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Micro structuring of coated tools for dry sheet metal forming of aluminium alloys

Richard Börner[1]; Peter Scholz[2]; Ralf Kühn[1]; Andreas Schubert[1]; Henning Zeidler[1]; Roland Müller[2]

[1] *Technische Universität Chemnitz, Professorship Micromanufacturing Technology, 09107 Chemnitz, Germany*
[2] *Fraunhofer Institute for Machine Tools and Forming Technology IWU, 09126 Chemnitz, Germany*

Richard.boerner@mb.tu-chemnitz.de

Abstract

Sheet metal forming is characterised by strong frictional forces involving an increase of the temperature and a tendency to adhesion. Consequently, use of lubricants is essential yet, especially for forming of Aluminium alloys. Furthermore, lubricant reduces tool wear. However, for economical and ecological reasons, dry forming is highly desired. Avoiding the application of lubrication requires a reduction of the coefficient of friction and the tendency for adhesion in dry forming processes. One approach is to increase the nominal surface pressure by micro structuring the tool. Additionally, different carbon based layers (a-C:H:Si and CVD diamond) are applied on the tool to reduce wear and tendency to adhesion. For using a a-C:H:Si layer, uncoated steel drawing tools are micro structured with calottes by milling. Because of a higher thickness of CVD diamond layers, calottes have to be generated directly in the coating using ablating processes like electrical discharge machining. To emulate the tribological system of a sheet metal forming process and characterise it, strip drawing tests are done. For a-C:H:Si coated drawing tools, the test results show a significant reduction of the coefficient of friction in micro structured, compared to polished drawing tools. To further increase the wear resistance of the tool it is intended to apply CVD diamond layers on steel tools as soon as the process is operational.

Keywords: Deep drawing, Dry metal forming, Electrical discharge machining, Hard material coatings, Micro milling, Micro structuring

1. Introduction

Aluminium alloys are characterised by their low density and low weight in comparison to other metals. Due to these beneficial properties, Aluminium alloys are used e.g. in car body parts. However, in sheet metal forming of Aluminium alloys there are problems such as its high tendency to adhesion and its hard oxide layer. The interaction of abrasive (caused by the Aluminium oxide layer) and adhesive friction mechanisms reduces the tool life and decreases the shape accuracy of the components [1, 2]. These effects can be reduced through addition of lubricant. Furthermore, hard material layers are applied on the active parts of the tools to reduce wear [3]. For ecological and economical reasons, a reduction or even a renunciation of lubricant should be aimed for. Therefore, additional possibilities for adequately replacing the lubricant have to be created. Structuring the surface of the active tool parts (hereinafter referred to as contact surfaces) represents an approach for controlling the material flow [4]. Riehle indicated that an increase of the surface pressure leads to a reduction of the coefficient of friction [5]. This can be achieved by a decrease of the material ratio (MR). Another approach is a hard tool coating. Combining both, a structuring of the coating has to be considered. Here, the structuring of hard material layers like CVD diamond is assessed. Due to its independence of mechanical properties electrical discharge machining (EDM) is an appropriate process to machine such hard layers. The required electrical conductivity for machining CVD diamond can be achieved by doping with elements such as Boron [6] and Silicon.

Aim of this study is to investigate the effects of micro structuring the tool surface by milling on the coefficient of friction and the feasibility of micro EDM to machine Si-doped CVD diamond.

2. Experiment

2.1. Micro structuring by milling

Referring to the relationship between the material ratio and the coefficient of friction [5], the contact surface of the flat drawing tool was reduced for a strip drawing test to MR = 87.5 % and MR = 75 % respectively by micro structuring. Calottes were chosen as form elements because of their non-directional behaviour. To avoid a sharp transition from the calottes to the contact surface in terms of an edge, an entrance radius is used. The geometrical dimensions were designed in a way that the thickness of the layer (about 2 µm) has no influence on the contour. The calottes were arranged in a grid parallel to the drawing direction. The drawing tools were manufactured using tool steel (1.2379) with a hardness of 60 HRC after the hardening process. A coated solid carbide ball end milling cutter was used for the dry machining. After a burr removal and polishing process, a surface roughness of Ra = 0.2 µm was achieved. Additionally, the calottes were measured by laser scanning microscopy as well as qualitatively analysed by SEM (Fig. 1; before the polishing).

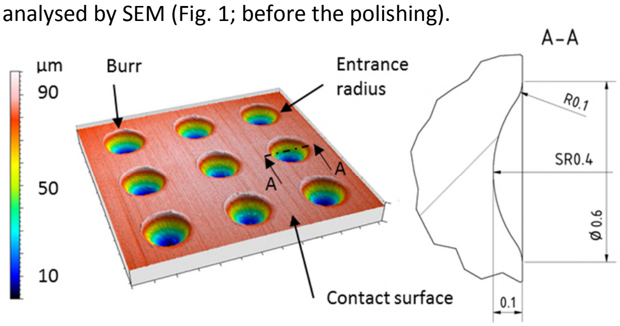

Figure 1. 3D image (3 mm x 3 mm) of the calottes, MR = 75 %.

2.2. Strip drawing

The tribological system between blank holder and Aluminium sheet in deep drawing is simulated by strip drawing tests using flat forming tools. Consequently, the impact of a structuring on to the coefficient of friction can be determined. In this setup, the metal sheet strip is fixed on a carriage and drawn trough a flat drawing tool loaded with the normal force F_N. The scheme of the strip drawing test is shown in Fig. 2.

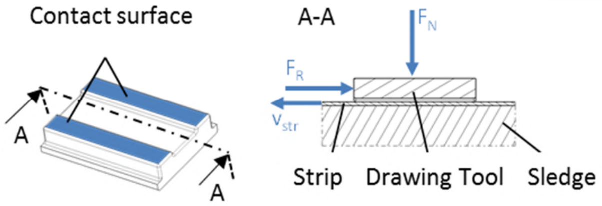

Figure 2. Schematic illustration of the strip drawing test.

Tests on material AA 5182 were carried out using nominal surface pressure in the range of 1 to 17 MPa and a drawing velocity of v_{str} = 50 mm/s. As reference, tests with coated and unstructured steel tools were performed. Amorphous carbon layers are already used for the reduction of friction for forming tools [3]. Thus, the strip drawing tests were carried out with a a-C:H:Si coating. Each drawing path amounts to 500 mm. Due to the strip width of 50 mm and the effective width of the drawing tool of 40 mm, there is no influence of the sheet metal's burrs on the test results.

2.3. Electrical discharge machining

For the investigation of CVD diamond machining by EDM, several experiments were conducted using a Sarix SX-100 micro EDM machine tool. A Si-doped CVD diamond layer of 10 µm thickness was used to ensure electrical conductivity on Molybdenum sheet material. A dia. 90 µm tungsten carbide electrode was used as tool. Voltage (90 V - 150 V, step: 10 V), discharge energy (5.9 µJ - 38.5 µJ) and tool polarity were varied to characterise the ablation behaviour.

3. Results and discussion

3.1. Strip drawing

Figure 3 shows the coefficient of friction over the drawing path for different material ratios with a surface pressure of 1 MPa.

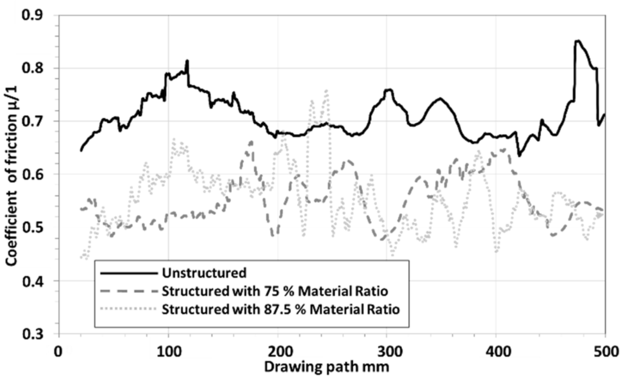

Figure 3. Results of the strip drawing tests.

Data analysis showed the highest coefficient of friction at the unstructured drawing tool (µ = 0.71). In comparison to that, the structured drawing tools showed at µ = 0.55 a 22 % lower coefficient of friction. However, the level of the measured coefficients of friction is obviously too high in relation to a lubricated forming process because of strong Aluminium build ups. The used combination of a a-C:H:Si layer and the sheet material AA 5182 led already at a relative low nominal surface pressure of 1 MPa to an extensive adhesion at the drawing tool and strong scoring at the metal sheet. Comparing the graphs it is visible that the achieved results of both structured drawing tools differ only little. Consequently, in future experiments the scattering of values has to be reduced in order to gain more and reproducible results.

3.2. Electrical discharge machining

Calottes with a diameter of about 100 µm were ablated with a good reproducibility using a positive tool polarity. The ablation geometries were analysed qualitatively by SEM and measured using laser scanning microscopy. Two SEM images of the generated calottes are shown in Fig. 4. It was recognised that there were no influences of the EDM process to layer adhesion.

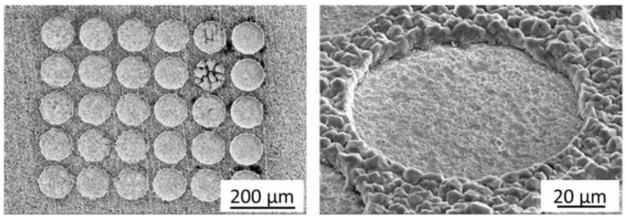

Figure 4. Calottes in Si-doped CVD diamond machined by EDM (150 V, varied discharge energy).

4. Summary and conclusions

It could be shown that the effective material ratio of the drawing tool's contact surface has an impact on the coefficient of friction and that it can be specifically varied through micro structuring. With the reduction of the material ratio, a decrease of the coefficient of friction was achieved.

Furthermore, the successful ablation of calottes in a Si-doped CVD diamond layer by using micro EDM could be realised. This process can be used for manufacturing hard coatings applied on active parts of forming tools.

5. Acknowledgements

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