

Analysis of the geometrical tolerances and surface roughness of the spinning process

P. Groche, R. Schäfer

Institute for Production Engineering and Forming Machines, Technische Universität Darmstadt

Summary

Metal spinning technology is currently often used for the manufacturing of sophisticated products for the aerospace or the lighting industry. Components produced using the spinning technology can be characterised by their geometrical tolerances and surface qualities. However, the realisation of the mentioned tolerances is up to now mainly based on expert knowledge. Moreover, there is no possibility to scale the components geometrical size without changes in the tolerances of the produced parts. Thus the objective of this study is to establish a law of similarity, which enables the user of the spinning process to fix these scaling problem.

1. Introduction

Metal spinning is a forming process used to manufacture hollow parts with axially symmetric cross sections. Previous to the spinning operation a blank sheet is mounted on a revolving mandrel (see fig. 1). During the forming a roller is moving across the blank in several passes. The passes are repeated until the blank fits to the mandrel geometry.

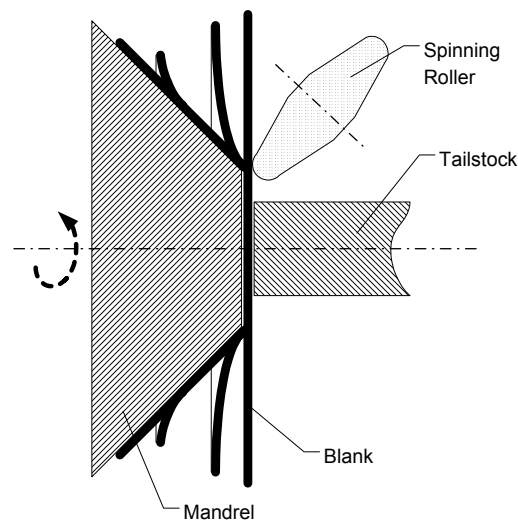


Fig.1: Schematic of spinning process

Metal spinning was associated with prototype and small size batches. However, due to the development of numerical controlled lathes, spinning is getting a cost effective option for both, medium and high volume production.

In the past spinning was primarily used to manufacture all day products like cooking pots. Due to the technological development of spinning lathes and superior forming strategies the achievable geometrical tolerances as well as the surface quality could be improved. As a result of this development spinning is currently often used to produce sophisticated products for aerospace or lighting industry applications.

In the past decade deterministic investigations to improve tolerances and surface characteristic of spun products were made. The acquired results are not universally valid or require complex control algorithms and therefore are not suited for industrial applications.

2. Objectives

Up to now a universal valid method for achieving required geometrical and surface tolerances in spinning processes is not found. Especially the realisation of specific surface qualities depends mainly on the skills of the machine operator. In certain cases the required surface characteristics at the interior face of the part have to be achieved by time consuming "trial and error" experiments.

The objective of this study is to characterize the dependencies of geometrical size and shape, surface quality and process parameters of spinning operations used to manufacture optical components. The gained data will be used to generate a similarity law which will facilitate the operator to geometrical scaling of a successfully accomplished spinning process without influencing the surface quality or the geometrical tolerances.

3. State of the Art

The spinning process is affected by material characteristics of the used blank and tools, blank thickness, roller geometry, roller feed and mandrel revolution velocity. The combination of these variables has an influence on the geometric shape and surface roughness of the spun part and the process forces [3].

In preliminary studies investigations on spinning forces [1] and buckling effects [2] were made. More recently Chen et al. specified the mentioned correlation of process parameters and surface roughness of spun cones using analytical regression analysis [3]. Finkenstein investigated the correlation of spinning forces, roller feed, mandrel revolution, geometrical tolerances and surface qualities [4].

However, the above mentioned studies did not consider the surface quality or were limited to the shear spinning of specific parts like cones or cylinders.

Nevertheless the parameters investigated by Chen and Finkenstein with respect to surface quality will be used for adjacent considerations in this study. The parameters can be divided into two groups, the machine parameters and the workpiece parameters:

Machine parameters:

- mandrel revolution
- roller feed
- roller geometry
- tool surfaces
- tool material

Workpiece parameters:

- blank thickness
- material properties

These variables can be labeled as phenomenological parameters. Phenomenological parameters are purely descriptive. Those variables are not capable to characterise underlying mechanisms and processes.

In contrast to the above mentioned variables, there is another set named fundamental parameters. In spite of the phenomenological parameters the fundamental parameters can be used to examine in-process correlations. Obviously the study of fundamental parameters will be more complicated, but the results are promise to be universal valid.

A list of fundamental parameters, known to have influence on the surface topology of sheet metal in contact dominated forming (investigated by Mössle [5], Ma [6] and Staevs [8]) are given below:

- contact pressure

- shear stress
- sliding velocity
- lubrication
- material properties

In contrast to the contact dominated forming, the achieved surface quality during contactless forming, which occurs for example in tensile tests, is affected by the following parameters.

- plastic strain ratio
- state of strain
- grain size

The effects of plastic strain and grain size were also investigated by Mössle. The effect of the state of strain was recently analysed at the PtU Darmstadt [9].

Within spinning processes, contact dominated forming caused by the roller, is the main forming operation. Additionally tensile stresses can be introduced into already formed areas of the part by the roller feed. As contact normal pressure between the part and the tooling only occurs underneath the roller, the forming caused by the above mentioned tensile stresses can be seen as contactless. Figure 2 illustrates the contact parameters. Figure 3 shows the tensile stresses which are introduced by the roller feed.

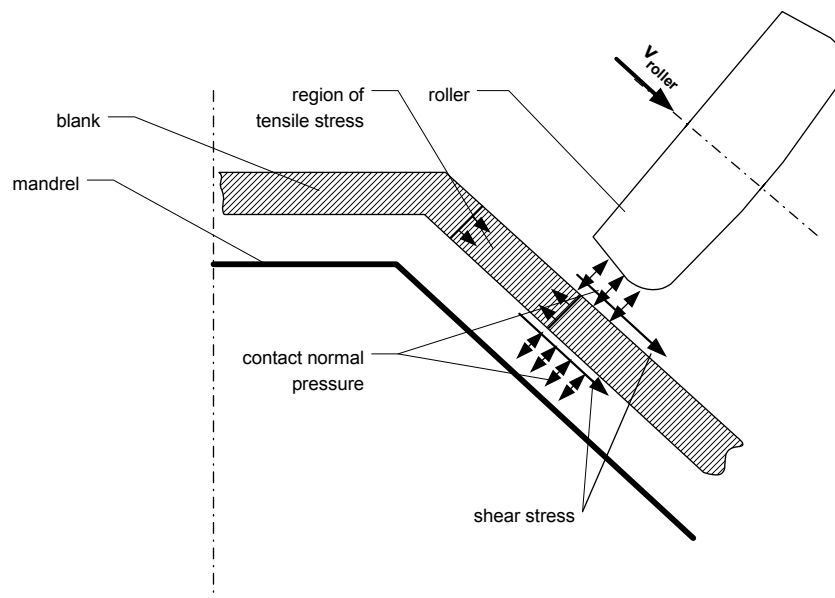


Fig. 2: Contact stresses in a spinning process

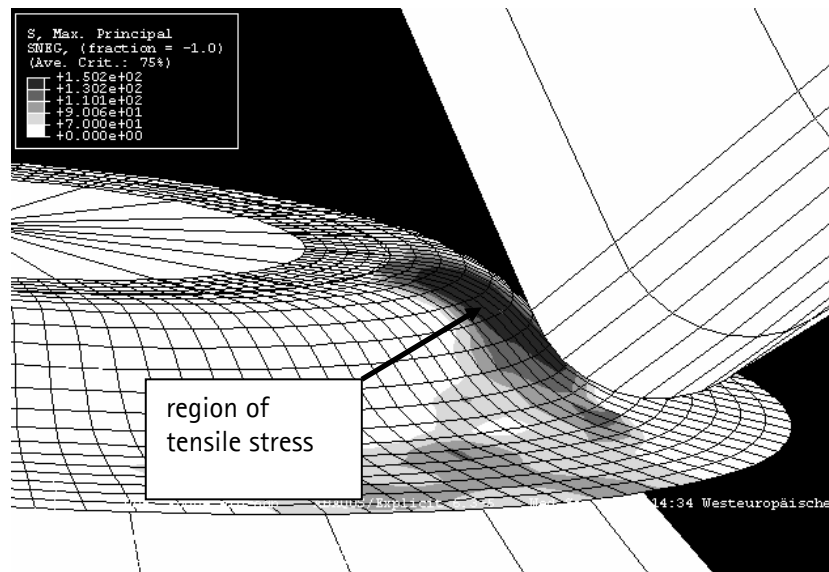


Fig.3: maximum principal stresses in plane

4. Approaches

In contrast to preliminary studies, which considered the correlation between the phenomenological parameters and the surface quality, this analysis focusses on the fundamental parameters in order to obtain a more general description of the surface behaviour in spinning processes.

However, the gained variables, like contact normal pressure, can not help the lathe operator to manufacture a component which is conform to the required geometric tolerances and surface qualities.

To close this gap between usability and global validity, a concept will be created to transfer correlations based on fundamental parameters to correlations based on phenomenological parameters (see figure 4).

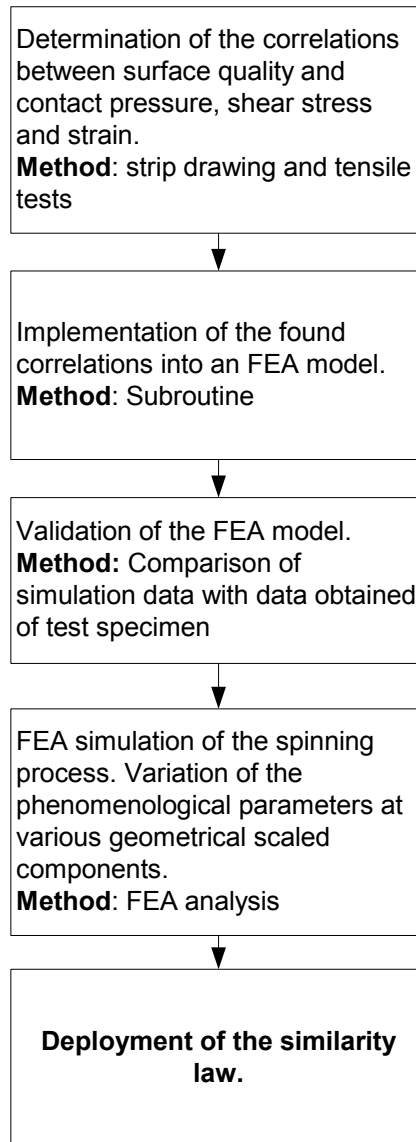


Fig.4: Concept for the analysis on surface quality and geometrical tolerances of the spinning process

The main objective is to determine correlations between surface quality and contact pressure, shear stress and strain status. The necessary data are obtained from model tests. Investigation of contact dominated parameters is done by strip drawing tests (see figure 5). The correlation describing the contactless forming will be examined by tensile tests.

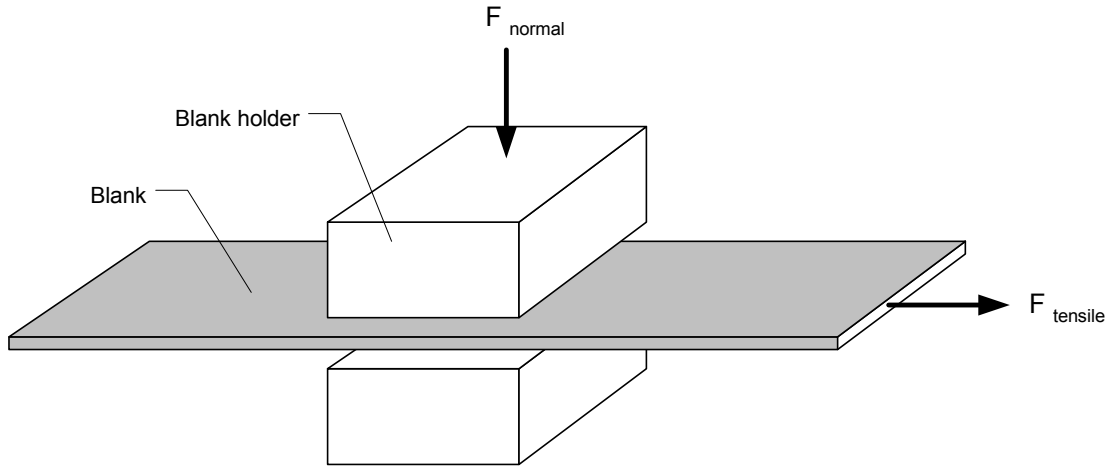


Fig. 5: Schematic of the strip drawing test

The focus of this study is on the surface behaviour of Aluminium, namely Al 99,5 and Al 99,9, both used in industrial applications of spinning of optical components.

During the stripdrawing tests the contact pressure, the sliding velocity and the lubricant have to be varied. Throughout these tensile tests the influence of the strain state can be analysed. The gathered correlations will be implemented into a FEA- spinning model. Thus, the modified software is able to compute surface parameters. To validate the FEA model it is planned to compare the simulation results with parameters obtained from manufactured specimens. Afterwards, the phenomenological parameters roller geometry, rollerfeed, blank thickness and the mandrel revolution are varied in several FEA simulations. These variations are accomplished at various geometrically scaled parts. After that the shape of the workpiece is altered and the parameter variations will be done as in the previous step. Based on these data the most significant phenomenological parameters can be extracted. Finally the correlation between the chosen variables and the surface characteristics will be determined.

5. First results

Investigations made by Mössle [5] and Emmens et al. [7] determined the correlations between contact pressure and surface roughness reduction. Similar compression tests were made with Al 99,. Figure 6 illustrates the correlation between the surface roughness and the contact normal pressure:

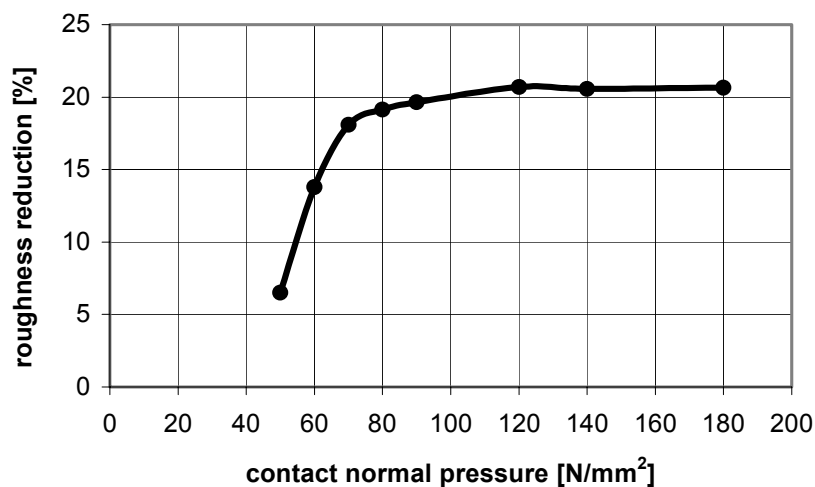


Fig.6: roughness reduction versus contact normal pressure

Those tests were done in a strip drawing test equipment without any movement between the sample and the tooling. Staeves investigated the dependency of sliding velocity and surface roughness [8].

He propagated that surface roughness can significantly be reduced by contact normal pressure with superposed sliding velocity. Figure 7 pictures the roughness reduction in dependency of the sliding velocity. The maximum roughness reduction occurred at moderate sliding velocities. Thus, in this paper the effect of the sliding velocity is taken into consideration.

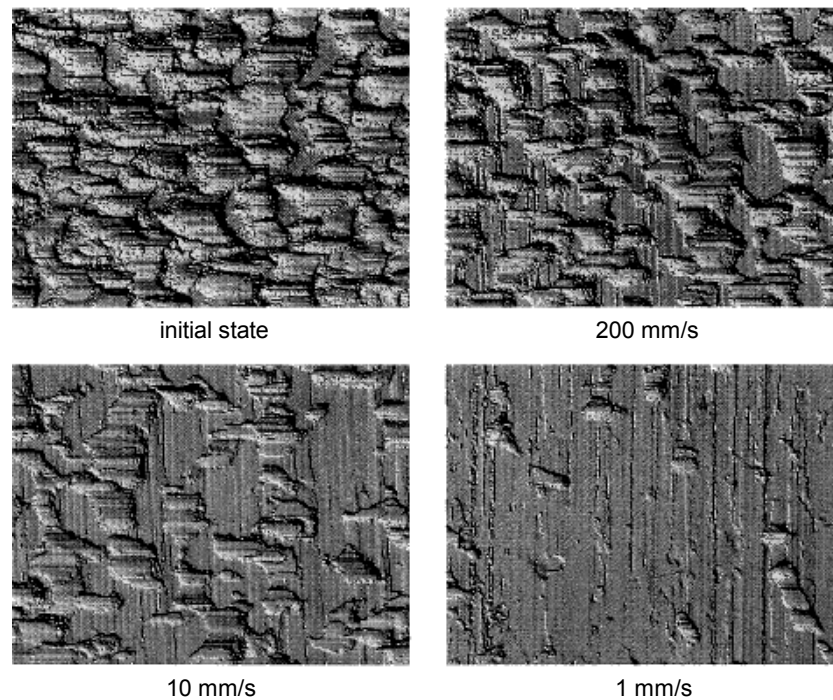


Fig. 7: roughness reduction of sample made of aluminium (contact pressure 10 N/mm^2); source: [8]

To prevent the application of a concept, which is not capable to fulfil the objectives of the study some considerations regarding size effects were made. In contact dominated forming the roughness reduction depends on contact normal pressure and shear stress. To accomplish a desired reduction in roughness every subarea of the blank has to be exposed to a specific value of contact pressure and shear stress. The value of the contact pressure as well as the location of this pressure spot at the internal face of the spinned component correlates with the blank thickness and the rollernose radius (see fig. 9 and fig. 10).

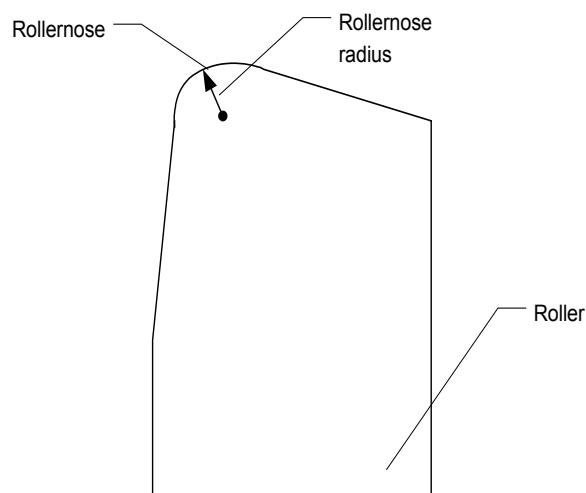


Fig. 8: Rollernose radius

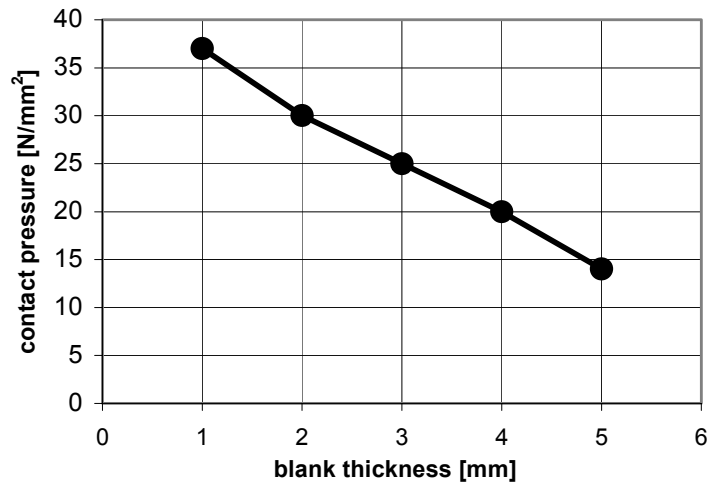


Fig. 9: correlation between blank thickness and contact pressure (rollernose radius 22 mm, penetration force 500 N)

The curve shown in figure 9 as received from a FEA simulation of the rollernose contact on a blank sheet (see figure 11). The contact pressure at the mandrel decreases at the same time the wall thickness increases. Figure 10 illustrates the contact pressure versus the rollernose radius.

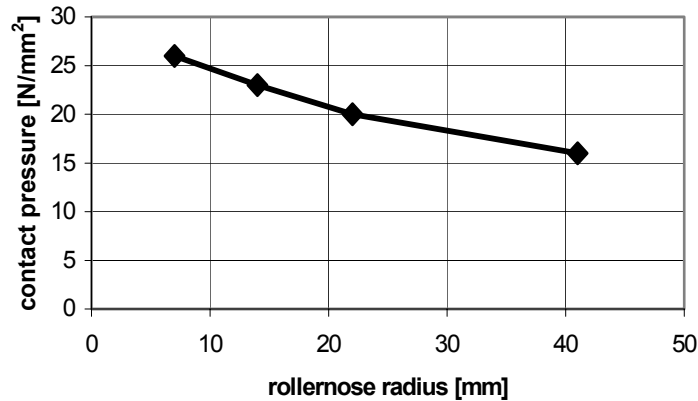


Fig. 10: correlation between rollernose radius and contact pressure (blank thickness 4 mm, penetration force 500 N)

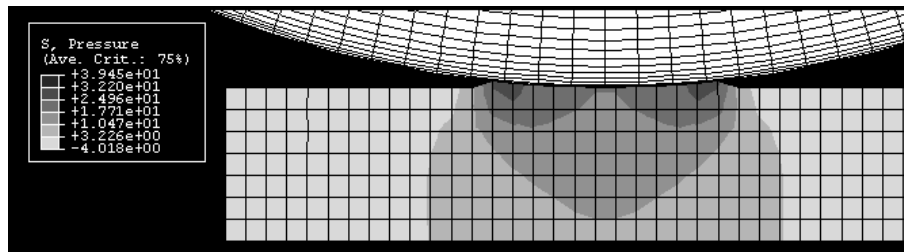


Fig. 11: Hydrostatic pressure in an aluminium blank contacted by a roller nose (blank thickness 2 mm, roller nose radius 14 mm)

Assuming that the surface roughness depends on the contact normal stress and the shear stress, a set of parameters can be established which ensure that every subarea of the blank is exposed to the required stress state. The parameter set consists of the roller tangential force, the blank thickness, the roller feed and the rollernose radius.

Figure 11 additionally displays a numerical problem. To gain proper results regarding to contact parameters a fine mesh is essential. Thus, the time needed to simulate a spinning process using a fine mesh is intolerable. Submodeling is a simulation technique capable to deal with this problem. The simulation process is divided in two parts: The simulation of a relatively coarsed meshed global model and the simulation of a fine meshed blank region for gaining proper contact data. The global model is used to analyse the dependencies in phenomenological parameters and geometrical tolerances. Moreover the values of the boundary conditions needed for driving the submodel are computed. The submodel is pie slice shaped and describes only a section of the blank. The cutting edges are provided with displacement boundary conditions computed in the global model. Thus, the deformation behavior of the submodel is conform to the corresponding section of the global model. At present a submodel which is capable to describe the spinning process was created.

6. Conclusion and future work

In this paper surface influencing phenomenological and fundamental parameters were shown and discussed. A concept capable to reach the objectives set up in the proposal was created and validated. First numerical and physical experiments were made. First the correlation between the surface quality and the contact pressure could be shown. Furtheron investigations on the surface conditions of contact pressure, blank thickness and rollernose radius and their dependencies were made. In a next step the correlation of shear stress and surface quality will be examined. The found dependencies will be implemented into an ABAQUS® FEA model using an existing subroutine. Afterwards first numerical studies with respect to surface quality can be accomplished. Tensile tests for the detection of correlations between surface quality and strain state will be done. After the successful implementation of all fundamental parameters into the FEA software, numerical parameter variations of phenomenological parameters will be carried out. Based on the obtained results a general similarity law can be defined.

7. References

- [1] E. Siebel, K.A. Dröge, Forces and material flow in spinning. *Werkstattechnik und Maschinenbau* 45 (1) (1955)
- [2] J.N. Feola, experimental analysis of shear deformation. M.S. thesis, Syracuse University, New York (1955)
- [3] M.D. Chen et al. , Forecast of shea spinning force and surface roughness of spun cones by employing regression analysis. *International Journal of Machine Tools & Manufacture* 41/2001 (2001)
- [4] E. von Finkenstein et al. , Möglichkeiten zur Qualitätsverbesserung an Drückteilen. *Bleche Rohre Profile* 42/1995 (1995)
- [5] E. Mössle, Einfluss der Oberfläche beim Ziehen von Blechteilen aus Aluminium. IFU Stuttgart, Springer Verlag (1983)
- [6] B. Ma, et al., An experimental investigation of steel surface characteristic transfer by cold rolling. *Journal of Materials processing Technology* 125-126 (2002)
- [7] W.C. Emmens, F. Schoepen, Some frictional aspects of aluminium in sheet metal forming. *Proceedings of the 19th IDDRG Biennal Congress* (1996)
- [8] J. Staeves, Eigenschaften und Beurteilung von Blechen. *Tagungsband 6. Umformtechnisches Kolloquium Darmstadt 1997* (1997)
- [9] A. Peter, Wirkung von Oberflächen in Abhängigkeit von der Oberflächentopografie beim IHU. *Tagungsband Internationale Konferenz Hydroumformung Stuttgart 2003* (2003)