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FLC DETERMINATION AND FORMING ANALYSIS BY OPTICAL MEASUREMENT SYSTEMS

Harald Friebe, Kostantin Galanulis, Oliver Erne, Ernst Müller

GOM mbH
Mittelweg 7-8, 38106 Braunschweig, Germany, http://www.gom.com

ABSTRACT

During recent years, optical measuring technologies have been introduced in the area of sheet metal forming . The Main applications areas are in the determination of material properties, forming analysis of metal sheets and the digitizing of metal sheet parts. Based on optical methods very detailed surface information with high local and temporal resolution is available. This supports new efforts for standardization of the generation of material properties (such as FLC values based on ISO 12004). Parallel to these values the determination of the real strain distribution enables the verification of simulation results and the real forming could be quantified. Based e.g. on digitized surface data and different interfaces the optical measuring systems become a part of complex process chains in the area of CAD/CAM and numerical simulations. These process chains mainly focus on optimizing the development of products and production processes and on improving the product quality. Using optical systems considerably decreases the development time for products and production while improving the quality.

Keywords: Optical measurement system, forming analysis, material properties, FLC determination, 3D digitizing

1. INTRODUCTION

This paper presents three optical measuring technologies which have become a part of sheet metal forming in many industrial applications during the past few years [9].

The optical measurement system ARAMIS determines full field distribution of coordinates, displacements, strains and more. One application is the determination of material properties such as the FLC determination based on proposal for the ISO-12004. The high local and temporal resolution enables in-process (time dependent and cross section based) and out of process evaluations.

Forming analysis by ARGUS delivers comparable results like the full field distribution of major and minor strain, the thickness reduction as well as the forming limit diagram for static measurement of stamped metal sheet parts. The main applications are the verification of numerical simulations and the fast and robust evaluation of forming processes in the stamping area.

Digitizing with ATOS provides the geometrical information of the complete shape of parts. This technology is mainly used in the automotive industry in reverse engineering, analysis and quality control applications, such as first article inspection, assembly control, tool manufacturing and optimization, production monitoring and incoming components inspection.

The main advantages of these relatively new technologies are:

a) coverage and visualization of the complete parts in 3D as well as comparison with CAD or numerical simulation data
b) fast measuring process in comparison with traditional single point based measuring systems
c) high resolution and accuracy
d) system mobility which allows the measurement of parts at different places.

The importance of these technologies will increase in the future as they improve the time compression of the part and its production development, and reduce the feedback time of production monitoring.

2. MATERIAL TESTING WITH ARAMIS

2.1 PRINCIPLE OF ARAMIS

The deformation analysis system ARAMIS (principle setup see figure 1and 2) is based on two cameras, which observe the deformation of surfaces. The surface is coated with a stochastic pattern (figure 3). With such a coating the measurement becomes independent from illumination and the optical properties of the material (reflection etc.). The measurement of a loading situation is done just with one pair of images from both cameras (in one shot). This enables the system to measure dynamic deformations only limited by the maximum frequency of the used cameras.

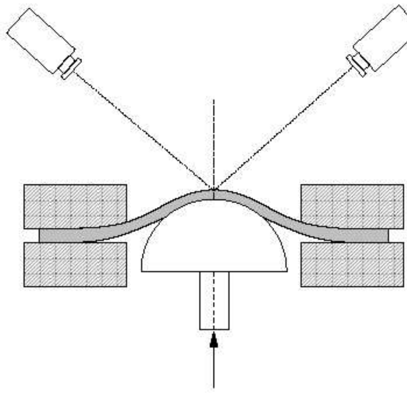

Figure 1: Principle setup for ARAMIS

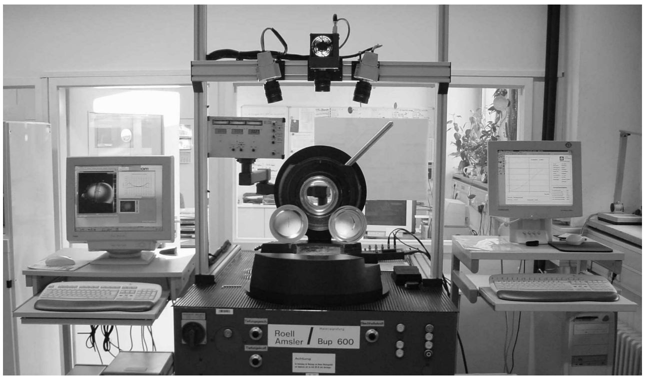

Figure 2: Camera system build on a testing machine

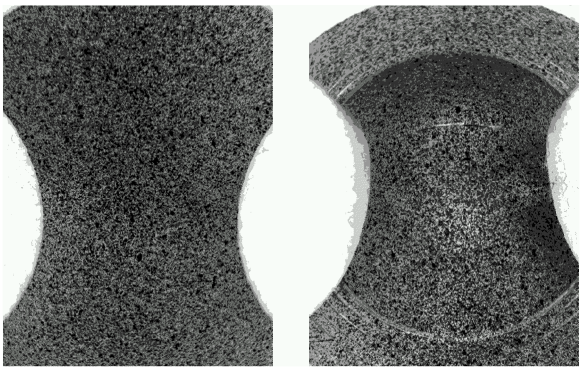

Figure 3: Undeformed and deformed nakajima specimen

Based on digital image processing a reference image is subdivided into facets (small rectangular areas). For each area the correspondent locations in all other images (from the second camera and from all different loading situations) are automatically determined with sub pixel accuracy. This is exemplary shown for a small area in figure 4 (see white facet).

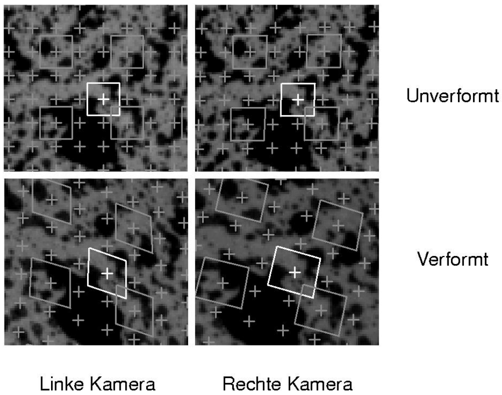

Figure 4: small area of an ARAMIS image from two different loading stages (undeformed and deformed).

This procedure leads to a full field results with high local resolution e.g. for 3D coordinates, 3D displacements. Based on the real 3D coordinates of a reference stage the surface strain tensor is determined for all deformed load stages (figure 5). The strain results (e.g. major-, minor-, mises-strain, thickness reduction, …) are calculated as technical strains and as true strains.

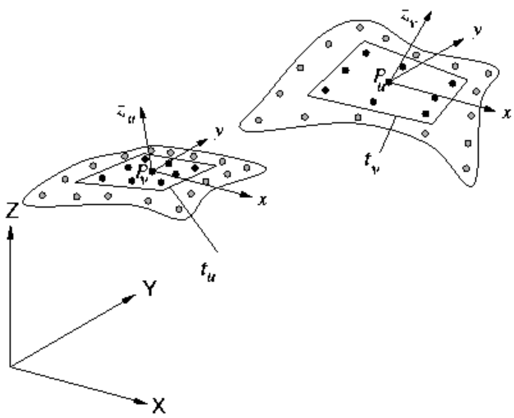

Figure 4: Surface strain calculation

The use of all pixels for the calculation and the independence from illumination and reflections provides a high measuring accuracy up to 0,01% technical strain. The temporal resolution is only defined by the maximum frequency of the used cameras. Today measurements with more than 50.000 images per seconds, loading speeds higher than 20m/second and strain rates over 100.000 % per second are possible. The amount of 3D points depends on the camera resolution and the geometry of the specimen (typically 10.000 to 100.000 3D points). The size of the 3D measurement field can be varied typically between 5x4mm^2 and 2000x1600mm^2 . The local resolution can be set down to

0.05mm distance between the measurement points and is proportional to the size of the measurement field.

The results can be shown as a 3D view of all the points (figure 5) for each calculated results value. The time dependent evolution of strains can be shown for single load stages or as a movie for all stages together. Additionally the reduction of the result data to sections or just a single point can point out special material or component behavior very easily.

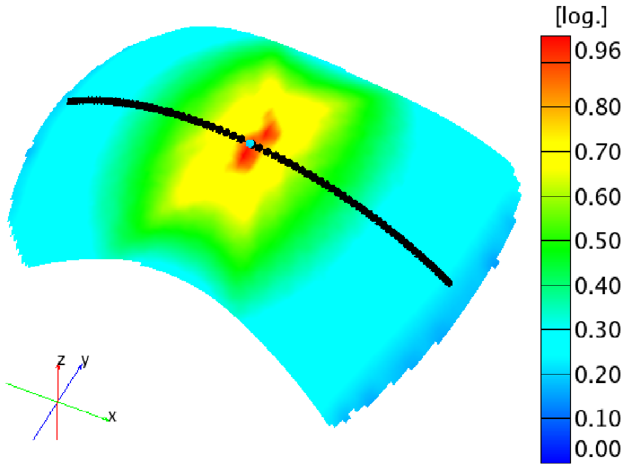

Figure 5: Major strain of a nakajima specimen 0.1sec before cracking

By using special structures on the specimen surfaces the ARAMIS System can be used for a wide range of temperatures (-100°C … 1500°C).

2.2 APPLICATIONS OF THE ARAMIS SYSTEM

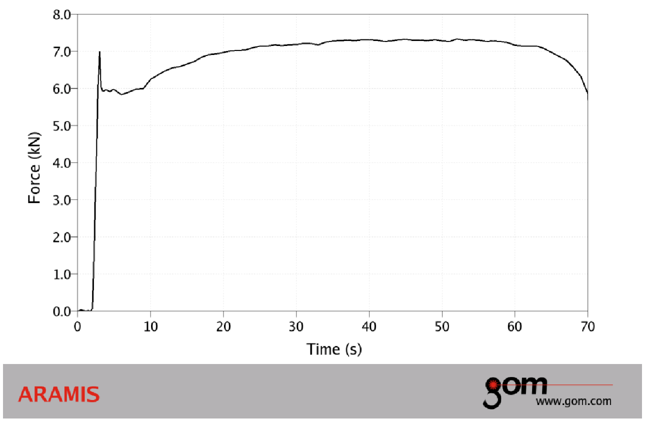

Figure 6: Force over time curve for a steel with a distinct yield effect

The deformation analysis by ARAMIS can be used for different tasks under different temperature conditions as e.g.:

- Material testing
- Component dimensioning
- Verification of FE-Methods
- Investigation of non-linear behavior
- Characterization of creep and aging processes
- Determination of material properties such as:
- E-Module, R-Value, N-Value, flow stress based on bulge tests, flow stress for tensile tests, Fließortkurve, FLC values

An example for localized material effects is the appearance of dislocation lines during the change from elastic to plastic deformations for a steel with a distinct yield effect (figure 5 and 6).

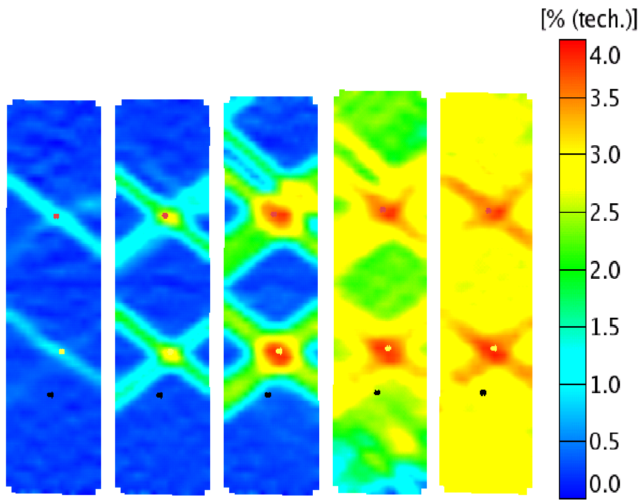

Figure 7: Longitudinal strain of dislocation lines in a tensile test (after 3.4 to 9 seconds)

Especially for the determination of material properties in ARAMIS are tools integrated, which allow a very simple generation of material properties. So it becomes e.g. easy for the user, to determine FLCs, flow curves from bulge tests, flow curves from a tensile test based on local values, which will be not limited by the beginning of necking.

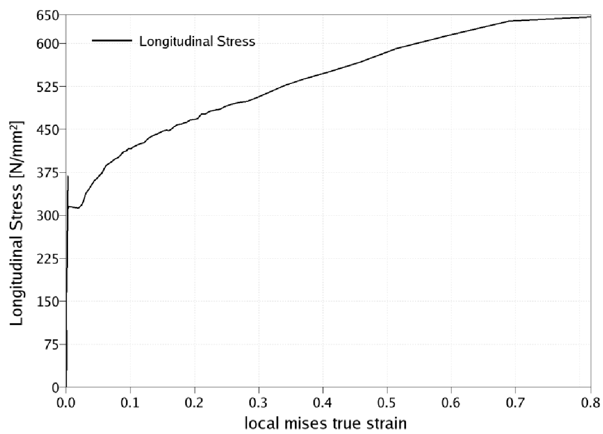

Figure 8: Flow curve base on a tensile test

2.3 FLC DETERMINATION WITH ARAMIS

The proposal for the ISO12004 defines different possibilities how the limit value can be generated:

1. Cross-section evaluation of the situation just before the specimen will crack (approx 0.1 sec before)
2. Cross-section evaluation of broken specimens
3. Time dependent post processing (not finished yet)

These possibilities are presented in detail on this conference by Dr. Hotz [3], and Dr Volk [4]. With the measurement results of ARAMIS all these possible workflows are supported.

The determination of the strain distribution of the broken specimen can be realized easily by measuring the undeformed and the cracked specimen. This can be done outside the loading device.

For the measurement of the situation just before cracking and for the time dependent postprocessing the ARAMIS System has to observe the specimen during the loading. In this case the system is fixed to the loading device and is designed in such a way that the measurement system does not interfere with the handling of the machine. An optimised lighting is realized by a central projection unit to allow both cameras to record the specimen during the deep drawing process inside the machine (figure 2).

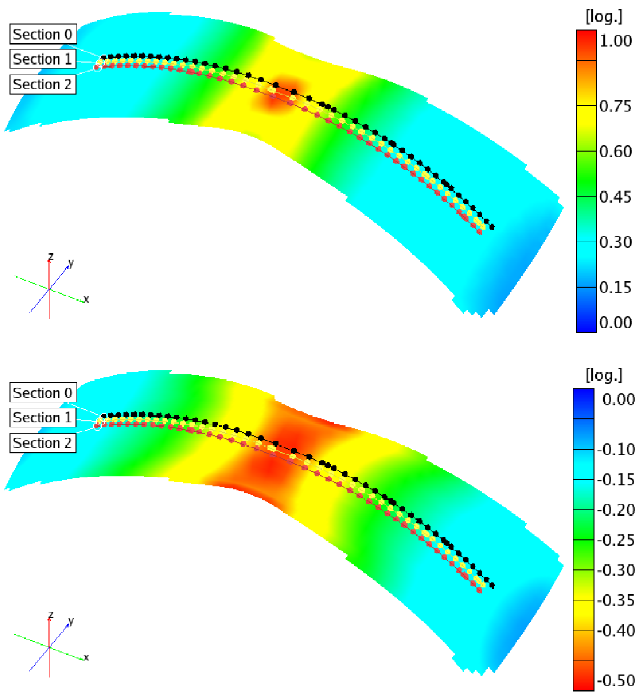

Figure 9: Major and minor strains just before cracking

As an example for the post processing in ARAMIS the second possibility should be explained more detailed. The specimen is prepared with a pattern, a reference image pair is captured before loading. At the end of the loading a series ob images is captured with a frequency of 10 Hz (as defined by the ISO proposal) until the specimen cracks. For the post processing only the reference images and the last images before cracking are stored and used to calculate the corresponding strain distribution. In figure 9, the major and minor strain distribution of such a situation is shown. In the next step three to five parallel section line have to be defined (distance from line to line is 2mm). The centre section line should be placed perpendicular to the crack-line (which is visible in the next observation) or parallel to the borders of waisted specimen. The section line should go through the area of highest strain, where the crack will start in the next image. The data of this sections are shown in figure 10 and are used for the FLC calculation.

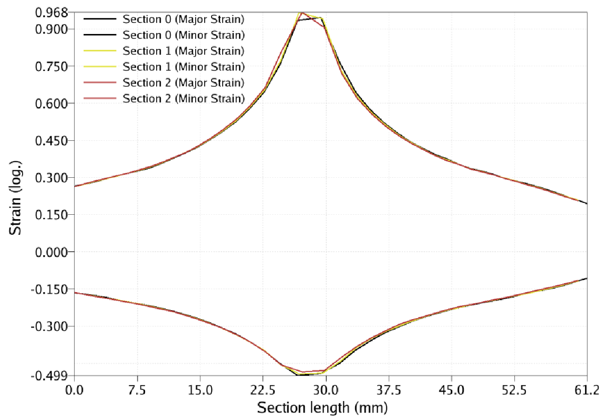

Figure 10: Section data for the sections in figure 9

For a complete FLC, the ISO12004 recommends at least five different geometries, for each geometry three specimen and for each specimen three to five parallel sections. At least 45 section data sets (5x3x3) have to be used for an FLC. The processing for a single section data set is shown in figure 11.

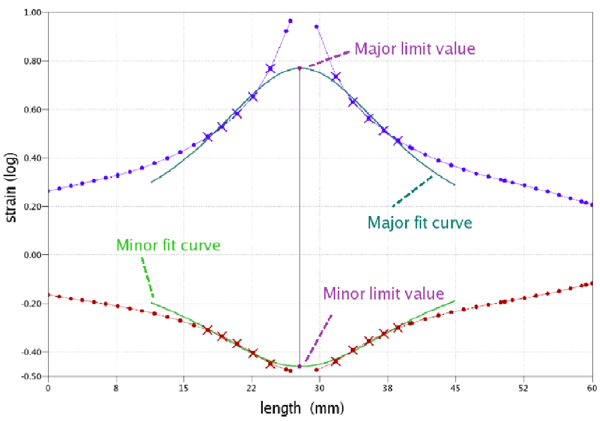

Figure 11: FLC values defined by section data

In figure 11 the dots describe the original section data points (blue for major, red for minor). Based on the ISO12004 a number of points is selected automatically from these points (blue crosses for major and red crosses for minor). These points are used to calculate a best fit curve for the major and minor points (inverse parable though the crosses). The intersection value of these curves with the crack position, is defined as the limit value for the FLC (Major limit value and Minor limit value). This value defines the beginning of the instable necking. Based on the ISO12004 this procedure can be done completely automatically. If all Nakajima tests for one material are made and the section data sets are generated, the following post processing for all data sets takes only a few seconds.

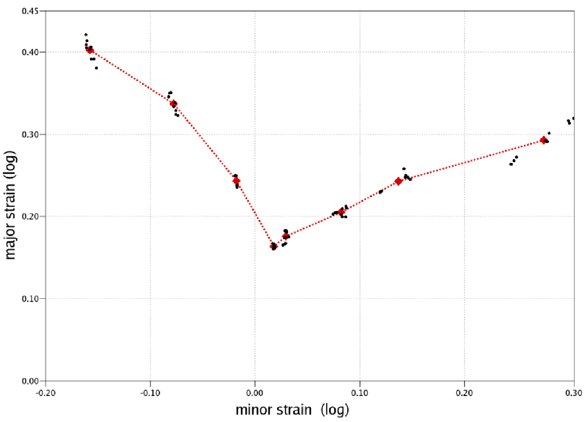

Figure 12: FLC based on ARAMIS data and cross section post processing

The result is a complete FLC as shown in figure 12. Eight different geometries are used here with three repetitions each. For each geometry three parallel sections were used. Thus, 72 section data sets were used for the FLC. The result from each single section data set is shown as a black point, the average for each geometry is shown as a red rhomb.

The FLC calculation based on section data of already broken specimen is introduced to ARAMIS in the same way.

After a successful validation, a time based procedure for FLD definition will also be introduced in ARAMIS (e.g. see [4]).

3 FORMING ANALYSIS WITH ARGUS

3.1 PRINCIPLE OF ARGUS

While ARAMIS is designed to measure temporal procedures, the software extension ARGUS is an optimized solution to measure equivalent information on formed metal sheet parts [8]. Circular dots are applied to the original sheet metal with a regular spacing of typically 1 mm to 5 mm prior to the forming process. For this purpose, mainly structures are used that were created by electrochemical etching, laser etching or printing (Fig. 13). These dots follow the deformation of the part during the forming process and are maintained even in case of large relative movement between the sheet metal and the tool. The center of these dots is the reference for determining the coordinates and for the following deformation analysis.

After the forming the shaped component is recorded with a digital camera from various views [5] (figure 14).

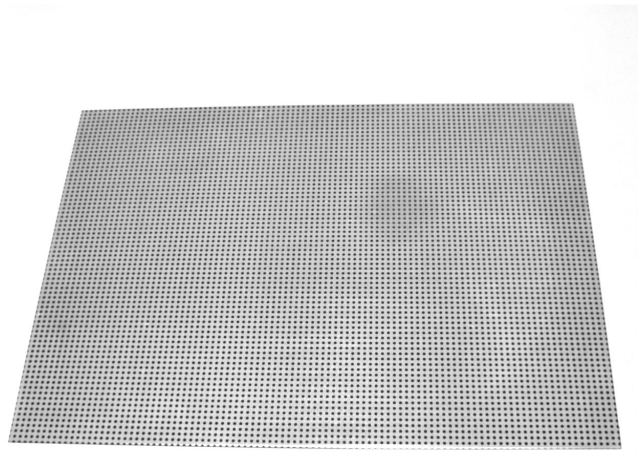

Figure 13: Regular dot pattern on a flat metal sheet

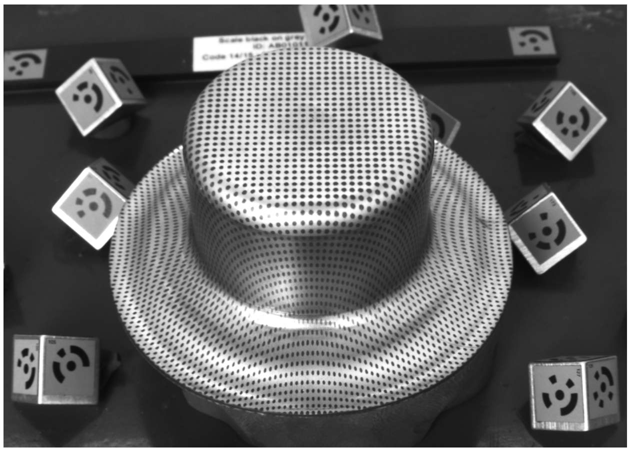

Figure 14: Example for a shaped metal sheet after the forming process

Photogrammetric algorithms use these images to determine the 3D coordinates of the dots on the sheet metal. Thus, the entire surface of the shaped sheet metal is described according to the density of the etched structure.

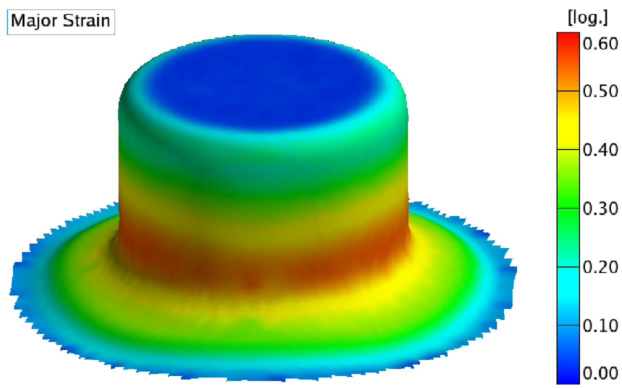

Figure 15: Major strain distribution

In this mesh each 2x2 point field is compared to the original geometry and the corresponding surface strain tensor in space is determined. As a result e.g. the major and minor strain and the thickness reduction of the sheet metal are available as surface information (Fig.15). The thickness reduction is directly calculated from the major and minor strain assuming a constant volume.

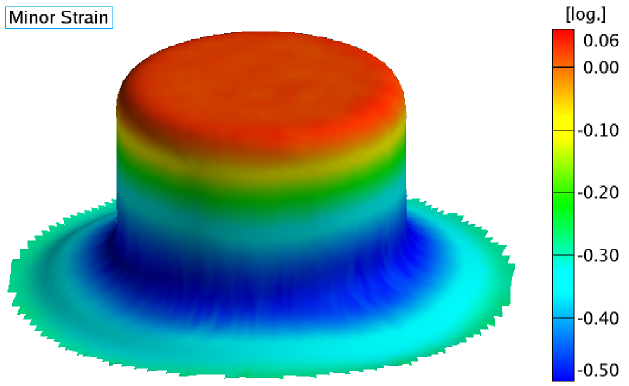

Figure 16: Minor strain distribution

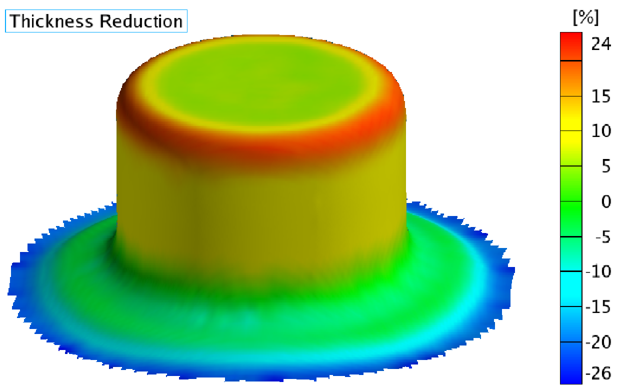

Figure 17: Thickness reduction distribution

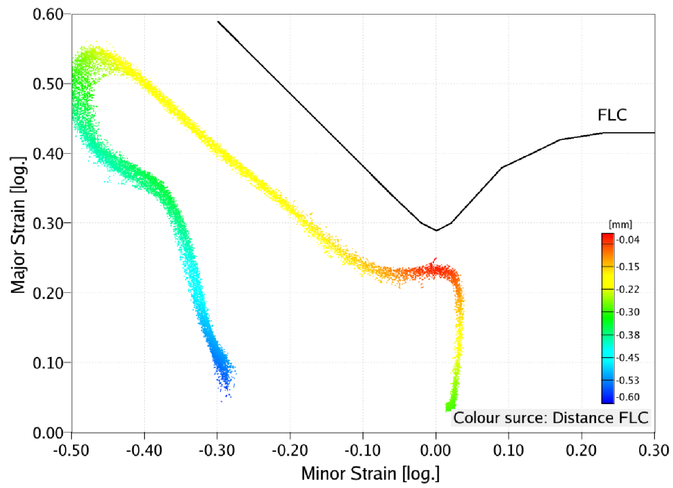

Figure 18: Forming limit curve inclusive measured strain values

The forming limit diagram compares the major and minor strain with given material characteristics (figure 16). Thus, the forming process can directly be evaluated with respect to the material limits

All calculated values are displayed in colour on the 3D contour as sections or as form limit diagrams. Short, precise and complete information on the shaping process is available by simply rotating the 3D contour. In addition, all calculated values and the respective 3D coordinates can be exported in user-defined ASCII files and imported into other post processors. If it is required to provide the results in the CAD coordinate system of the component, ARGUS can carry out coordinate transformations.

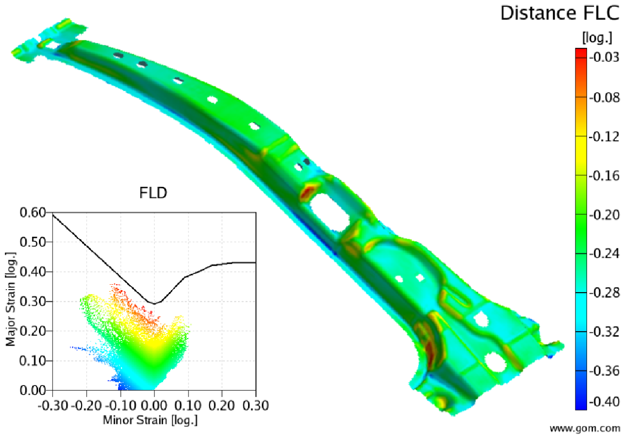

Figure 19: Strain distribution on a complete B-pillar shown as distancevalues from FLC

The recording principle of the system allows for flexible adaptation of the measurement to various applications. A minimum of three views is required for measuring. As the individual views are recorded successively with a single camera, the system can be used for simple and for very complex parts (figure 19) as well as for small and large measuring volumes. As during the photogrammetric calculation the system is calibrated automatically, no other preparations of the system is needed except for adjusting the lenses to the desired measuring volume. The main advantages of the ARGUS System are:

- coverage and visualization of the complete parts
- fast and robust measuring process for prompt investigations in the stamping area
- fully automatic calculation which guarantees a high level of consistency and repeatable accuracy
- independent of the operator
- mobility of the system

3.2 APPICATIONS OF THE ARGUS SYSTEM

Typical applications for the ARGUS system in the deep drawing are e.g.:

- Trouble shooting and process optimization in the stamping area and tool try-out.
- Verification of simulations (FEM)
- Definition of material properties such as FLC, flow curve for bulge tests, …

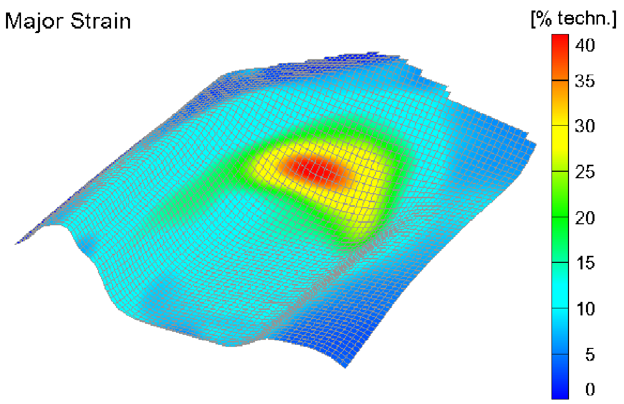

Figure 20: Sheet metal part before optimization

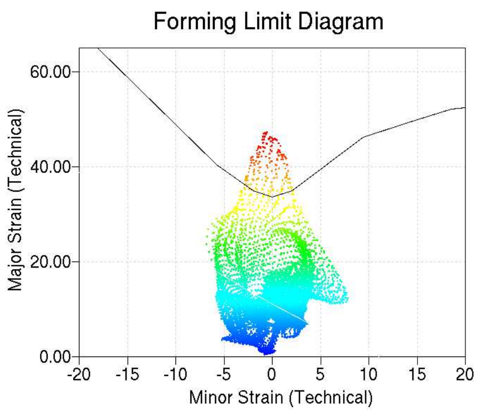

Figure 21: FLD before optimization

The optimization of a stamping process supported by the ARGUS system is useful. The real strain conditions of a critical part can be determined easy as shown in figure 20 and 21. The strain values exceed the FLC for the material. During and after the optimization process ARGUS is used, to follow the change of the strand distribution and the progress (figure 22/23).

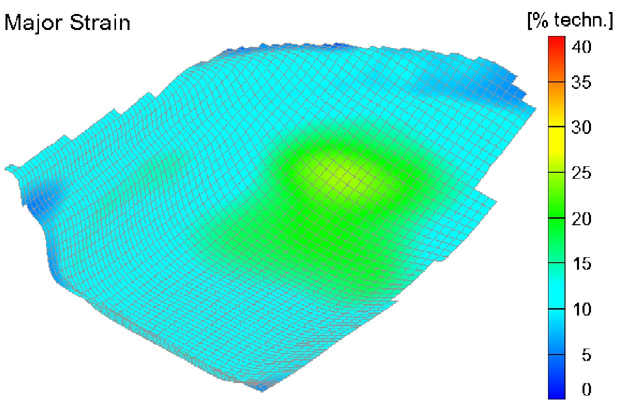

Figure 22: Sheet metal part after optimization

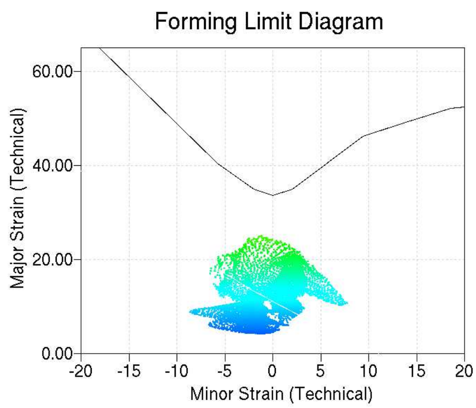

Figure 23: FLD after optimization

3. FORMING ANALYSIS WITH ATOS

Adding a fringe projection unit to the ARAMIS stereo-camera-concept the powerful digitizing system ATOS is available [7] (figure 24). The measurement results of the ATOS system are the 3D coordinates of the complete object surfaces with high local density and high accuracy, sectional data and information about geometrical elements such as holes and edges (figure 25). The user can easily adjust the system for different object dimensions (from a few mm³ to multiple m³) to optimally meet the measurement requirements.

Figure 24: ATOS measuring a sheet metal

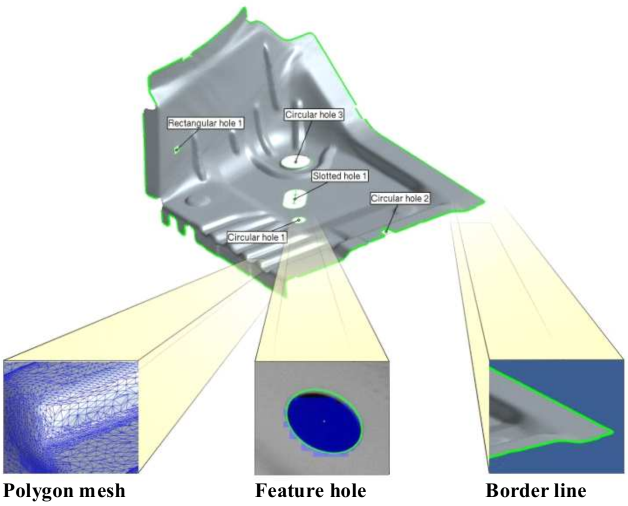

Figure 25: ATOS measuring results on a sheet metal

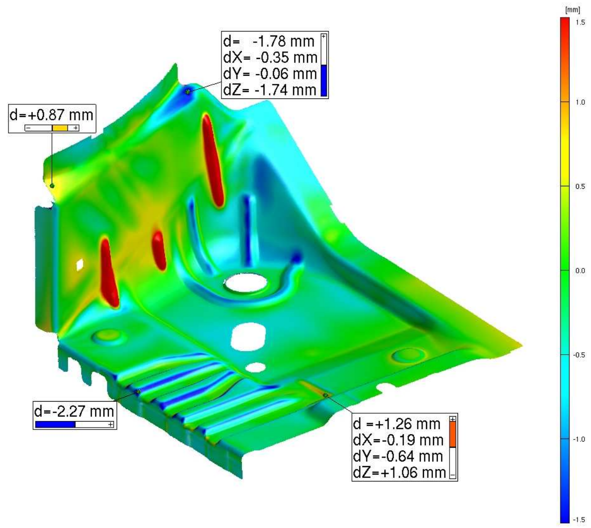

Figure 25: Color-coded deviation plot with annotations

In the area of metal sheet forming, the ATOS System can be used for multiple tasks as:

- 3D Digitizing in verification of stamped parts
  Under consideration of RPS alignment and measuring plans detailed inspection reports are available. In figure 25 the result of a comparison between measured surface and CAD data is shown (the color presents the deviation distribution)
- 3D Digitizing in tooling
  - Measuring blanks to optimize the milling strategy
  - Direct milling on measurement data
  - Measuring after tool try-out
    Generation of CAD data of modified tools (reverse engineering)
- Provide data for FEA meshes
- Verification of FEA analysis
  (e.g. geometry and spring back)

SUMMARY

Optical measuring systems for digitizing, forming analysis and material property determination such as FLC are a part of advanced process chains in the development of products and production processes for sheet metals and tools. Already today, time, costs and quality are optimized, thus increasing the competitiveness of companies

The importance of these technologies will increase more in the future as they improve the time compression of the part and its production development, and reduce the feedback time of production monitoring

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