XIII International Conference on Computational Plasticity. Fundamentals and Applications
COMPLAS XIII
E. Oñate, D.R.J. Owen, D. Peric & M. Chiumenti (Eds)

THE INFLUENCE OF COMBINED SHEET METAL FORMING ON THE INCREASING FORMABILITY BY EXPERIMENTAL AND NUMERICAL INVESTIGATIONS

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Key words: Viscoplasticity, Deep Drawing, Material Modelling, Damage, Electromagnetic forming

Abstract. Classical sheet metal forming processes such as deep drawing are widely used in the industry. The final shape of the deformed sheet metal depends on several forming factors such as lubrication, punch speed and geometry of the acting tools. A quantity to measure the formability of the workpiece material is the forming limit diagram (FLD) where maximum major and minor strains are compared to their forming limit curve (FLC). This work aims to increase these FLCs by combining deep drawing with a subsequent electromagnetic high-speed forming. The principle is based on the fact that the maximum formability of the material is reached after the quasi-static deep drawing. At this point, the punch is replaced by one which is modified with coil windings in the edge radius region. A high current pulse is induced through the coils and leads to a high-speed electromagnetic post-forming of the sheet. A sharper radius can be observed at the end of the process without material failure which is reflected by a higher FLC. The process chain is investigated for a complex geometry as a cross shaped cup. An efficient viscoplastic material model for large deformations is used for the numerical investigation, coupled with rate dependent Lemaitre [1] type damage formulation. The user material subroutine is implemented via the UMAT interface to the commercial explicit package of LS Dyna.

1 INTRODUCTION

Due to their characteristics of lightness, corrosion resistance and high mechanical properties, aluminum alloys are finding an increasing use in industrial applications. However, conventional forming methods are still used in this field to deform a sheet into a desired form. A wide range of phenomena are known influencing the quality of highly differing results. Related to increasing formability, the use of higher strain rates and non-linear strain paths are prominent, e.g. in electromagnetic forming ([3]). Therefore, innovative forming technologies are studied in this paper in order to obtain complex shaped geometries. The process chain of forming a cross shaped cup is investigated in cooperation between the Institute of Applied Mechanics (IFAM) of the RWTH Aachen and the Institute of Forming Technology and Lightweight Construction (IUL) of the TU Dortmund. For this purpose an experimental setup has been selected which leads to a design combining a standard quasi-static deep drawing forming process with an electromagnetic pulse forming operation.

The simulation and prediction of the complex material behavior demands for an efficient material model. A viscoplastic formulation based on the multiplicative decomposition of the deformation gradient in the context of hyperelasticity has been used to model the material behavior both during deep drawing and in the electromagnetic forming step. It includes all important characteristics as the nonlinear kinematic and isotropic hardening, anisotropy, and ductile damage in the context of continuum damage mechanics, see [4]. The model is incorporated into the commercial simulation software LS Dyna.

2 EXPERIMENTAL INVESTIGATION

The experimental investigations are focused on the combined forming of a cross-shaped cup. It is based on a classical deep drawing setup where a steel punch deforms a sheet which is clamped between a blankholder and a die. When the final displacement of the punch is reached after the quasi-static deep drawing, it is replaced by a similar tool, equipped with coil windings across the edges. A highly damped alternating current is induced through the coils and leads to a deformation in the region of interest. The current over the time is presented in Figure 1. An optimization of the current impulse is investigated in [2] for the example of combined cup forming.

The deep drawing depth of $50\,mm$ is carried out by a punch with an edge radius of $20\,mm$, as shown in Figure 2a. Further, the interface to capacitor is presented which generates the energy for the electromagnetic post-forming. Figure 2b demonstrates the punch head including 5 rows of coil windings. For demonstration purpose, the upper edge remains without coil windings. So that no post-forming takes place in this region. The final result of the deformed sheet can be observed in Figure 2c. Here, a distinct change in the edge radius can be observed after the electromagnetic post-forming (left edge) in comparison to the result after deep drawing (right edge). The increasing formability is reached without material failure.

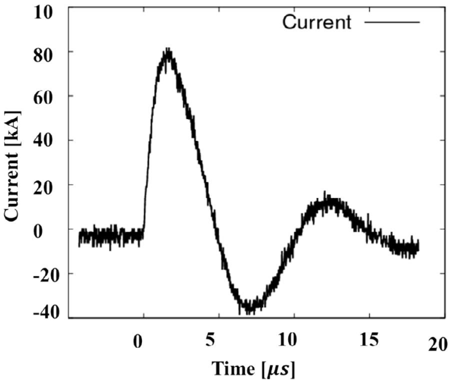

Figure 1: Induced current impulse over the time

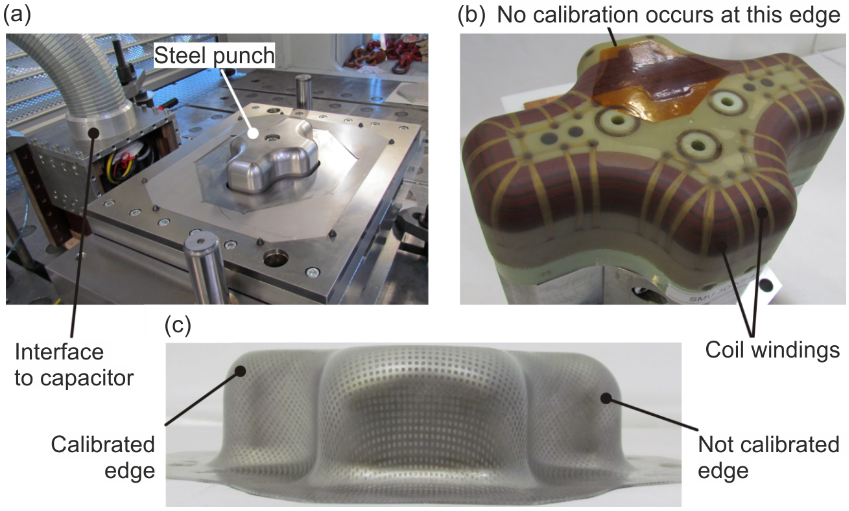

Figure 2: (a) Experimental setup to realize the process chain on cross-shaped cups (b) The punch head with coil windings for electromagnetic post-forming at the punch edges (c) A comparison between the post-formed and not post-formed edges

The workpiece material is aluminum En AW-5083. The material characterization is based on uniaxial tensile tests at quasi-static and high-speed ($1000\,s^{-1}$) strain rates. The latter tests were performed at the company Nordmetall GmbH based on a rotation striking mechanism.

3 NUMERICAL INVESTIGATION

The experimental setup is transferred into a finite element model (see Figure 3). Due to symmetry conditions and for a faster calculation, only a quarter of the cup is analysed. Rigid body definitions are used to model the tools and die where a friction coefficient of $\mu = 0.06$ is assumed to act between the die and workpiece. 26820 brick elements with

8 nodes and single integration points have been used to model the blank. Five elements are placed over the thickness direction to correctly take thinning into account as well as through thickness and shear stresses. The simulation is performed using the three-dimensional (3D) explicit finite element solver of the commercial software LS-Dyna where the user material subroutine is implemented via the UMAT interface. The simulation of the combined forming process represents a coupled field problem which consists of an electromagnetic and a mechanical part. The Maxwell equations are here solved in the eddy current approximation, see [5]. The coupling of both, quasi-static and electromagnetic forming, is treated in one simulation step.

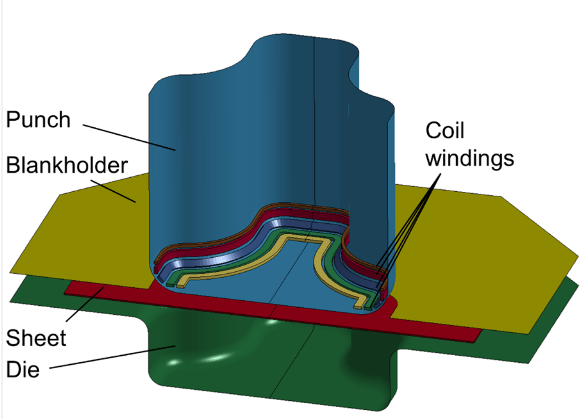

Figure 3: Setup and tools in forming of a cross shaped cup.

4 RESULTS

A sharpened edge radius is obtained at the final stage of the simulation according to the experimental observation. Figure 4 shows a cut through the full setup for a better representation of the deformed edge. While the initial radius of the punch (represented in blue) remains unchanged it provides a good comparison to the final shape of the deformed sheet metal (represented in red). The sheet workpiece matches the radius of the die (represented in green), where no material damage can be noticed.

The major and minor strains of the sheet blank are plotted into a forming limit diagram, see Figure 5. The red dotted cloud denotes the strain ratio after quasi-static deep drawing and the black dotted cloud after the electromagnetic post-forming. While in general the shape of both clouds remains similar, a shift of the right part to the biaxial stretching region of the FLD is present at the end of the electromagnetic forming. This shift directly corresponds to the post-formed edged of the workpiece. Hence, an increased formability is obtained without the occurrence of damage.

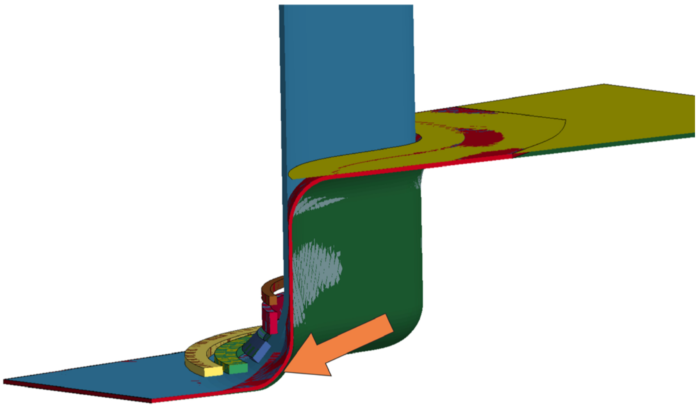

Figure 4: Cross section of the post-formed edge.

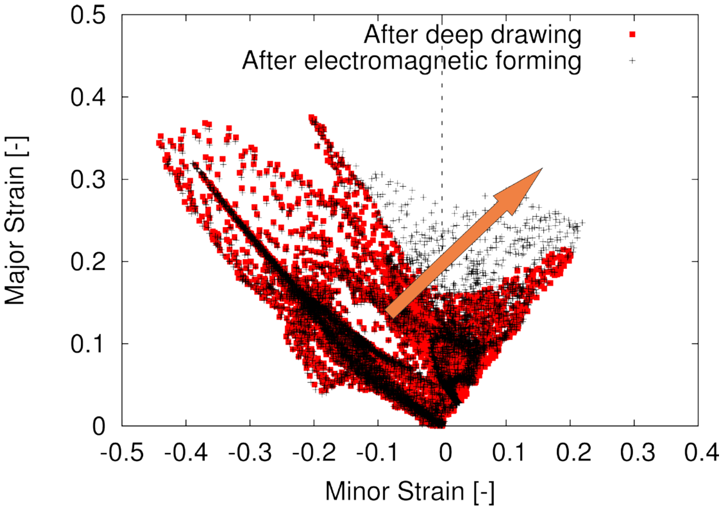

Figure 5: FLD after the simulation of quasi-static and high-speed forming process.

5 CONCLUSIONS

The investigated process chain on a combined quasi-static and electromagnetic forming serves to display the increasing formability on the example of a cross shaped cup. Experimental observations have shown that first deforming a sheet metal by quasi-static deep drawing, until the maximum formability is reached, combined with a high-speed post-forming process can increase the forming limits of the material. In this work, an aluminum alloy En AW-5083 was used for the workpiece. Based on these observations, a finite element simulation of the same process is used for a detailed investigation. The numerical example investigates the potential of a previously presented constitutive framework by means of a coupled damage-viscoplasticity model for large deformations with a Lemaitre type rate dependent damage formulation. In a good matching to the experimental result, the simulation has shown a similar increase of the radius in the electromagnetic post-formed region. Further, investigating the strain ratios in a forming limit diagram have confirmed the shift of the forming limits to a higher level.

6 ACKNOWLEDGEMENTS AND FUNDING

This work is based on the results of PAK343 Methods for quasi-static-dynamic combined forming processes within the projects TP1 (O. Koray Demir, Christian Weddeling and A. Erman Tekkaya) and TP3 (Yalin Kiliclar, Ivaylo N. Vladimirov and Stefanie Reese). The authors would like to thank the German Science Foundation (DFG) for its financial support.

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