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New Specimen Design for Wear Investigations in Dry Sheet Metal Forming

Deniz Yilkiran*[1], Amer Almohallami[1], Daniel Wulff [2], Sven Hübner[1], Milan Vucetic[1], Hans Jürgen Maier[2], Bernd-Arno Behrens[1]

[1]Institut für Umformtechnik und Umformmaschinen, Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany
[2]Institut für Werkstoffkunde, Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany

Abstract

In this study a new specimen for wear investigations on a wear testing stand in dry sheet metal forming will be presented. The study is focused on the investigation of the surface pressure in the contact area between wear specimen and sheet metal (DP600+Z). In a first step a numerical model was developed. The FEM model shows the resulting surface pressure on the specimen's surface over the entire length of a 60 mm cycle of wear tests. In the experimental wear investigations conducted on a wear testing stand the high strength steel DP600 with a galvanised surface was used. Both, the numerical model and the experimental validation of the model were carried out at room temperature.

Keywords: surface pressure, FEM modelling, wear tests, deep drawing

1 Introduction

In order to realise a dry metal forming process different approaches are possible. In the priority program 1676 founded by the German Research Foundation (DFG), dry sheet metal forming as well as dry bulk metal forming processes are subject to current research. In summary, the technological implementation of a dry forming process is carried out by the use of coating systems, hard material coatings, structured surfaces or ceramic tools [1, 2, 3]. The vision of a dry metal forming process involves several advantages. Regarding to [4] these are particularly:

- Reduction of process steps (in production)
- Reduction of environmental impact
- Reduction of health burden

One approach investigated in one subproject of the program is to generate a friction reducing and wear resistant tool coating with an oxidative heat treatment. The formation of the layers on hardened conventional tool steel surface (X153CrMoV12, EU alloy grade 1.2379) takes place in a conveyor shield gas furnace by controlling the oxygen activity in the process atmosphere as reported in [5]. The surface morphologies were analysed by means of imaging methods e.g. SEM- (Scanning Electron Microscopy) and FIB-SEM- (Scanning Electron Microscope with Focused Ion Beam) analyses, while the chemical composition is analysed by e.g. synchrotron radiation [6].

The formed oxide layers (generally α-Fe_2O_3 and SiO_2) have friction reducing properties as shown in [5, 7, 8]. A dry sheet metal forming process therefore seems to be technically possible but wear resistance of the layers also have to be proven.

In sheet metal forming, wear investigations can be realised in several experimental setups [9, 10, 11]. For gaining results with a good cost-benefit ratio, experiments are ideally conducted automatically and with sheet metal from a coil. In this case new sheet metal comes into contact with the tool surface with each test cycle which is similar to an industrial application. With the aim of realising a new dry sheet metal forming process, wear investigations were done on an automatic wear testing stand with sheet metal from a coil.

Analyses of selectively oxidised samples have shown that the oxide layers have only thicknesses of a few 100 nm. Figure 1 illustrates an exemplary FIB-cross section of a sample with an α-Fe_2O_3 oxide layer.

*E-mail address of corresponding author: dyilkiran@ifum.uni-hannover.de

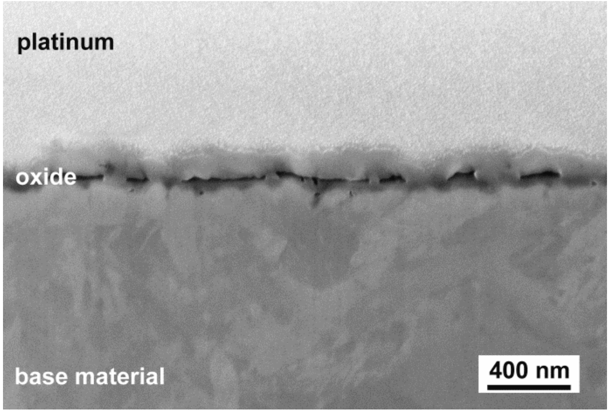

Fig. 1: FIB-SEM-cross section of an oxidised specimen with an α-Fe_2O_3 layer

For the preparation of FIB-SEM-cross sections an additional layer (e.g. platinum) on the sample`s surface is required. The reason is that during the cutting of the cross section a rounded inlet area arises. The rounded area in figure 1 is only in the deposited platinum layer. Consequently, the view on the oxide layer itself and the base material is orthogonal.

The measured average thickness of the oxide layer shown in figure 1 was about 145 nm. Thus, the oxide layers are relatively thin so that appropriate analytical methods must be used. Such analysing methods have individual limits in the samples dimensions and weight. The proven one-piece geometry of past wear studies with a weight of about 1.8 kg and the dimensions 80 mm x 65 mm x 45 mm (l x w x h) is not suitable for such high-performance analytical methods. Therefore a new specimen design has to be developed in order to study the wear mechanism and the wear performance.

2 Numerical investigations

First of all the newly designed specimen was numerically investigated in order to understand and test the distribution as well as the status of the contact pressure between metal strip and specimen. These investigations are necessary to identify, if the calculated contact pressure meets the pressures exerted on the drawing radius in real deep drawing processes. Thus, a numerical model was created in Abaqus CAE 6-13.1 finite element system to simulate the strip drawing process of a high-strength steel blank of DP600+Z over the newly designed specimen made of tool working steel of EU alloy grade 1.2379 (X153CrMoV12) and coated with an α-Fe_2O_3 layer, cf. figure 2.

To calculate the contact normal pressure exerted on the surface of the specimen during the drawing of the sheet metal strip, the specimen needs to be modeled as a deformable (elastic) body. Despite the simple geometry of the specimen analytical rigid modeling of the specimen would prevent gaining information about contact normal pressures on its surface.

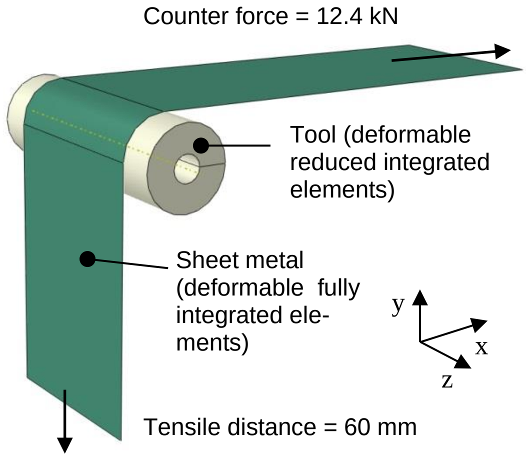

Fig. 2: Numerical model for the new specimen design

Reduced integrated hexahedra solid elements with an edge length of 1mm were used to model the specimen in order to reach an acceptable calculating accuracy in the shortest possible time.

Since the sheet metal will be formed around the specimen during the experiments it is modeled using deformable (elastoplastic) fully integrated quadrilateral shell elements with a thickness of 0.98 mm. It is essential to employ 5 integration points over the thickness of the shell elements in order to simulate the mechanical bending of the band without losing information by miscalculations.

The friction coefficient between specimen and band has been identified through numerical and experimental investigations explained in [7] and has the value of $\mu = 0.15$

In this research it is planned to simulate a continuous sheet metal strip drawing experiment with a constant drawing velocity of 30 mm/s and a total displacement of 60 mm. In earlier investigations on the same machine it has been observed that it takes 0.2 sec to reach this velocity. In order to validate the numerical model with experimental results, this acceleration is implemented in the simulation. The same time profile is used for the holding force ascending from 0 to 12.4 kN in the first 0.2 seconds and remaining constant at a value of 12.4 kN during the drawing process. The material model of high-strength steel DP600+Z in 0.96 mm used to describe the plastic flow behaviour of the band has been explained in [7]. Figure 3 shows the flow curve of DP600+Z steel measured until uniform elongation and extrapolated using the approach of Hocket-Sherby to an equivalent plastic strain value of 0.5 which is presented in the following equation (3):

$$k_f = \mathrm{b} - (\mathrm{b} - \mathrm{a}) \cdot EXP(-m \cdot \varphi^n) \qquad (1)$$

with b = 0.752, a = 0.368, m = 7.64 and n = 0.709.

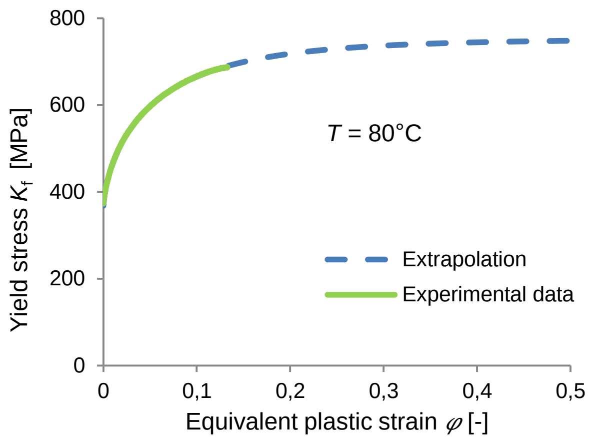

Fig. 3: Measured and extrapolated flow curves of the material DP600+Z in 0.96 mm

3 Experimental details

Within the design of a new specimen geometry several requirements must be fulfilled. These are:

- Heating of the specimen
- Monitoring of the heating (preferably close to the surface)
- Separation between active and passive elements (economic efficiency)
- Active elements as small as possible (regarding analyses)

The following figure 4 illustrates the realised new wear test specimen geometry. The specimen includes two parts, one active and one passive element. The active wear element, with a diameter of 16 mm and a width of 50 mm, is a rotationally symmetric cylinder that can be manufactured very economically as a turned part. The passive element is a socket that can be used long time without major signs of wear. The active element is assembled on the socket with two screws on the longitudinal axis and a bolt on the bottom of the lateral surface for protection against rotational movement during the wear tests.

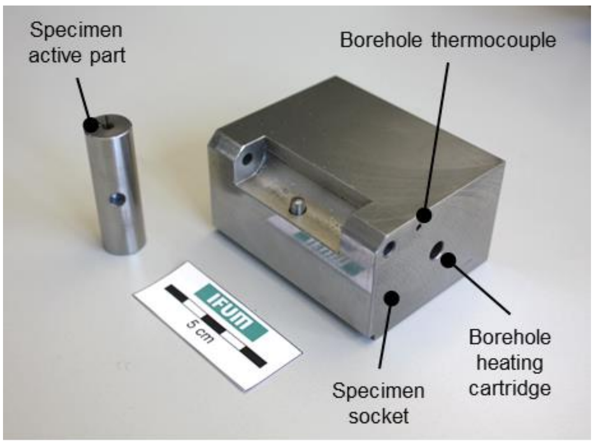

Fig. 4: New wear specimen including an active element (left) and a passive element (right)

The temperatures occurring in a stationary forming process of high-strength steels are higher than room temperature as a result of internal and external frictional heat. To mimic such a stationary forming process in dry sheet metal forming, it must be possible to heat up the specimens. For monitoring purposes the adjusted temperature thermocouples were placed in the specimen socket as close as possible to the surface of the active element. A secondary monitoring of the temperature is effected by a tactile thermometer directly on the surface of the active specimen element. The results are methodological benefits as well as economic benefits by separating the active from the passive part of the specimen. Previous investigations with a bigger one-piece specimen have shown that problems can occur, especially in the surface analysis. High-performance analytical methods e.g. SEM-, EDX- (energy-dispersive X-ray microanalysis), GIXRD- (grazing incidence X-ray diffraction) analyses require small specimen geometries. This can be guaranteed with the newly developed wear test specimen.

The experimental investigations of the surface pressure were conducted on a wear testing stand where the sheet metal is transported via two gripper slides from a decoiler to a coiler over the active element of the wear specimen. In figure 5 the new wear specimen is shown in the assembled situation on the wear testing stand.

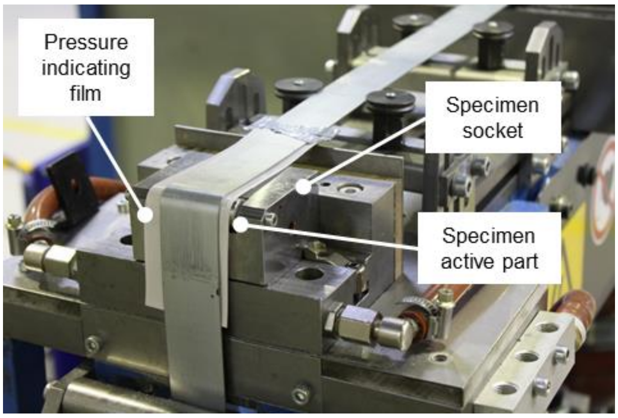

Fig. 5: New wear specimen assembled on wear testing stand

It can be seen in figure 5 that pressure indicating films were used for the experimental investigation of the resulting surface pressure. The sheet metal was drawn over the surface with a drawing speed of 30 mm/s and a length of about 60 mm per cycle. Similar to the investigations with oxidised specimens the surface of the sheet metal was cleaned from prelubes with a 10 % Tickopur solution.

4 Results and Discussion

The numerical investigations show a high calculated contact pressure during the drawing process between the sheet metal and the specimen, cf. figure 6.

The maximum contact normal pressure of 215 MPa is located on both edges of the band. This is due to the slightly twisted band as a consequence of drawing it.

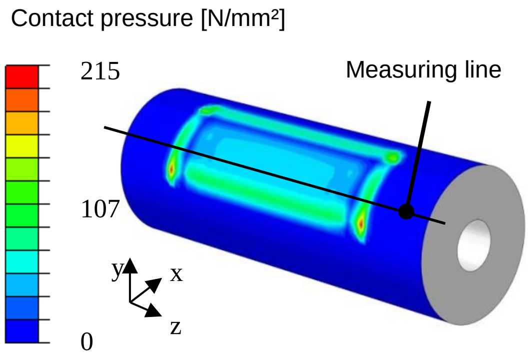

Fig. 6: Numerical calculation of the contact pressure between sheet metal strip and specimen

Local contact pressure is distributed over the curved (bending) surface of the specimen. In this area the pressure varies between 50 and 90 MPa. The results of the contact pressure investigations confirm the reliability of the specimen geometry and that it represents the drawing edge of the tools in a standard sheet metal drawing process.

Concerning the validation of the numerical model, the calculated drawing forces were compared with the measured ones determined by testing experiments to verify the assumed mechanical behaviour of the metal strip. The following diagram in figure 7 shows a comparison between the calculated and measured drawing forces. It can be recognised that the forces are almost identical. It also emphasizes the stability and the constant progression of the forces generated by the machine.

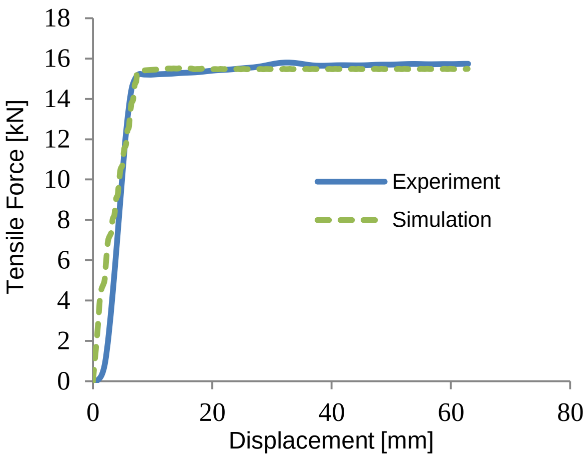

Fig. 7: Comparison between the measured and the calculated drawing forces

Moreover, a path of nodes is defined on the surface of the specimen (cf, figure 6) to compare the local calculated contact pressure with experimental results. The following diagram in Figure 8 shows the numerical contact pressure calculated along this path.

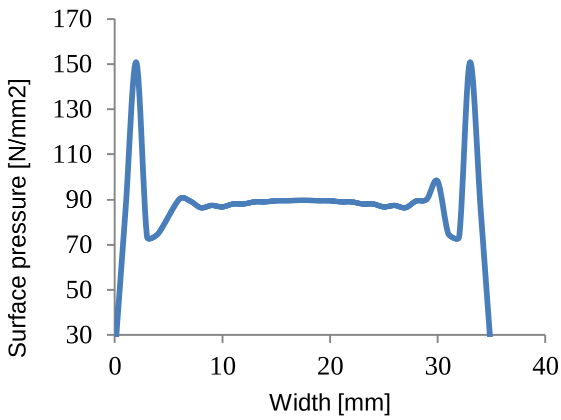

Fig. 8: Numerically determined contact normal pressure along the path shown in Figure 6.

Figure 8 illustrates that the numerical contact pressure along the exemplary path has a value of about 90 N/mm² in the interesting area. For validating the numerically calculated contact pressure, experiments with pressure indicating films were done. For this purpose, the pressure indicating films were fixed to the bottom of the sheet metal with sellotape as shown in figure 5. The following figure 8 shows a result of the surface pressure analyses using pressure indicating films.

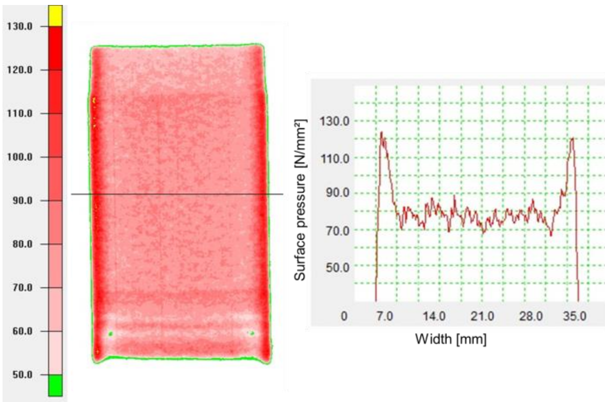

Fig. 8: Exemplarily analysis of a pressure indicating film

The evaluation of the pressure indicating film shown in figure 8 illustrates that the average value of the measured surface pressure is about 80 N/mm² in the interesting area. Depending on the measurement line the average surface pressure has a value between 75 N/mm² and 85 N/mm². Furthermore, it can be seen that on the left and right edge of the metal strip higher contact stresses are resulting cf. numerical investigations (figure 6). These edge effects are less relevant for further considerations, since normally similar situations do not exist in real deep drawing processes.

5 Conclusion and Outlook

Within the present paper it was shown, that the development of a new specimen geometry for dry sheet metal forming wear tests involves beneficial innovations. Economical and also methodological advantages are a result of the separation of an active and a passive specimen part.

While manufacturing the newly designed specimen, a numerical model for the determination of the resulting surface pressure in wear investigations was developed by means of the numerical simulation system Abaqus CAE 6-13.1. Numerical investigations in the contact zone between sheet metal strip and cylinder surface of the specimen have shown that the surface pressure has an average value of about 85 N/mm² to 90 N/mm², depending on the measurement area.

In experimental investigations with the new two-part specimen the surface pressure was determined using pressure indicating films. These investigations were done at room temperature with a native specimen without oxidised surface. Here the average of the measured surface pressure was about 75 N/mm² to 80 N/mm², depending on the measurement area. This result shows that there is a good accordance between the simulated and the experimentally investigated surface pressure. The numerically calculated surface pressure is in fact slightly higher than the experimentally investigated value, but still in a tolerable range.

In future investigations the numerical model will be advanced for the prediction of the resulting wear on selective oxidised specimens. The new specimen geometry will be used for further wear experiments with a variation of the resulting surface pressure.

Acknowledgements

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References

[1] K. Bobzin, T. Brögelmann, S. Bastürk, F. Klocke, P. Mattfeld, D. Trauth: Development of an in situ Plasma Treatment of X155CrMoV12 for a (Cr,Al)N PVD Tool Coating for Dry Metal Forming in Cold Forging, Dry Met. Forming OAJ FMT 1 (2015) 57-62.

[2] M. Herrmann, H. Hasselbruch, F. Böhmermann, B. Kuhfuss, H.W. Zoch, A. Mehner, O. Riemer: Potentials of Dry Rotary Swaging, Dry Met. Forming OAJ FMT 1 (2015) 63-71.

[3] A. Mousavi, A. Brosius: Tool concepts for dry forming, Dry Met. Forming OAJ FMT 1 (2015) 79-82.

[4] F. Vollertsen, F. Schmidt: Dry Metal Forming: Definition, Chances and Changes, International Journal of Precision Engineering and Manufacturing Green Technology, 01 (2014) Vol. 1 59-62.

[5] D. Wulff, D. Yilkiran, U. Holländer, D. Lützenkirchen-Hecht, R. Wagner, S. Hübner, K. Möhwald, H. J. Maier, B.-A. Behrens: Selective oxidation of 1.2379 tool steel surfaces – an approach for Dry Metal Forming, Dry Met. Forming OAJ FMT 1 (2015) 72-78.

[6] D. Wulff, U. Holländer, D. Lützenkirchen-Hecht, R. Wagner, D. Yilkiran, B.-A. Behrens, K. Möhwald, H. J. Maier: Characterisation of selective oxidised steel surfaces by GIXRD, 11th DELTA User Meeting & Annual Report 2015, (2015) 70-71.

[7] A. Almohallami, D. Yilkiran, D. Wulff, S. Hübner, M. Vucetic, H. J. Maier, B.-A. Behrens: Numerical Modelling of the Tribology of a Selective Oxidised 1.2379 Tool Steel Surface Developed for Dry Metal Forming, Dry Met. Forming OAJ FMT 1 (2015) 91-95.

[8] D. Yilkiran, D. Wulff, A. Almohallami, U. Holländer, S. Hübner, K. Möhwald, B.-A. Behrens, H. J. Maier: Selectively Oxidised Tool Surfaces for Sheet Metal Forming, THe „A" Coatings - 12th International Conference in Manufacturing Engineering 179-184.

[9] A. Ghiotto, S. Bruschi, F. Sgarabotto: Novel experimental set-up to investigate the wear of coatings for sheet metal forming tools, International Journal of Material Forming, Volume 8, Issue 4 (2015) 581-589.

[10] T. Trzepiecinski, A. Bazan, H. G. Lemu: Frictional Characteristics of Steel Sheets Used in Automotive Industry, International Journal of Automotive Technology, Vol. 16, No. 5 (2015) 849-863.

[11] A. Gaard, P. Krakhmalev, J. Bergström: Wear Mechanisms in Galling: Cold Work Tool Materials Sliding Against High-strength Carbon Steel Sheets, Tribology Letters, Volume 33, Issue 1 (2009) 45-53.