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Development of a tool concept with selectively oxidised inserts for dry deep drawing

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Abstract

In order to manufacture sheet metal components with a reduced negative impact on the environment, dry metal forming gains more and more attention. The use of liquid lubricants has a negative impact on the environment, as those contain environmentally harmful additives that are not biodegradable. Furthermore, the production process becomes more complex by the use of these lubricants due to more required cleaning stages between the production steps for the components. One approach is the utilisation of selectively oxidised tool surfaces, acting as low friction separation layers between the tool steel and sheet metal surface. The friction reducing ability of α-Fe_2O_3 layers on tool steel has been shown in previous work. The present study deals with the development and design of a forming tool with removable selectively oxidised inserts with α-Fe_2O_3 coating for dry deep drawing.

Keywords: Dry deep drawing, Avoidance of lubricants, Wear testing, α-Fe_2O_3 layer, surface analyses,

1 Introduction

Wear resistance and friction behaviour are essential tribological properties in surface engineering. According to estimates from the literature, it can be assumed that wear is responsible for direct losses of 7 % of the gross national product in the industrialised countries. In Germany, wear causes a total loss of about 35 billion euros per year [1, 2]. In addition, tribologically related losses are further indirect economic burdens due to e.g. production failures, maintenance as well as rework as a result of low product quality [2, 4]. Thus, it is crucial to reduce friction and wear between the moving tools, especially forming tools involved in a production process of metallic parts. In sheet metal forming, such as deep drawing, hardening the tools by heat treatments is a common procedure to protect these tools from high dynamic load changes as well as to support their resistance against wear and avoid wear damages. The most convenient way to reduce friction and wear is to apply lubricants to the blank surfaces before the forming process. Therefore large amounts of environmentally harmful lubricants are applied. Besides the advantages, there are still disadvantages by the use of lubricants in sheet metal forming. The disposal is elaborate, costly and polluting. Another problem is the contamination of the stamping plants and the extension of the process chain requiring additional cleaning stages. For example, in the automotive industry particles of residual oil on the component surfaces have a negative influence on the joining processes after forming. The aspect that mineral-based lubricants contain harmful additives is also described in the literature [3, 4]. Due to this facts, conventional mineral oil based lubricants cannot fulfil the requirements of a sustainable production in metal forming. One approach to avoid the use of liquid lubricants in sheet metal forming is the development of friction reducing and wear resistant separation layers through selective oxidation. Those friction-reducing oxide layers are generated within a heat treatment at defined temperatures and atmosphere on a hardened tool steel X153CrMoV12 (EU alloy grade 1.2379). Through the implementation of this new approach an unfavourable metal-metal contact between the forming tools surface and the workpiece can be avoided. The thin oxide layer on the tool steel surface and the native sheet metal oxide layer yield a favourable oxide-oxide contact. In previous studies various approaches to dry metal forming in

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particular sheet metal forming have been investigated. It was found out that, these oxide layers on 1.2379 tool surfaces favour wear and friction minimizing properties. Especially α-Fe_2O_3 layers were investigated in extensive researches [5, 6]. For the validation of the research results obtained in the first two phases, a forming tool was designed and developed. The knowledge gained in previous work with regard to wear and friction is to be continued in a targeted manner and transferred to a deep drawing process. The results obtained prove the fundamental suitability of tool coatings produced by selective oxidation for use in dry metal forming. The focus of this work will be on forming trials and the production of three-dimensional components.

2 Construction of a forming tool for a deep drawing process

A rectangular cup geometry (160 mm x 80 mm) was used as the basis for the development and design of the deep-drawing tool. Tool areas that represent high tribological load and surface pressure are specifically considered. In a drawing ring those areas (longitudinal and corner areas) were provided, which can be equipped with oxidised and non-oxidised (reference) inserts. In this way, the layer system can be validated in a sophisticated way and the transferability to realistic applications can be tested. The planned use of two materials (dual-phase steel DP600 and a deep-drawing steel DC04) will allow possible applications of the oxide layers to be tested within the project. The use of oxide layers would be conceivable both in the area of forming high-strength steels and in the area of forming softer deep-drawing grades. So dry forming can be specifically investigated with these materials on the basis of the selected test geometry.
Two different approaches were chosen for the design of the deep-drawing dies with selectively oxidised inserts. The first tool concept is a conventional drawing ring and blank holder with oxidised inlays in the longitudinal and corner areas which are changeable. In the second variant of the tool concept, the inlays are only inserted in the longitudinal area. Furthermore beads and strips are used to allow the workpiece material to flow in a controlled manner during the deep-drawing process. The used inlays consist of tool steel 1.2379 and are hardened to 56+2 HRC with the drawing die and the blank holder. The inlays were coated by means of a heat treatment. An overview of the deep drawing tool concept with selectively oxidised inlays is shown in Fig. 1.

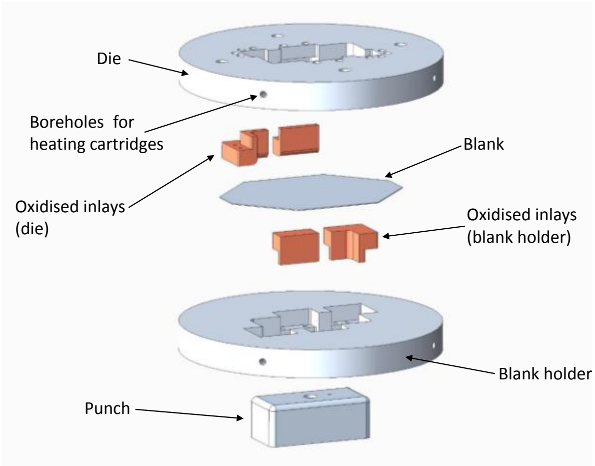

Fig. 1: Overview of the deep drawing tool components

Figure 2 shows an example of a die. For illustration purpose, two oxidised inlays were installed in the die. The diameter of the drawing ring and the blank holder is 380 mm. When designing the tool pockets it is crucial that they are plane to the inlays so that they do not protrude from the tool surface. Protruding inlays during the deep drawing process would reduce the component quality enormously or even change tribological results negatively. For this purpose, the inlays were manually reworked before being installed in the drawing ring. With the designed tool concept, the wear investigations are to be extended to complex geometries. Due to the varying load cases between the longitudinal and corner areas , these investigations ensure transferability to industrial processes.

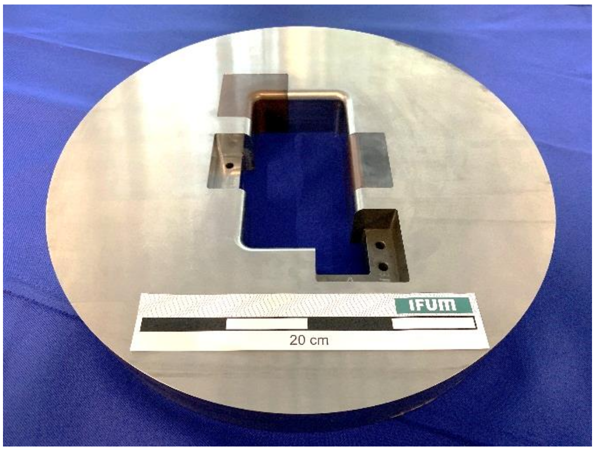

Fig. 2: Drawing ring with oxidised inlays

The oxidised inlays for the drawing ring have a drawing radius of 8 mm. The selection of the drawing radius is based on the previous wear test specimens. Here, tribological investigations were carried out with the aid of strip drawing tests with deflection to analyse the friction behaviour of the oxide-oxide contact The inlays in the longitudinal areas have a length of 60 mm, a width of 30 mm and a height of 45 mm. The inlays in the corner area are symmetrically arranged and thus have a length and width of 60 mm and a height of 45 mm. Figure 3 shows a CAD-drawing of two oxidised inlays for the longitudinal and corner areas.

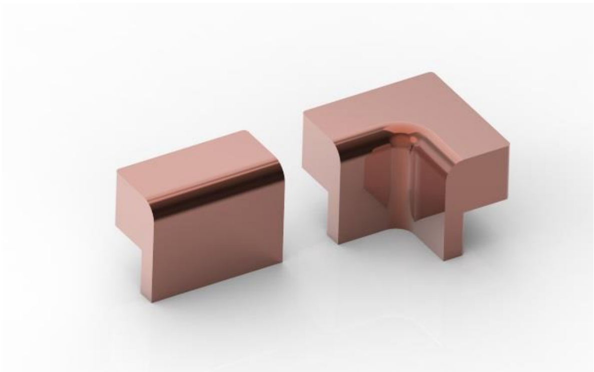

Fig. 3: CAD-drawing of the oxidised inlays for the die

2.1 Numerical investigation of the deep drawing process

The deep-drawing tests carried out were also numerically examined with focus on the contact pressures on the die arising from the different sheet materials. For this purpose, a three-dimensional FE quarter model was created in the Abaqus CAE 6.14-2 software. As shown in figure 4, the tools punch, blank holder and die were modelled as elastically deformable bodies. Therefore 8-node reduced integrated hexaeder elements with an average element edge length of 1 mm (type: C3D8R) were employed. The young's modulus was set to 200,000 MPa and poissons ratio to 0.3. The sheet material was modelled elastic-plastic deformable. 4-node reduced integrated shell elements with an average element edge length of 1 mm (type: S4R) were used. The sheet thickness was set to 1 mm. The friction coefficient between sheet and tool has been identified through numerical and experimental investigations explained in [7] and has the value of $\mu = 0.1$. Further information on material characterisation was taken from previous work [7, 8]. The data of the punch displacement and blank holder force were transferred from the experimental investigations to the simulation model. An isothermal process with a temperature of 120 °C was assumed.

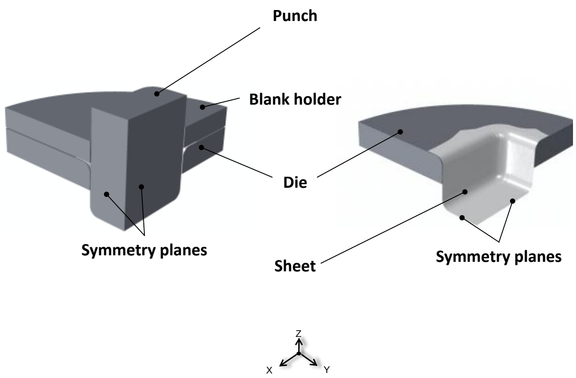

Fig. 4: Schematics of the FE quarter model for deep drawing process simulation

At the top of figure 5 a comparison of the calculated von Mises stress σ_V distribution for the materials DP600 and DC04 at a drawing depth of 50 mm is shown. The different stress values clearly illustrate the use of materials from two different strength classes. Accordingly, various contact pressures σ_N arise on the die in the two deep-drawing processes with DP600 and DC04. For both materials, the highest stresses occur in the corner areas of the die. Up to 397 MPa are locally observed in the case of DP600 and up to 308 MPa in the case of DC04. In contrast, contact pressures are significantly lower on the longitudinal areas of the die. A local maximum of 255 MPa was calculated on the longitudinal areas in the process with DP600 and a local maximum of 105 MPa with DC04. In figure 5, as the increased von Mises stresses in the sheet imply, tangential stresses occur in the area of the die corner. These tangential stresses result in local thickening of the sheet material. The drawing gap is 1.2 mm. As a result, an increased contact pressure develops in the corner area of the die after a certain thickening of the material. These investigations show that a complex load profile can occur in the process due to the geometry of the tool. Accordingly, the wear of the coating will occur with strong local dependency. In the example of the rectangular cup shown, the critical points are located in the corner areas of the die.

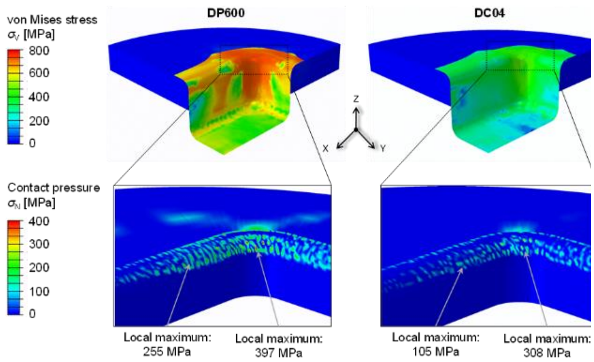

Fig. 5: Von Mises stress in the deep-drawn sheet materials (top); the contact pressure arising on the die due to the different sheet materials (bottom)

3 Conclusions

In this study a forming tool for the wear analysis of an α-Fe_2O_3 oxide layer was developed in focus of the dry metal forming process. The active parts of the tool were designed as removable inlays in order to investigate the wear of the α-Fe_2O_3 oxide layer at different load cases of the tool. In addition, a numerical model was developed which allows a prediction of the surface pressure in a tribological system for repeated sliding wear load conditions in a dry deep drawing process. As the numerical investigations show, different load cases can be realized with the developed of a tool geometry as well as the use of different sheet metal materials (DC04 and DP600). Thus, the layer removal behaviour on the tools in complex dry metal forming processes can be examined numerically and empirically.

Acknowledgements

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