

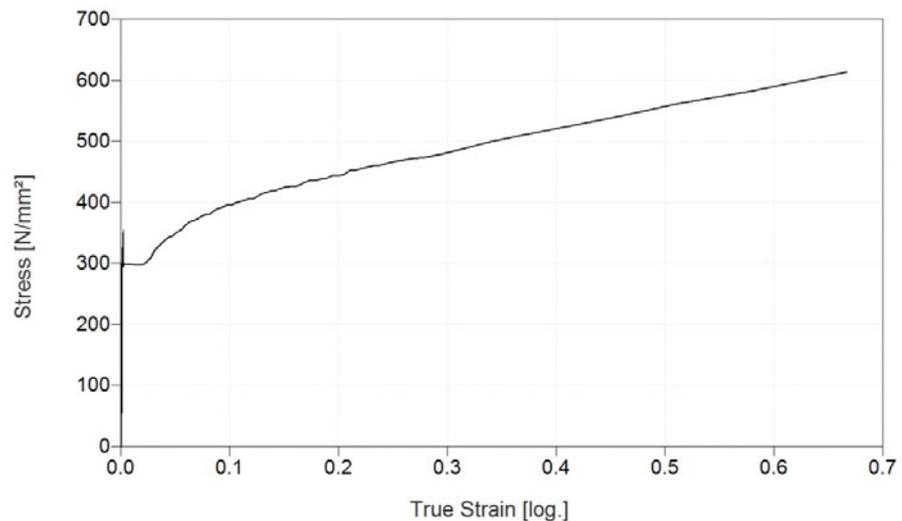
## Application Example: Material Testing

### Material Properties: Improved Determination of Yield Stress for Sheet Metal Materials

Measuring Systems: ARAMIS

Keywords: True stress, true strain

The material characteristics of sheet metal material to be used, for example in the design of a new car, have to be determined and specified precisely and reproducibly in a test laboratory. An important magnitude to describe the material behaviour during the forming process and in case of a crash is the yield stress.



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## Material Testing / Material Properties

### Improved Determination of Yield Stress for Sheet Metal Materials

The design of a new car and the manufacturing of the individual sheet metal parts are calculated and optimized with the help of simulations long before production starts. Variant types are calculated, their characteristics are compared and optimized for manufacturing the car as cost-effectively as possible in an easy and reliable way. Only then the forming tools will be produced to manufacture the first prototypes.

For an exact simulation of the forming process, the material characteristics and values need to be known precisely. If the characteristic values are wrong, poor forming tools will be designed during the simulation. This results in the fact that the desired shape will not be achieved when forming the sheet metal. In addition, the forming limits of the material might be exceeded at critical points which may cause local neckings or cracks in the sheet metal and require expensive recasting of the deep-drawing dies. Therefore, the material characteristics of the sheet metal material to be used have to be determined and specified precisely and reproducibly in a test laboratory.

An important magnitude to describe the material behavior during the forming process and in case of a crash is the yield stress which indicates at what point the material passes from the elastic state to the stage of plasticity and deforms permanently.

#### Determining the Yield Stress During a Tensile Test

The tensile test specified in DIN EN 10002-1 determines the material characteristics using a strongly defined specimen geometry and very tight test parameters. During the test, the active force, the strain and the cross-section are measured continuously. The strain is integrated via the measuring length of the strain gauge (usually 50 or 80 mm).

The specific stress corresponds to the active force divided by the cross-section of the specimen in the measuring range. The change in the cross-section during the test is calculated from the longitudinal strain of the specimen (constant volume  $A_0 l_0 = A_n l_n$ ).

After reaching the uniform strain, the local necking of the specimen starts. Now, the determination of the specimen's cross-section becomes incorrect when using a conventional tactile strain gauge as the longitudinal change of the specimen is averaged over the entire measuring length. The strongly increased local strain values and their changes in space and time are therefore not captured with the standardized tensile test.

Using the ARAMIS system, however, provides for determining the local deformations in both surface directions for a defined surface and, based on the consistent volume, for calculating the thickness reduction as well. This gives additional information about the uniform and non-uniform distribution of the spacial and temporal deformations on the surface of the specimen. The necking area can be investigated in more detail and the local changes in the cross-section of the necking area and its environment can be determined.

In addition, Lüders bands occurring locally and their changes are measurable and graphically visualized during the tensile test.

Fig. 1 shows the "local" strain recorded with ARAMIS, in this case the major strain, together with the "global" measuring value of a tactile strain gauge for the same specimen. The local strain values are available for each point of the tested surface for the entire duration of the measurement.

Fig. 2 shows the global strain characteristic determined by a tactile strain gauge in the tensile test as a function of time. This strain characteristic is compared to the strain characteristic locally measured with ARAMIS in the necking area.

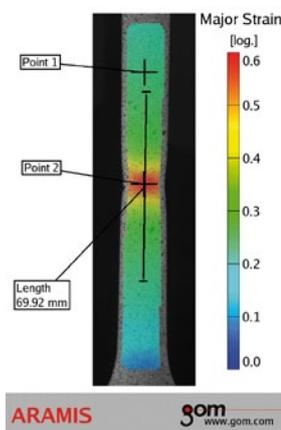


Fig. 1: Local measuring values with drawn in measuring length of common strain gauges

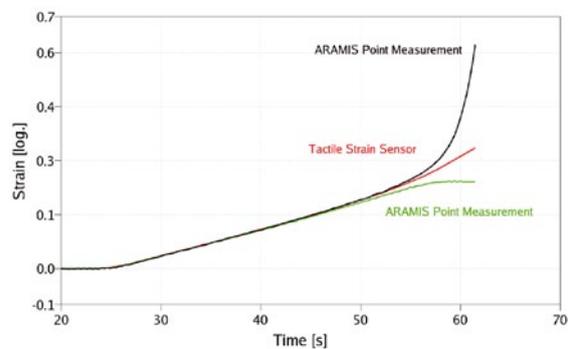


Fig. 2: Local ARAMIS measuring values in the necking area and far away from the necking compared to "averaged" tactile measuring values

For small deformations, the measuring values match well. Just before breaking, the local strain in the necking area (ARAMIS measuring values, black line) deviates from the global value measured with the tactile strain gauge. As the strain gauge integrates the strain over its entire measuring length (red line) it cannot provide local peak values. As soon as the necking starts, the deformation of the specimen concentrates more and more in the necking area (black line). Areas far away from the necking deform less and less and just before breaking they no longer deform at all (green line).

In order to achieve a local measuring value (high measuring data density at short basic length), using the optical measuring system ARAMIS is recommended.

As shown in fig. 3, the ARAMIS system is positioned in front of a tensile test machine.

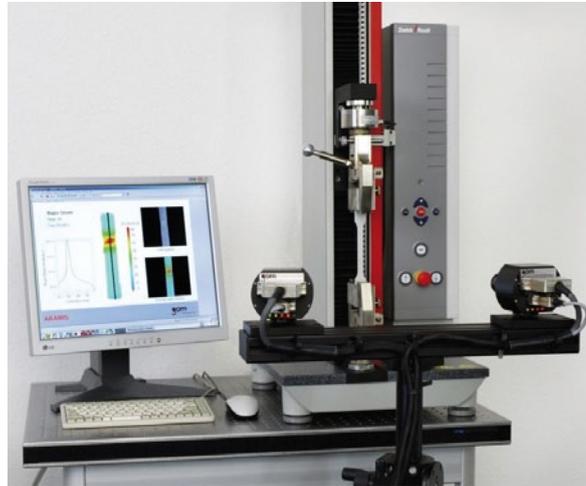


Fig. 3: Tensile test machine with ARAMIS system

The complete deformation behavior of the specimen can be captured and evaluated during the deformation process up to the moment of breaking by recording and evaluating numerous stereo image pairs (synchronous recording of both cameras) together with the corresponding load values (force).

The animations of figures 4 and 5 show the current shape of the specimen for each recorded image (stereo images).

Fig. 6 shows the local deformation of the specimen for all measuring points during the entire tensile test based on the image pairs evaluated with the ARAMIS system.

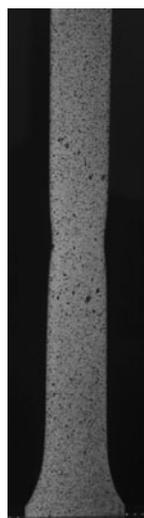


Fig. 4: Image of the left camera

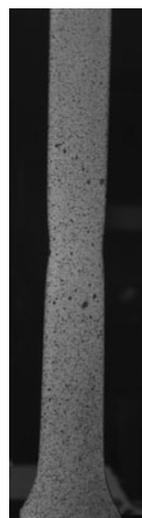


Fig. 5: Image of the right camera

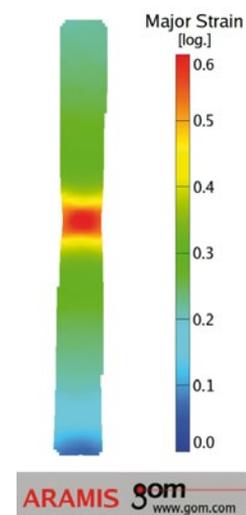
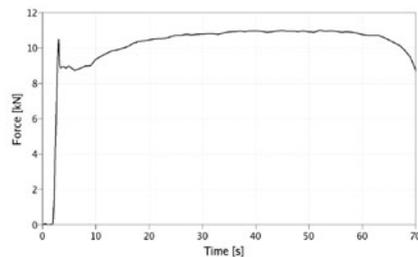


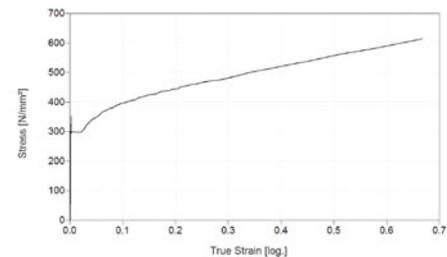
Fig. 6: Deformation of the tensile test specimen

Fig. 7 shows the course of the force during the test which the measuring system takes over from the tensile test machine and saves it.

From the temporal deformation and the force values recorded during the test, the "true stress" ( $\sigma$ ) is calculated with respect to the "true strain" ( $\epsilon$ ) and displayed (Fig. 8).



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Fig. 7: Force-time diagram

Fig. 8: True Strain - True Stress Diagram

### Determination of the Biaxial Yield Stress Using the Hydraulic Bulge Test

To determine the biaxial yield stress by means of the hydraulic bulge test, a sheet metal board is clamped between the blank holder and the stamper and is loaded with oil pressure. By continuously increasing the oil pressure, the specimen is further loaded biaxially and deformed until failure. The equation to determine the yield stress is based on the membrane theory and therefore is used preferably for a low sheet metal thickness.

Due to the biaxial state of stress, the material failure by local necking and following crack occurs considerably later with the bulge test than with the tensile test (uniaxial state of stress). The bulge test allows for determining the yield stress up to considerably higher forming degrees than with a conventional tensile test.

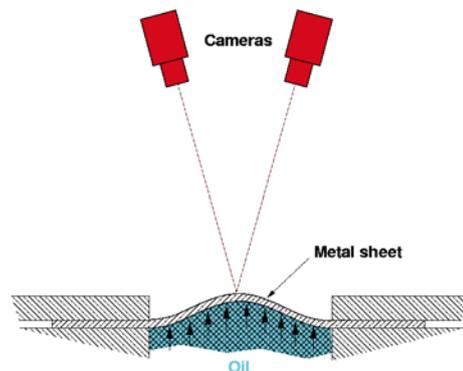


Fig. 9: Test setup



Fig. 10: Sensor setup at test machine (without protective cover)

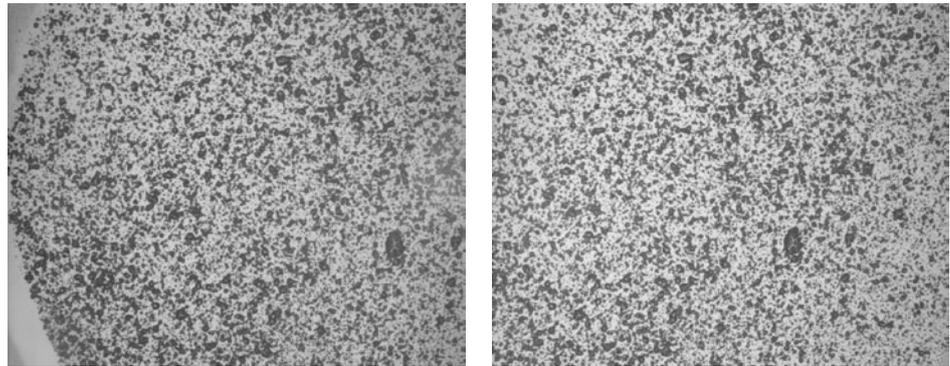


Fig. 11 and 12: Left and right camera image showing a representation of the stochastic pattern on the specimen

Thus, the ARAMIS system combined with a conventional sheet metal test machine is an excellent method to improve the determination of the yield stress for simulation calculations and other applications.

### Determination of the Deformation

To record the momentary deformation state of the sheet metal, a stochastic pattern is applied to the specimen prior to start the forming process, e.g. by means of a color spray.

Due to the synchronous recording with two cameras, stereo image pairs result (left and right image). By comparing the deformed pattern with the original pattern, the respective current deformation state can be determined. Such images are recorded for the entire image sequence from the beginning of the deformation up to the breaking and are then evaluated. ARAMIS can thus record and evaluate the complex deformation process of the specimen until it breaks.

In the bulge test, the effective material load (yield stress) is determined by the current shape of the specimen, the equivalent total strain at the top of the dome and the current oil pressure.

The animation in fig. 13 shows a film of the current shape of the sheet metal at each recorded image and the local deformation of the sheet metal under load. Fig. 14 shows the local thickness reduction calculated from the major and minor strain.

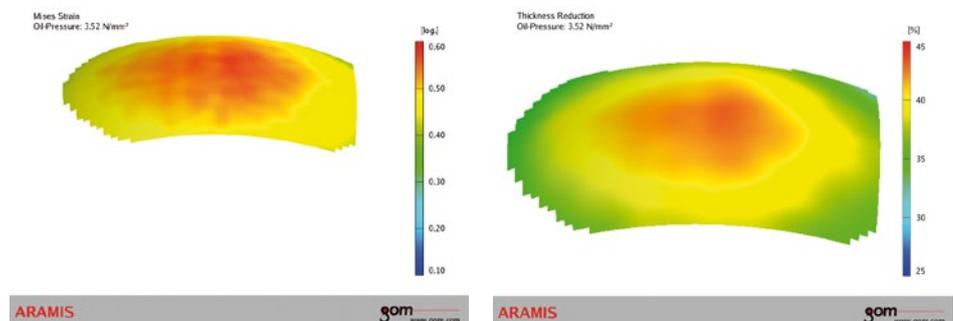


Fig. 13: Shape of the sheet metal specimen with visualization of the equivalent total strain acc. to von Mises.

Fig. 14: Thickness reduction (calculated from the local change of the pattern on the sheet metal surface)

The evaluation mode of the ARAMIS system provides for generating own films (e.g. as \*.avi file) from the image series which graphically document the course of the deformation in detail including the corresponding measuring values and material characteristics (acc. to fig. 13 and 14).

The flow curve is calculated from the oil pressure, the local shape (curvature) and the current thickness of the sheet metal at the top of the dome of the specimen (fig. 15).

In addition to determine biaxial flow curves, ARAMIS also provides for determining Forming Limit Curves (FLCs) easily and without any problems by using the same measuring setup. In this case, the specimen generally is not formed by means of hydraulic oil but by a mechanical stamp which makes it even easier to carry out the test.

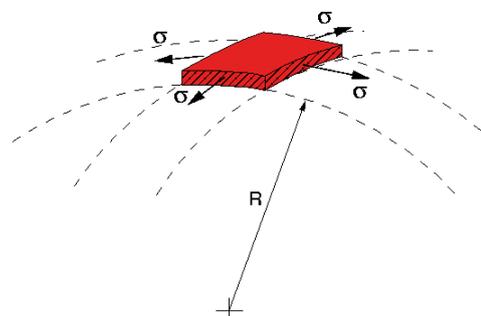


Fig. 15: Schematic representation to calculate the local biaxial yield stress

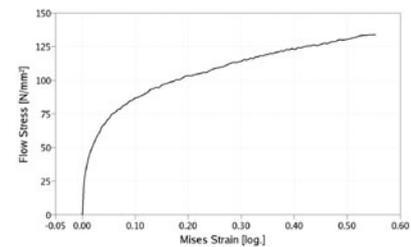


Fig. 16: Biaxial flow curve

In both applications, ARAMIS allows high-resolution, easy and precise recording and evaluation of deformation tests. The measuring data is graphically displayed and converted to current material characteristics. In addition, local effects are captured and represented thus allowing for a complete understanding of the local material behavior during the forming process.

The determined local characteristic values now allow for precisely calculating in advance the material behavior during the forming process such that optimum tool shapes can be generated with the simulation. In addition, the newly determined characteristic values allow a precise forecast on the crash behavior of the formed sheet metals and structures.

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