

Investigations on Aluminium Alloys with a 3D-ESPI-System

Introduction

Aluminium as a construction material gains increasing interest. Therefore, better knowledge about material properties is required. The standard point by point measuring techniques typically show strong integration effects and are, therefore, not suited for investigations in non linear or plastic conditions. A new 3D-ESPI-system offers the possibility of obtaining full-field and non-contact analysis in two or three directions without marking.

Full field measurement

Quantitative data analysis is carried out by the easy to use Windows 95-software. The system provides a measuring sensitivity between 30 nm and 100 nm, depending on its configuration. The inspection area can be chosen with a standard zoom lens and macro adaptors between 0.2" x 0.3" up to 8" x 12" (extension modules for areas up to 3ft x 4ft are also available). With these capabilities the 3D-ESPI-system can be used for quantitative strain analysis.

Fig. 1: 3D-ESPI-system in tensile testing machine. The background picture shows the measured strain distribution of the specimen around the hole.



Compact 3D-ESPI-system

The 3D-ESPI-system uses the measuring principle of speckle interferometry for in-plane and out-of plane measurement as described in references, [1], [2]. The complete system consists of a miniaturized electro-optical sensor head and a ruggedized industrial control and analysis electronic system. The sensor head contains a high resolution CCD-camera and a total of four full field laser illumination systems. The four illumination systems are combined to produce two in-plane and one out-of-plane measuring direction. The sensor's small size and light weight guarantees easy portability and set-up in front of the components or attached to tensile testing machines, fig. 1.

The measuring results can be presented in different plots, such as colour graphic, 3D-representation, profiles, etc. Interfaces to standard software packages make postprocessing easy and allow combination of different calculation and testing results. While the system can be used for tests on any material, [3], in the following examples some applications on aluminium are described.

Analysis of aluminium samples

Samples of three different alloys of aluminium were tested with the 3D-ESPI system. The samples were loaded in steps. At each load step the deformation in x- and y-direction was recorded and stored automatically by the 3D-ESPI system. The x-coordinate follows the longitudinal and force direction of the sample. Then each measuring step was automatically analyzed by the ISTR software. For each step, the deformation fields in x- and y-directions as well as the strain fields $\Delta \varepsilon_{xx}$ and $\Delta \varepsilon_{yy}$ are achieved. The mean strain value in longitudinal and transverse direction was calculated at each measuring step by averaging the strain field data, fig. 2.

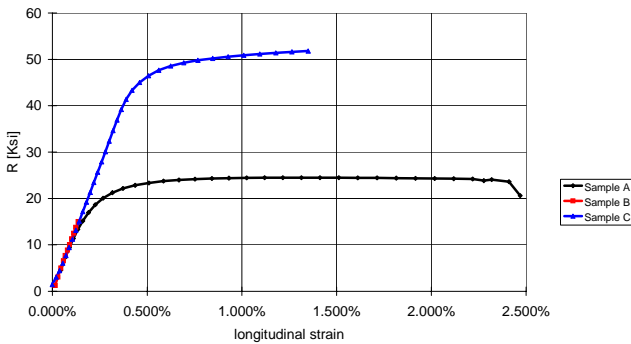


Fig. 2: Strain-stress curve for 3 different samples.

Calculation of E-Modulus and Poisson's ratio

The stress depending Poisson's ratio was defined as the ratio of the transverse strain to the longitudinal strain. In the elastic range, the Poisson's ratio is calculated as the ratio of the slope of the transverse strain and the longitudinal strain, fig. 3. The E-Modulus is calculated as the slope of the stress-strain curve, fig. 4. While this information could also be achieved by classical 2-point measuring techniques, the following results require full field measurement.

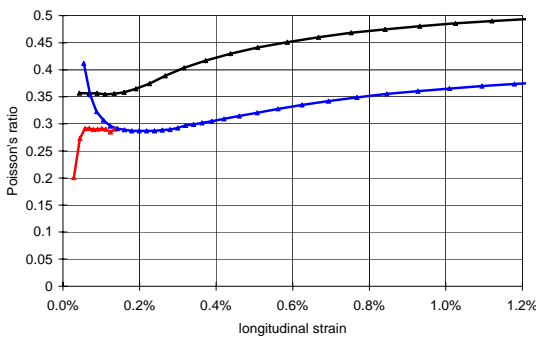


Fig. 3: Poisson's ratio of the samples in relation to longitudinal strain

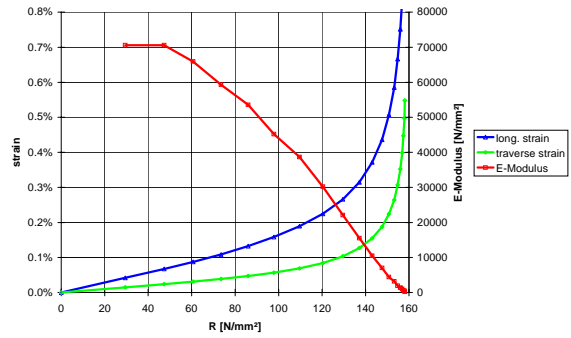


Fig. 4: Longitudinal strain, transverse strain, E-Modulus as a function of stress for sample A.

Visualize plastification zones

The measurement of sample A shortly before fracture shows clear indications of local strain concentrations at the position of the later fracture, fig. 5. In the top images the primary measuring results of the 3D-ESPI in x- and y-direction are shown. The so called phase maps visualize the deformation in x- and y-direction as fringes. The deformation fields are obtained by evaluation and quantification of these phase maps (lower images). From the deformation fields, the strain fields can be calculated (bottom). The images can be interpreted as colour representation of up to 10.000 strain gauges values and are similar to Finite Element images. The colours represent the strain amplitudes.

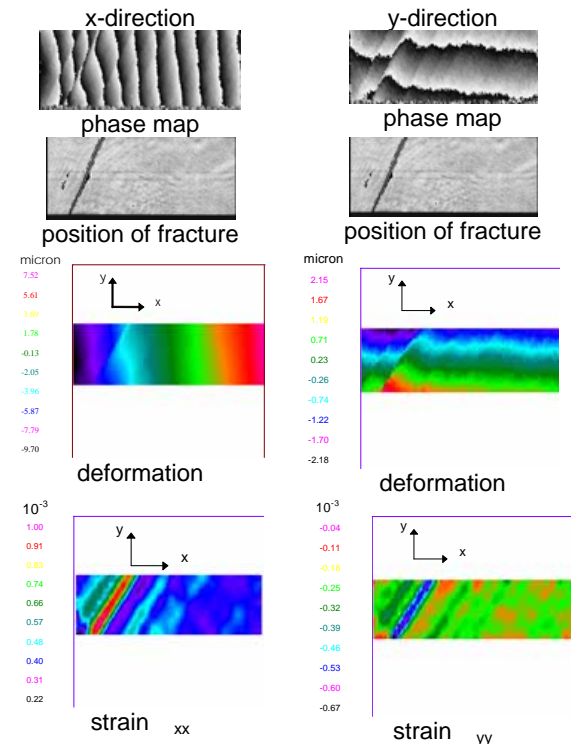


Fig. 5: Deformation and strain fields of sample A before fracture. The phase maps (top) show clearly the position of the later fracture. It shows up as well in the evaluated deformation and strain fields for each coordinate direction.

Analysis of shear bands

The material properties of aluminium for deep-drawing process require better understanding of the effects at plastification. Fig. 6 shows the longitudinal strain distribution of a sample around a shear band. The local strain concentration can clearly be seen. The so called "orange peel" effect results from such local plastifications, which show additional out-of-plane strains. The out-of-plane deformation of the same shearband is shown in fig. 7.

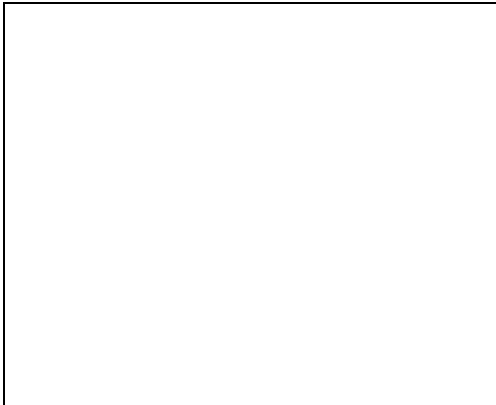


Fig. 6: Longitudinal strain concentration at a shear band

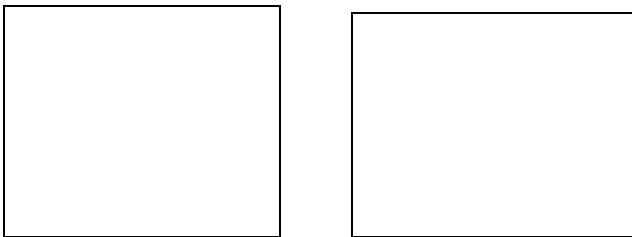


Fig. 7: Out-of-plane deformation of the same sample

Strain field at notched specimen

The plastic behaviour of aluminium can be tested by measurements on notched specimen. The 3D-ESPI system shows the strain distribution on the sample at any load step without preparation of the sample, fig. 8. Therefore it is possible to determine the plastic zones in relation to the nominal stress.

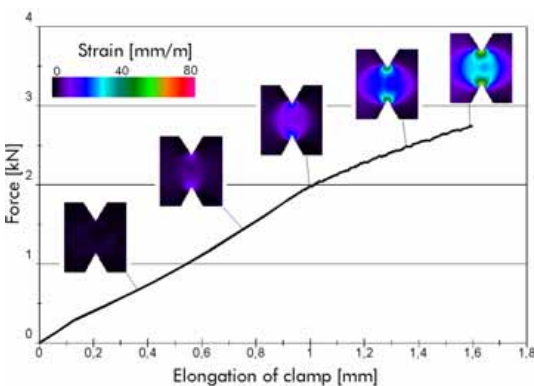


Fig. 8: Strain distribution at different load levels on a notched aluminium sample

Local strain concentrations move

In case of a notched specimen, local shear bands can be observed between the two notches, fig. 9. The shear bands appear at different locations between the notches, but always start at the notches. These local effects equalize, when the sample is strained over a big range. Therefore, the total strain distribution shows only the integral strain field with concentrations at the notches, fig. 10.

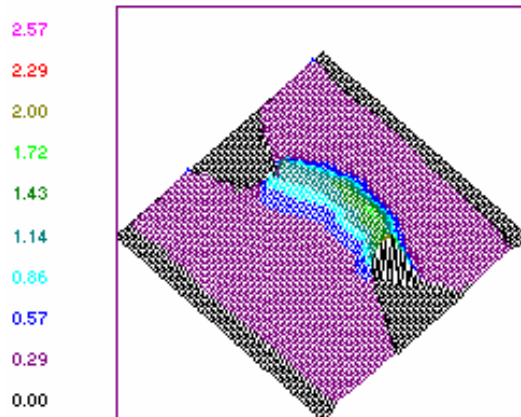


Fig. 9: Local shear band between two notches. These effects can be seen at different positions during the loading cycle. Values in mm/m

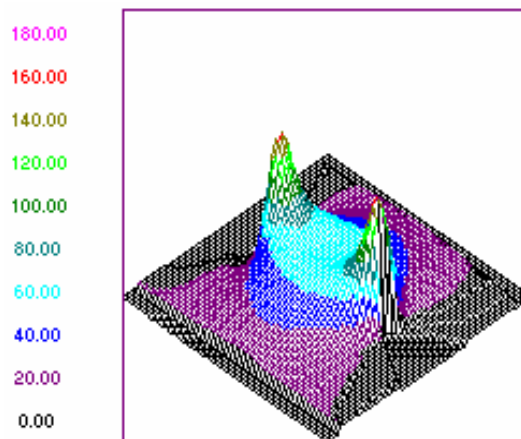


Fig. 10: Strain field at a notched aluminium tensile sample. Values in mm/m

Applications of 3D-ESPI in material testing of aluminium have just begun. Recent developments now offer simplified applications of the 3D-ESPI-system in tensile testing machines on aluminium samples. Since the use of aluminium in automotive industries is increasing, the demand for better material characterization is rising. Therefore, the use of a full-field and non-contact strain measuring system will support this demand.

References:

- [1] R. Jones and C. Wykes, Holographic and speckle interferometry, 2nd edition, Cambridge University Press, Cambridge 1989
- [2] A. Ettemeyer, Non contact and whole field strain analysis with a laser optical strain sensor, VIII International Congress on Experimental Mechanics, June, 10-13, 1996, Nashville, Tennessee
- [3] A. Ettemeyer, Z. Wang, T. Walz, Applications of speckle interferometry to material testing, presentation at KSME conference, Nov., 1st, 1996, Seoul, Korea

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