Influences on the Part Quality in Conventional Deep Drawing Processes

Iris ALTPETER, Melanie KOPP, Michael KRÖNING,
Fraunhofer Institute Nondestructive Testing, University Saarbrücken,
Saarbrücken, Germany
Martin MILCH, Cord SCHÄFFNER, Bernd-Arno BEHRENS
Institute of Metal Forming and Metal Forming Machine Tools, University of Hannover,
Garbsen, Germany

Abstract. Trends in the automotive industry tend towards safety, fuel saving and reduction of exhaust gas result in an increased application of high strength steels as well as stainless steels in the car body production. Deep drawing is a tension/compression forming process of a sheet metal blank to a hollow part without a volitional thickness changing. This permanent deformation occurs when the applied stress exceeds the elastic limit of the material. The elastic deformation within the overall amount of deformation is not desired and leads to the so called spring back, which is directly related to the materials strength, sheet thickness and Young's modulus. Besides strength and elastic modulus there are more factors affecting the part quality or the spring back behavior of deep drawn components. This paper will cover the effect of relevant forming parameters, as there are the die radius, the height of the beads and the drawing clearance. Furthermore, the residual stresses, which are correlated with spring back, were measured by means of the 3MA sensor (***M**icromagnetic **M**ultiparameter **M**icrostructure- and Stress-**A**nalyses*).

Introduction

The focus on light weight construction originates from the desire for weight reduction on automotive parts. This results in reduction of the primary energy consumption in transportation and adds a contribution to the reduction of CO_2 emissions. In this context the potentials of high strength steel grades are used. But the application of high strength steels is connected with an increase of spring back. In deep drawn components, spring back is one of the criteria for accuracy of shape geometry. One of the reasons for spring back is the redistribution of residual stresses when the part is taken from the forming tool [1] as the case after the cutting process of the part. Besides the material properties also the process parameters are influencing the spring back behaviour [2], Figure 1. Spring back is resulting from the stresses and strains caused by the forming process, material parameters respectively. Hereby, spring back can be increased when radial tensile stresses are superimposed by tangential compressive stresses (deep drawing) [3]. In contrast, spring back can be decreased when radial tensile stresses are superimposed by tangential tensile stresses (stretch forming) [3, 4, 5, 6, 7]. In deep drawn parts factors as residual stresses are influencing the spring back behaviour. Residual stresses are stresses that are inside or locked into a component or assembly of parts.

The internal state of stress is caused by mechanical processing of the parts [8, 9, 10]. No external forces or moments are working on the locked system that is in balance. This paper demonstrates the interrelation between residual stresses and spring back. Furthermore, the influence of the process parameters on spring back and residual stresses is shown.

1. Non-Destructive Characterization of residual stresses by Means of 3MA (Micromagnetic Multiparameter Microstructure- and Stress-Analyses) -basics

3MA is the acronym for micromagnetic multiparameter microstructure and stress analysis. 3MA uses several independent electromagnetic measuring quantities derived from

- magnetic Barkhausen noise
- incremental permeability
- upper harmonics
- eddy current

for residual stress measurement independent from microstructure states or other disturbance influences. Up to 41 testing statistics can be evaluated by using these methods simultaneously. For a quantitative residual stress measurement a calibration of the 3MA system is necessary [11-16]. The first step consists of data acquisition of electromagnetic and reference values on a calibration set with different residual stress states. In a second step electromagnetic values were combined with reference values by using a least square algorithm. Reference values can be achieved either by X-ray method or by tensile test. The so determined approximation function allows a quantitative determination of residual stresses independent of microstructure states on samples with unknown residual stress states. The measurement performance reaches up to 40 measurements per second. With respect to its high performance, it mostly yields the ability of on-line testing with most applications during processing. The most important components of a 3MA measurement system are the probe and the hardware front-end with an integrated controller. The probe, consisting of a magnetization unit, transmitter receiver unit and preamplifier, can be adapted and customized to almost any component geometry and particular user requirements. Standard types of 3MA-probes are using uni-axial magnetization. So the determination of stress or strain depending on the direction is only possible by rotating the probe on the material surface. Thereby, the information of the actual orientation of the u-shaped magnetization unit is acquired.

2. Residual stress measurements on deep drawing parts

In a first step 3MA measurements were carried out on different deep drawing parts.

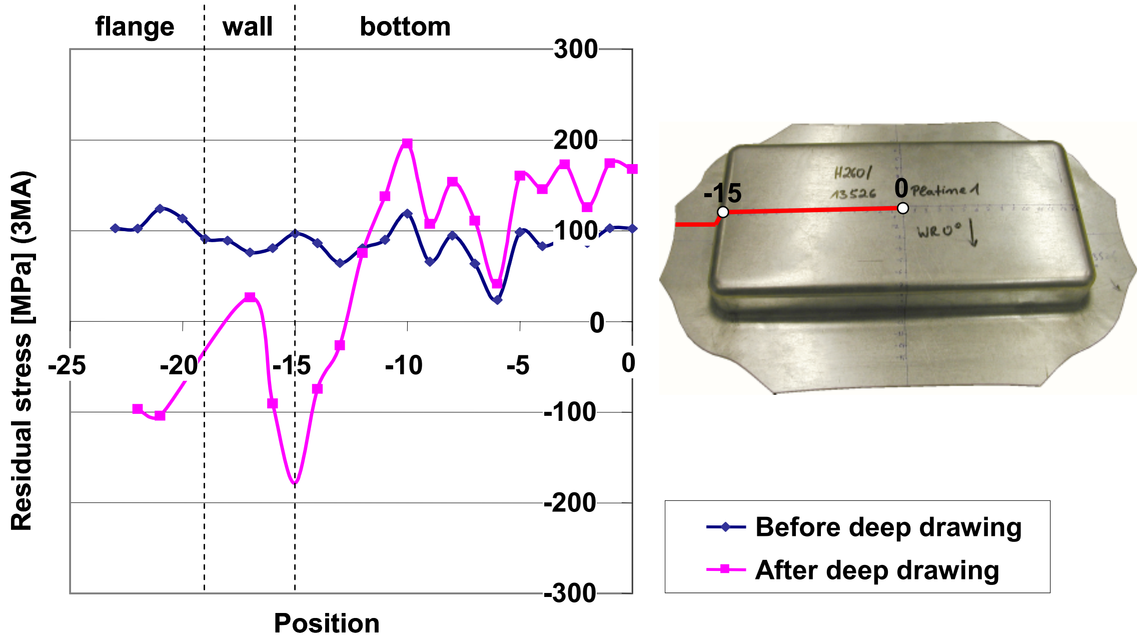

Figure 1. Residual stress measurement before/after deep drawing on a sheet of steel grade H 320 LA

Figure 1 shows the residual stress values on sheets determined by 3MA before and after deep drawing. This figure shows the residual stress values along a measuring trace of a rectangular geometry from the middle of the bottom to the flange in comparison to the stress state before deep drawing.

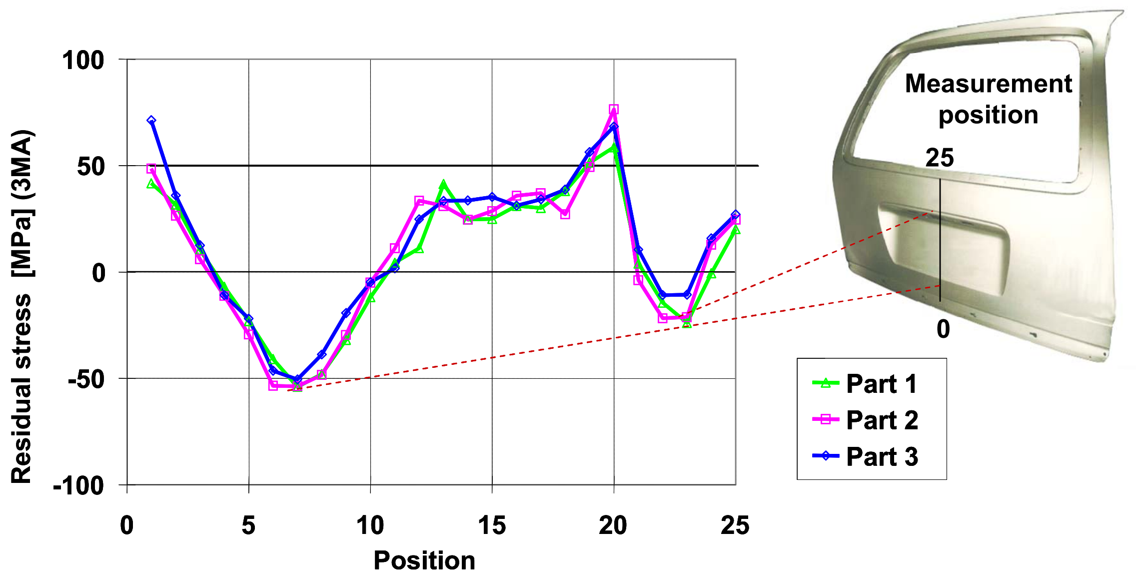

Figure 2. Distribution of residual stress in rear flaps of cars

A further example is the nd (non destructive) residual stress measurement on rear flaps of cars. The figure 2 shows the residual stress distribution along a measuring trace for three rear flaps.

3. Analysis of the correlation between residual stress state and spring back

Many factors are influencing spring back. One of them is the blank holder force and therefore the state of plastification of the material. Different blank holder forces were used to get increasing strains in the wall of u-shaped geometries. The influence of blank holder forces on residual stresses, represented in the Barkhausen noise amplitude, is measured with 3MA. As shown in figure 3, the spring back angle was decreasing with increasing blank holder forces. The figure shows the Barkhausen noise amplitude M_{MAX} along a measuring trace at the inside of the wall of u-shape geometries, deep drawn by different blank holder forces. Between the measuring positions 2 and 4 the curves show a strong dependence on the blank holder force. The decrease in Barkhausen noise amplitude is strongly connected with the increase blank holder force and plastic strain and therefore with the change of the residual stress state in the component.

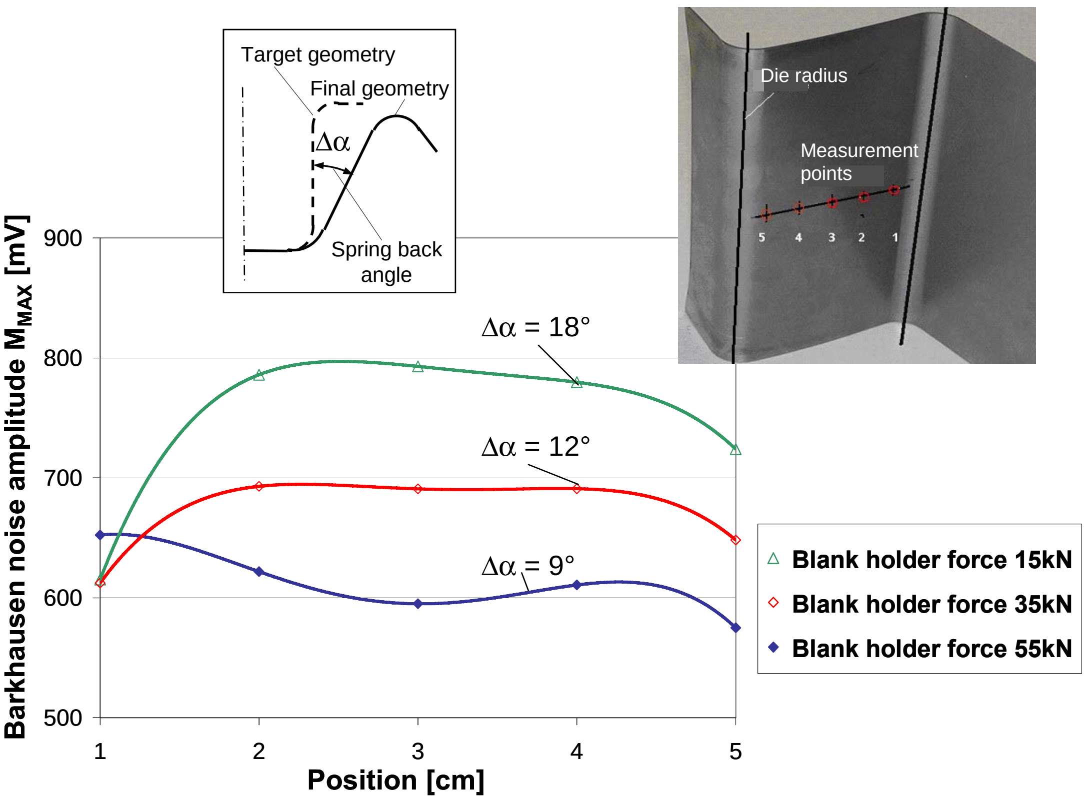

Figure 3. Influence of blank holder forces on steel sheets of H 320 LA

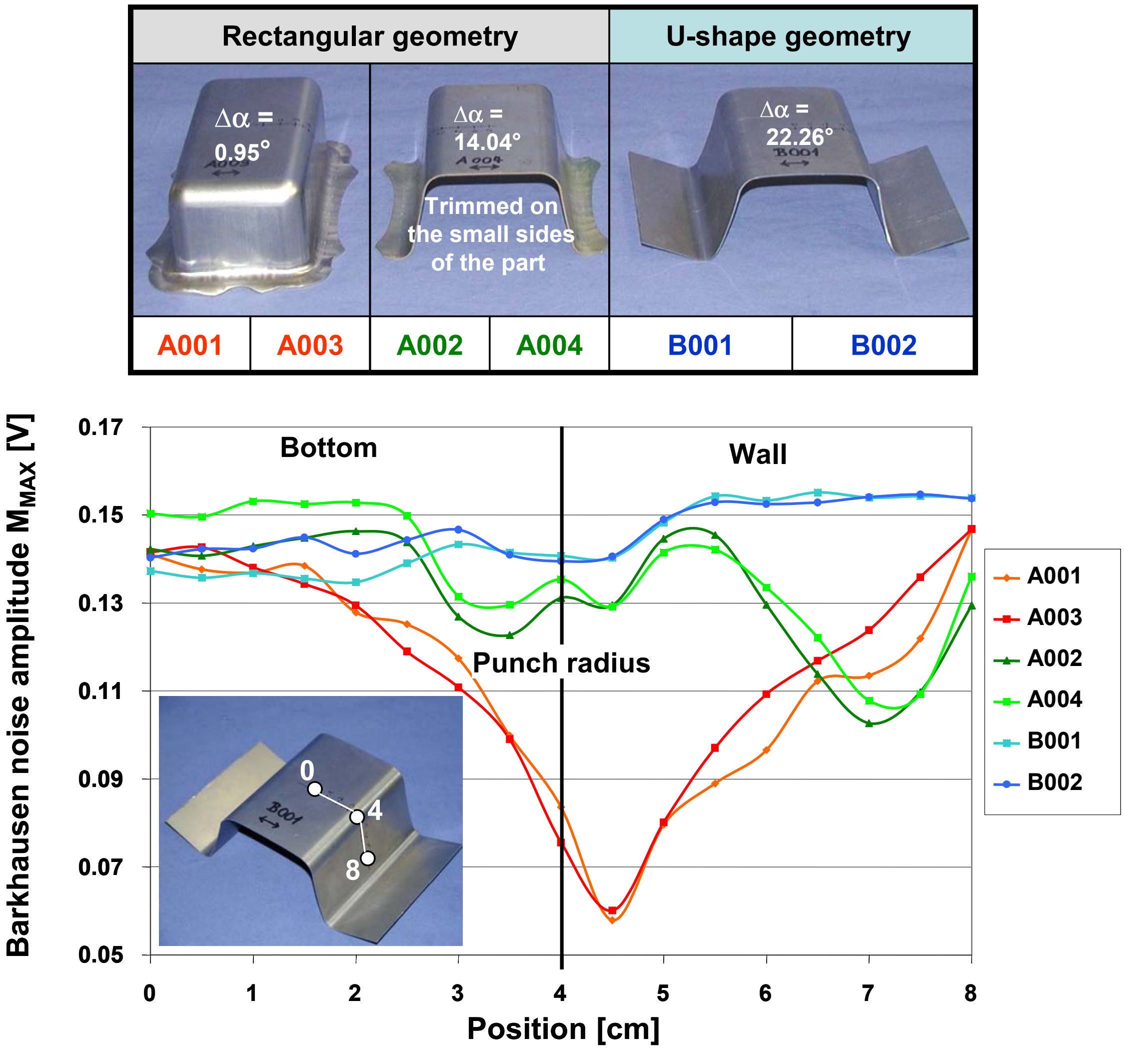

Figure 4. Influence of geometries on steel sheets on the spring back

In order to investigate the influence of different geometries on residual stress and spring back different samples were produced and measured by using Barkhausen noise

- Rectangular geometry
- Rectangular geometry, trimmed on the small side of the part
- u-shape geometry

Figure 4 shows the maximum Barkhausen noise amplitude measured from the middle of the bottom (position 0) till the die radius (position 8). The samples are magnetised parallel to the die radius. After cutting free the rectangular part the spring back is increased and the amount of residual stresses is decreased. The spring back angle Δα for the trimmed deep drawn part is lower than the spring back angle of the U-shape geometry. The reason for the lower spring back angle is the additional tangential tensile stress during the deep drawing process compared with the deep drawing process of the U-shape geometry. At the die radius (position 4 - 5) the maximum Barkhausen noise amplitude was doubled after cutting free the component. The reason for this is the variation of the residual stress state by cutting free. The increase of the maximum Barkhausen noise amplitude can be caused either by increasing the tensile residual stress or decreasing the compressive residual stress.

4. Influence of strain on Barkhausen noise in the cross tensile test

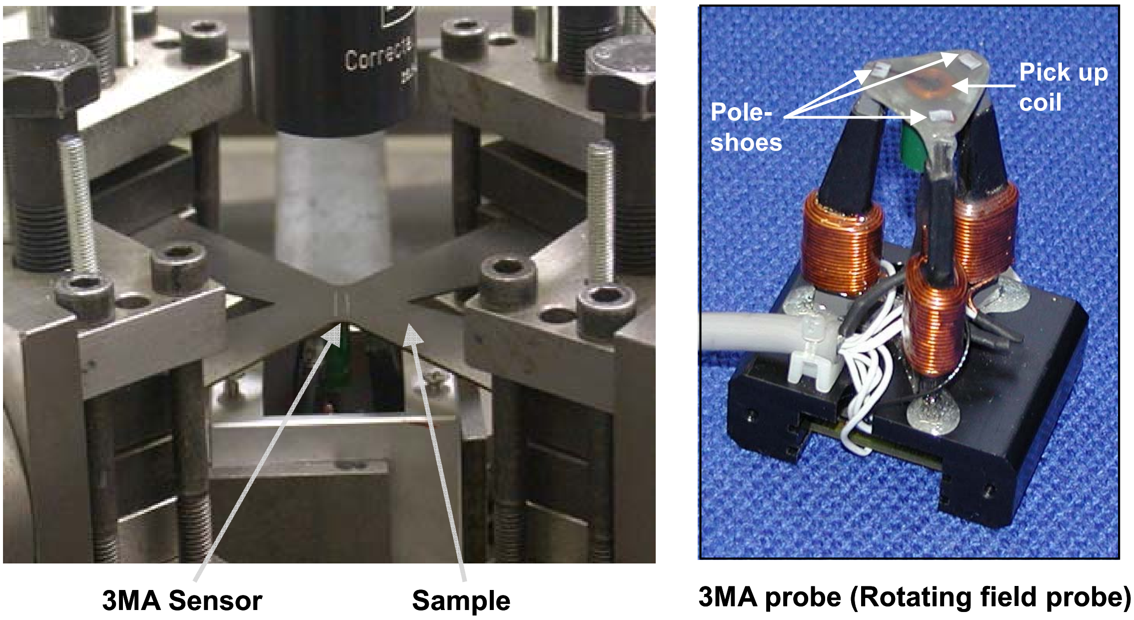

Figure 5. Cross tensile test with 3MA rotating field probe and cross tensile sample (left) and special probe using a rotating magnetisation (rotating field probe) (right)

For acquisition of multi-axle stress- or strain states and for first online measurements a special so called rotating field probe was developed which simultaneously acquires information of all directions by using a rotating magnetisation. This special probe uses three 120° shifted pole shoes which are driven by 120° rotated sinus shaped signal, Figure 5, right.

The rotating field probe allows stress measurements in all directions; the standard probe only in one direction. By measuring the Barkhausen noise amplitude in dependency of rotating magnetic field so called magnetic pole figures are obtained.
For the cross-tensile tests [17, 18] the samples are produced by erosion. Afterwards, on the sample a measuring area is marked for monitoring the increasing elongation / strain with the CCD camera during the test. The sample is fixed and the force is introduced via a conical gear wheel simultaneously to each extension of the sample. Due to the sample geometry the material flows out of the thickness during the test. The lengthening of the sample in the measuring area is continually recorded by a CCD camera during the test. The specimen is loaded until material failure. Parallel to the elongation the change in the Barkhausen noise pole figures are continuously registered during the test.

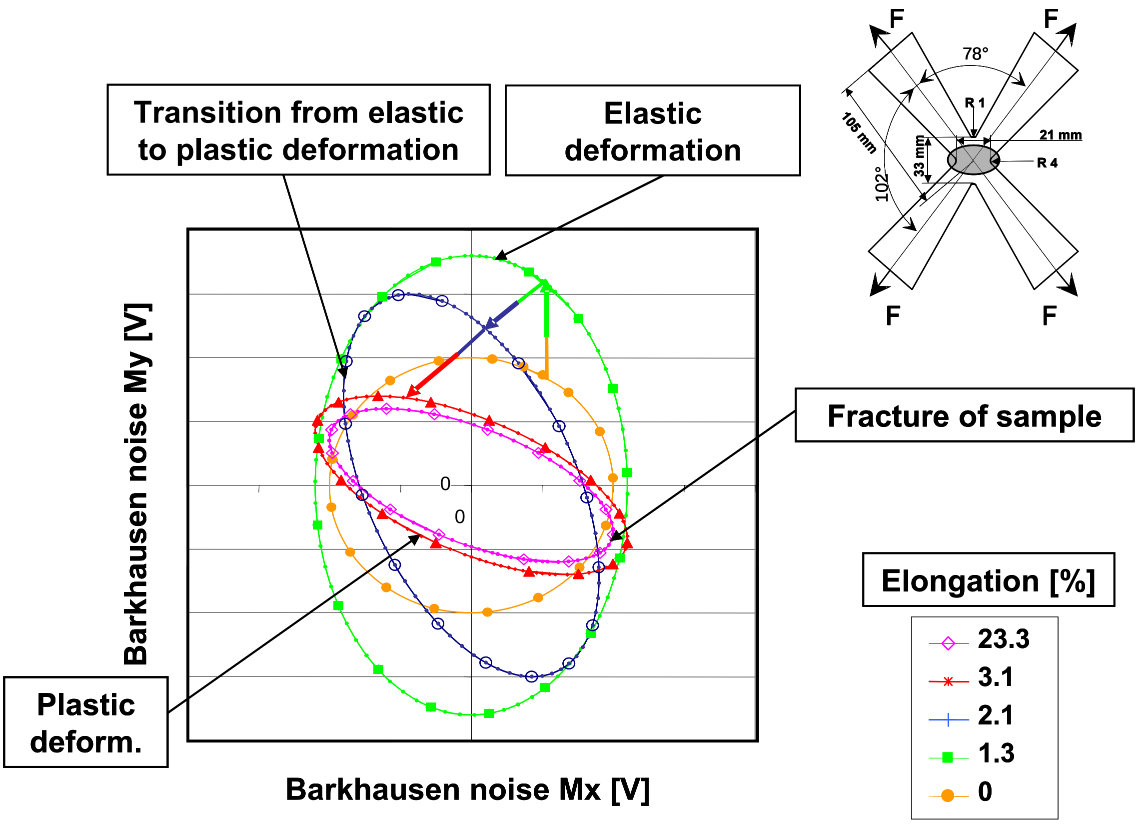

Figure 6. Measurement of pole figures during the cross tensile test on H 320 LA

Figure 6 shows the pole figures schematically.

- At the beginning of the test the pole figure is circle like.
- With increasing elastic strain the pole figures get the shape of ellipses with the major-semi-axis in maximum force direction.
- With further increasing strain in the transition range from elastic to plastic deformation the elliptical pole figures are turning away from the direction with maximum force.
- Especially the results derived from the plastic deformation range can be used to predict failures.

Especially the results derived from the plastic deformation range can be used to predict failures in the critical areas of a forming process. The pole figures form the so called working area begin with a strain of 3.1 % until fracture (23.3 %). Using the knowledge about in-process monitoring and subsequent feed back controlling (e.g. by adjustment of blank holder force) it would be possible to keep constant one special pole figure within the optimum working area.

4. Conclusion

By means of 3MA residual stresses in deep drawn components were measured non-destructively. Beside the in-process measurement of magnetic pole figures during the cross tensile test also the influence of the blank holder force on spring back was presented. Moreover, the change of residual stresses in a rectangular cup was shown depending on the forming process and subsequent machining. Further investigation is necessary to quantify the correlation between residual stresses and spring back.

Acknowledgements

The authors wish to acknowledge financial support from the DFG (German Research Foundation).

References

[1] Hütte, H. Dissertation, Universität Hannover (2001)
[2] Doege, E. Hütte H. and Elend, L.-E.: 2nd Int. Conf. and exhibition on design and prod. of dies and molds, Turkey, (2001)
[3] Kahl, K.-W. and Schiefenbusch, J.: Neuere Entwicklungen in der Blechbearbeitung, 9/1 - 9/21 (1982)
[4] Schiefenbusch, J.: Industrie Anzeiger, **29** - 30 (1982), 104
[5] Davis, R. G.: VANITEC, **25**-31 (1978)
[6] Ueda, M., Ueno, K. and Kobayashi, M.: J. of Mech. Working Techn., **163**-179 (1981) 5
[7] Davies, R. G.: J. of Appl. Metalworking, **120**-126 (1984), 3
[8] Macherauch, E. Wolfstieg, U. and Wohlfahrt, H.: HTM, **201-**211 (1973), 3
[9] Kloos, K.-H.: Werkstofftechnik, **293–**332 (1979), 10
[10] Preckel, U.: Dissertation, Universität Dortmund (1987)
[11] Altpeter, I.: Dissertation, IZFP Saarbrücken (1990)
[12] Altpeter, I. : Patent, IZFP Saarbrücken (1995)
[13] Kröning, M.: VDI-Z, 74-78 (1994)
[14] Pitsch, H.: Dissertation, IZFP Saarbrücken (1989)
[15] Altpeter, I.: Inverse Problems, 18 (2002) **1907** – 1921
[16] Tschuncky, R.: Master Theses, IZFP Saarbrücken (2004)
[17] Huck, M. Dissertation, Universität Hannover (1992)
[18] Hallfeldt, T., Dissertation, Universität Hannover (2001)