function of punching force and lubrication a) for uncoated and b) for DLC coated 1.3343 steel sheets

Figure 3 shows two graphs for the cavity depth as a function of punching force and lubrication, with uncoated (Figure 3a) and DLC-coated die sheets (Figure 3b). Within these test series, all curves also show a degressive increase of the cavity depth. For uncoated and coated dies, the deepest cavities (275 µm) were obtained with oil 2 at 120 kN. In Figure 3a, the influence of the different lubrications onto the forming process without any die coating was investigated. With lubricant (oil 2) the deepest cavities were generated within these experiment series. The viscosity of the forming lubricate MBO 2797 is lower than from oil 1 which improves the ability to infiltrate even the smallest cavities or lubricant pockets inside the tool. Furthermore it is developed to withstand even high pressure without destroying the lubricating film. For the DLC-coated sheets (Figure 3b), the forming lubricant (oil 2) leads to the deepest cavities, too. In summary, the combination of a DLC tool coating with the forming lubricant (oil 2) is to be preferred.

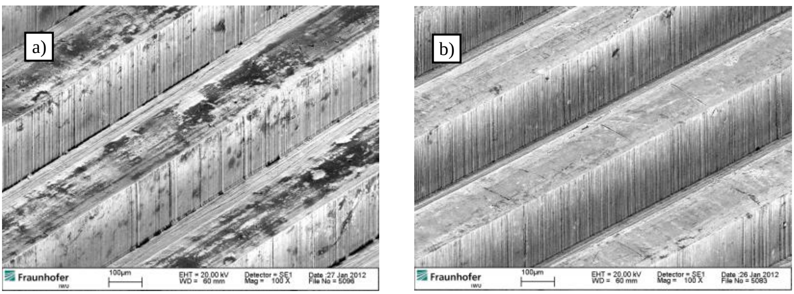

Figure 4: SEM-images of a) 1.3343, 80 kN, oil 1 and b) 1.3343, 80 kN, DLC coating, oil 1, test samples

Figure 4 depicts two SEM-images of test samples. For uncoated dies, a rougher surface at the flanks is observable (Figure 4a). A smoother surface was obtained with a DLC coating (Figure 4b). In addition to the SEM investigations, the optically measured roughness was lower for the DLC-coated samples on the webs (table 4).

Table 4: Surface roughness at the cavity bottom and the webs

	Mean Surface Roughness R_q in µm	
	Cavity bottom	Web
Figure 4a	0.423 ± 0.02	0.604 ± 0.02
Figure 4b	0.409 ± 0.02	0.543 ± 0.02

4 Summary

In the present work the influence of lubricants and coatings are investigated as well as different die materials onto a micro impact extrusion process. With the usage of die coatings with a low friction coefficient, like DLC coating, and special developed forming lubricants, the deepest cavities in comparison to other coating / lubricant combinations were possible. Due to the lower resistance to forming for this combination, the forming process leads to deeper cavities for lower punching forces.

5 Acknowledgement

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References:

[1] Schubert, A.; Jahn, S. F.; Müller, B.; Hackert-Oschätzchen, M.: Study on the Influence of the Forming Velocity in Micro Impact Extrusion with Modular Dies. In: Proc. euspen 2011, Vol 1, pp. 20-24.

[2] Neugebauer, R.; Schubert, A.; Richter, F.; Koriath, H.-J.; Peter, S.; Berg, S.; Jahn, S. F.; Müller, B.; Müller, M.: Fabrication and characterization of a form- and force-locked piezo-metal sensor module In: Proc. 3rd. Scientific Symposium of the CRC/Transregio 39 – 2011, pp. 23-28.

[3] Qin, Y.: Micro-manufacturing engineering and technology, Elsevier, 2010.

[4] Vollertsen, F.; Biermann, D.; Hansen, H. N.; Jawahir, I. S.; Kuzman, K.: Size effects in manufacturing of metallic components. In: CIRP Annals-Manufacturing Technology 58 (2009) pp. 566-587.

[5] http://www.cewotec.de/de/produkte/duennschichten/schichttypen#Schichttabelle last checked: 1/27/2012.