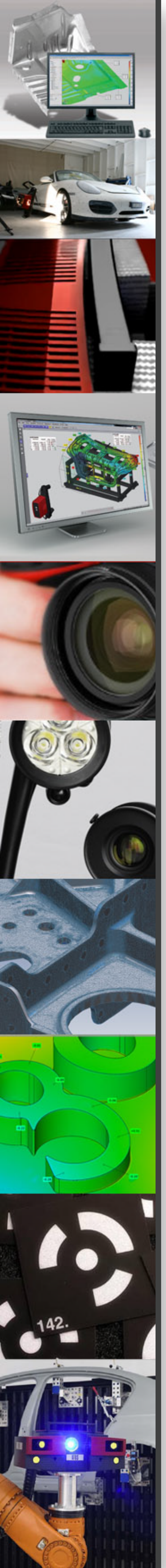
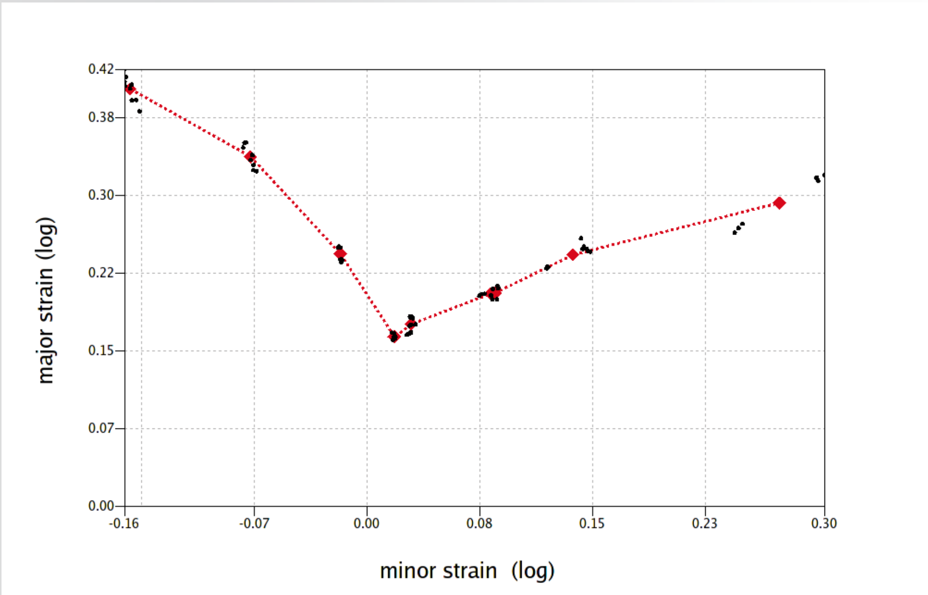


Application Example: Material Testing

Material Properties: Determination of Process Limitations in Sheet Metal Forming - Forming Limit Diagram

Measuring Systems: ARAMIS
Keywords: Forming Limit Curve (FLC), Forming Limit Diagram (FLD), material characteristics

The forming limit diagram (FLD) offers the chance to determine process limitations in sheet metal forming and is used in the estimation of stamping characteristics of sheet metal materials.



FLC Chart

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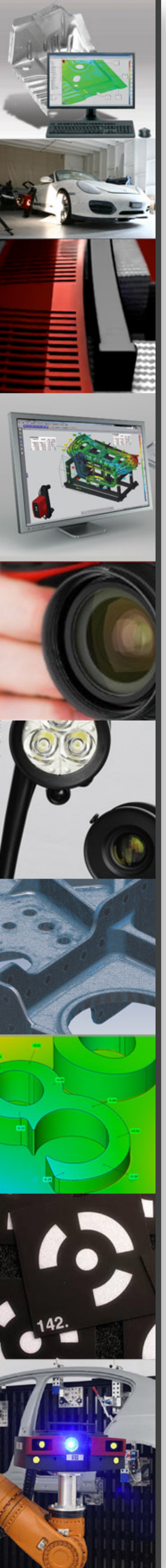


Material Testing / Material Properties

Determination of Process Limitations in Sheet Metal Forming - Forming Limit Diagram

Forming Limit Diagram

The Forming Limit Diagram (FLD) together with the Forming Limit Curve (FLC) provide a method for determining process limitations in sheet metal forming and are used to assess the stamping characteristics of sheet metal materials. Usually, the Forming Limit Diagram is used in method planning, tool manufacturing and in tool shops to optimize stamping tools and their geometries. The comparison of deformations on stamped metal sheets with the FLD leads to a security estimation of the stamping process. The forming analysis and the comparison of the data with the FLC provide for a reliable assessment of sheet metal forming processes.

In case of problems with the stamping tools used, the sheet metal forming process can be optimized (e.g. board and tool geometries, blank holder pressure, lubrication, material) based on the ARGUS measurements (see also „Optimization of Metal Forming Tools by Forming Limit Analysis“).

An additional important field of application for FLDs are numerical simulations of transformation processes. The FLC of the material used represents characteristic material identification data for the forming simulations.

Normally, the material manufacturer determines the Forming Limit Curves according to the Nakajima or Marciniak tests. This way, the material quality can be clearly defined which helps the customer to choose the right material.

Determination of Forming Limit Diagrams According to Nakajima

The Nakajima test is a known method to determine the Forming Limit Curve of sheet metal materials.

The Nakajima test is based on the principle of deforming sheet metal blanks of different geometries using a hemispherical punch until fracture occurs (Fig. 1). By varying the specimen width (Fig. 2), different deep draw and stretch forming conditions occur on the sheet metal surface (from a regular biaxial deformation to a simple tensile load).

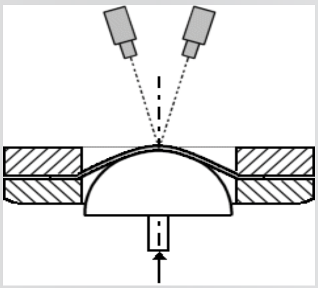
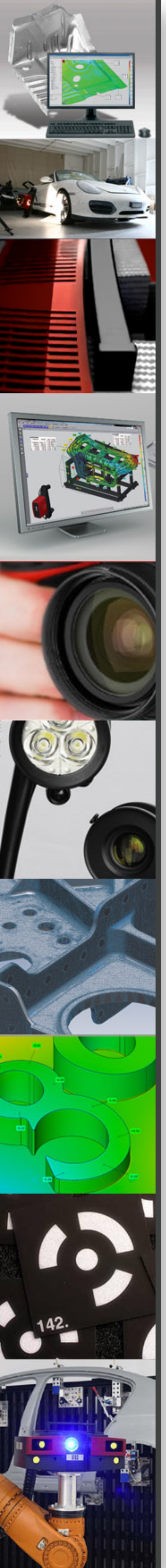


Fig. 1: Test arrangement

Fig. 2: Different specimen geometries, from the entire blank to strongly waisted blanks



The characteristic, maximally achievable deformations (prior to breakage) of the different specimen shapes are determined and define the forming limit curve of the corresponding material. So far, a forming limit curve was generally determined by applying a pattern of circles and lines to the sheet metal blanks prior to the forming process. Due to the load on the sheet metal, these circular marks deform to ellipses, the main axes of which represent the strain on the surface in major and minor direction. After the forming process, the "deformed" line patterns were measured manually using measuring magnifying glasses, microscopes and flexible measuring strips. This method is limited by the contour sharpness of the deformed pattern, the time-consuming evaluation, the low local resolution and the subjective and user-dependent recording of measurement values.

In order to meet today's requirements, the characteristics of sheet metal materials must be determined precisely, reproducibly and efficiently. By using the optical measurement system ARAMIS, the preparation of the specimens, the forming process and the determination of the deformation characteristics can easily and reproducibly be carried out such that today exact material characteristics are available at low costs.

When preparing the specimens, instead of the circular or line mesh, a stochastic pattern is applied to the surface using a color spray (Fig. 3). In addition, guidelines were prepared (acc. to ISO 12004 Recommendation) which guarantee a regular and reproducible load of the specimen.

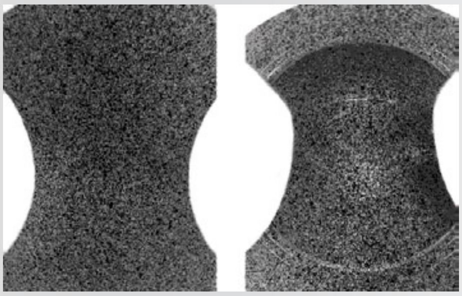


Fig. 3: Undeformed and deformed Nakajima specimens with stochastic pattern

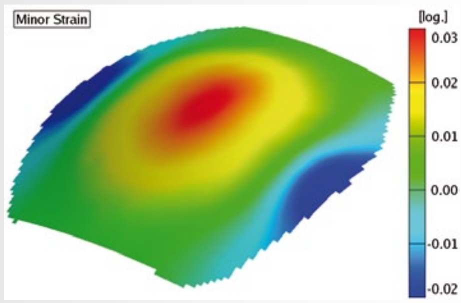


Fig. 4: Minor strain, punch dome area

Recording of the line mesh is replaced by the allocation of stochastic patterns. Thus, the number of measuring points is considerably increased. In addition, minor blurs and defects in the pattern are compensated such that numerous reliable measuring values are created.

ARAMIS automatically divides the reference image into small overlapping areas (squares or rectangles) and defines the corresponding area in the stereo image. Optimized calculation methods provide for assigning the corresponding area ultra-precisely (sub pixel range). By assigning all image details to the stereo image, the shape of the sheet metal in its reference state is measured based on the calibration data of the system. Now, the image details of the reference image can be allocated to the images of the recorded subsequent stereo image pairs. Thus, after the automatic evaluation, the shape and the deformation of the sheet metal was precisely recorded and measured for each recording moment.

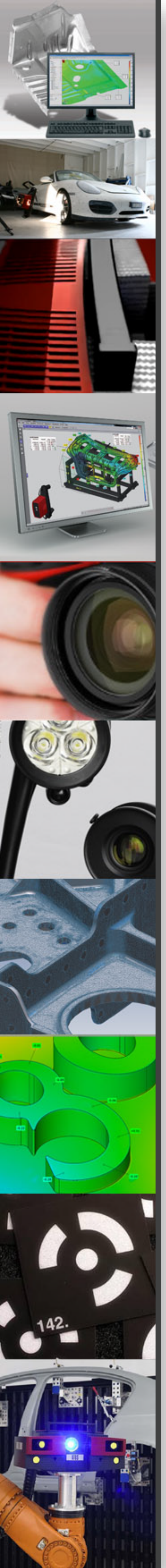


Fig. 5 shows typical setups to efficiently measure and define the Forming Limit Curve with ARAMIS installed above a sheet metal forming test machine.

Fig. 5: Measuring setups above different sheet metal forming test machines to determine Forming Limit Curves

While recording stereo image pairs during the deformation process, the progress of the deformation and the load can be captured and documented (Fig. 6).

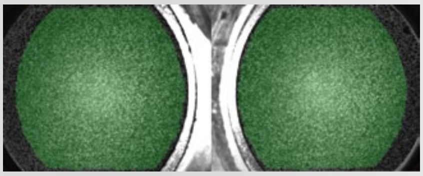


Fig. 6: Measuring image of the left and right camera: The evaluated area is marked in green (visible area of both cameras)

By recording and evaluating numerous images with the corresponding load parameters (force and deviation) during the forming process, the complete deformation behaviour of the specimen up to its fracture can be captured, examined and exported as data set for subsequent evaluations. The animated illustration in Fig. 7 shows the current shape of the sheet metal for each recorded image and the local deformation of the sheet metal under load.

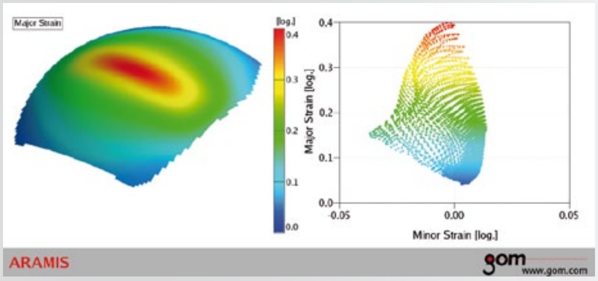
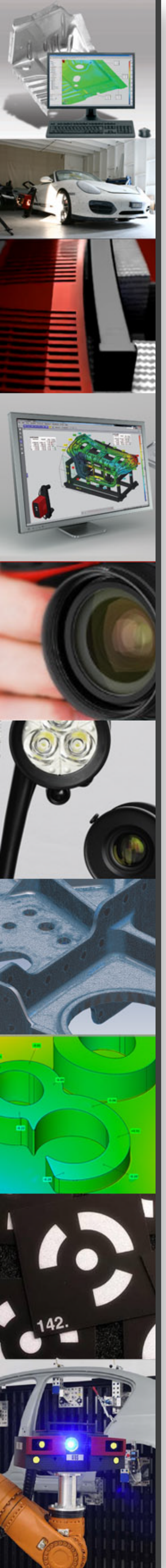


Fig. 7: Deformation of the sheet metal specimen with the current major strain (color representation, measured by ALCAN)



For a fast calculation of the points on the Forming Limit Curve sometimes only the reference image pair before applying the load and the last image pair directly before the fracture occurs are evaluated. This guarantees that heavily loaded areas are captured and included into the FLC determination.

In the ARAMIS software, sections are defined perpendicular to the break line to calculate the FLC data. From this section data (normally five parallel sections), an FLC point with its measuring deviation is calculated automatically according to the currently valid guidelines. For customized FLC calculations, this section data can be exported and processed using proprietary evaluation algorithms.

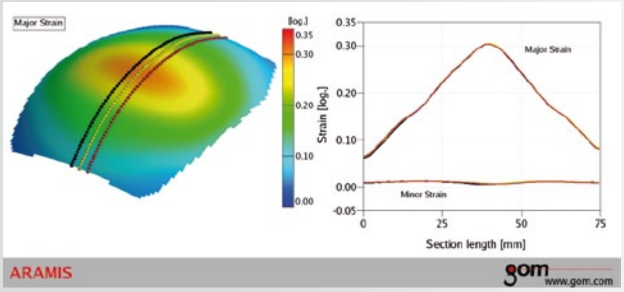


Fig. 8: Sections with respective section data. The diagram shows the major and the minor strain over the section length

The measuring values are shown as 3D section graphics (Fig. 8) and in a Forming Limit Diagram (Fig. 9). ARAMIS calculates the characteristic values (theoretical maximum of major and minor strain) by the computation of an ideal shape of the curve from the captured measuring values. Fig. 9 shows the measuring results of 8 different sheet metal geometries. Of each geometry, the deformations at material failure were evaluated for 3 specimens each with 3 sections and displayed in the FLD diagram.

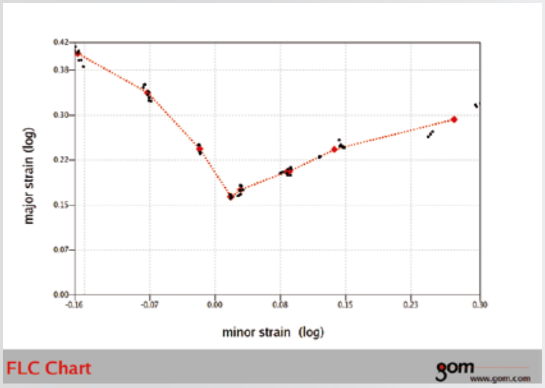


Fig. 9: FLC of a 1 mm thick steel sheet metal

The measuring points (major and minor strain) averaged from the different specimen geometries are now connected and thus allow for designing the Forming Limit Diagram of the currently tested material.
Using ARAMIS, deformations and strain can easily and precisely be measured. Installing the system above a test machine provides for efficiently and reproducibly capture Forming Limit Diagrams.

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