Strain Analysis on a T-branch Pipe Connection with 3D-ESPI and FEA

Introduction

Speckle interferometric techniques (ESPI) offer theoretically good opportunities to validate Finite Element Analysis (FEA). The practical approach is typically limited to the comparison of displacement values. In this paper the analysis of a triform T-branch will be shown and the comparison of the simulated strain values will be compared with data, obtained from quantitative 3D-ESPI-measurement.

Triform T-branch test specimen

Fig. 1 shows a principal draft of the object to be analysed and the measuring field, where the data of FEA and 3D-ESPI were compared. The dimension of both steel tubes is ∅ 274x15 mm, the thickness of the stiffening plate 20.3 mm. The pipe was internally pressurized with a pressure difference of 37.5bar.

FE simulation

The FE model is shown in fig. 2. It was made using ANSYS 5.3 and consists of eight-node shell elements, type SHELL93. Symmetry is used in order to decrease the size of the model. Boundary conditions due to symmetry of the triform T-branch are applied at all symmetry planes.

3D-ESPI-measurement: The measurement was carried out with a 3D-ESPI-system, which was directly attached to the T-branch. The 3D-ESPI-system consists of a miniaturized optical sensor head, fig. 3, with integrated diode lasers and high resolution CCD-camera. The system provides four full field laser illuminations from different angles which - together with the central CCD-camera - produce total three measuring directions. The camera records the image of the inspected area at each load step. The recorded images are compared in an image processing computer (PC-based).

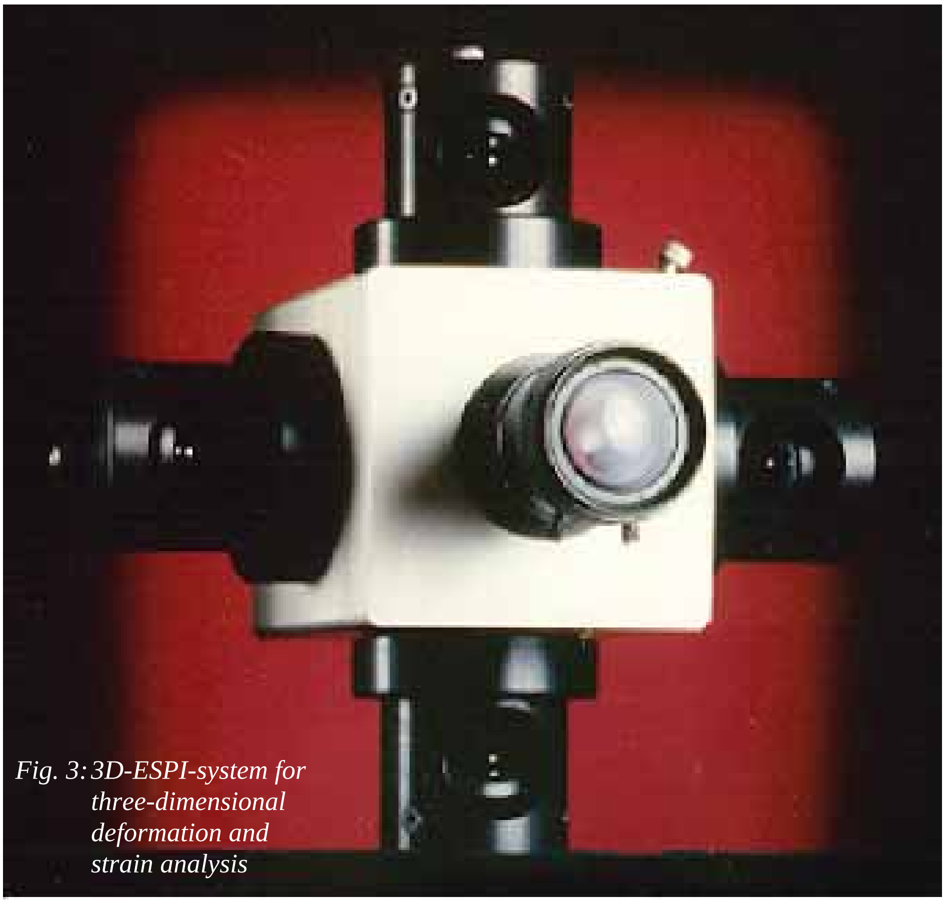

Fig. 3: 3D-ESPI-system for three-dimensional deformation and strain analysis

The comparison shows the quantitative amplitude of displacement of each object point in the observed area with respect to the camera. The measuring sensitivity of the 3D-ESPI-system is between 0.03 µm and 0.2 µm in the out-of-plane and the in-plane measuring direction, [1], [2]. The dimension of the measured area was 4.7" x 3.1".
In order to avoid relative movement between pipe and sensor the sensor was directly clamped to the pipe.

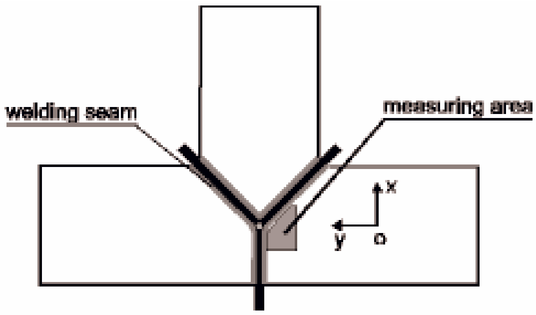

Fig. 1: Triform T-branch and measuring area

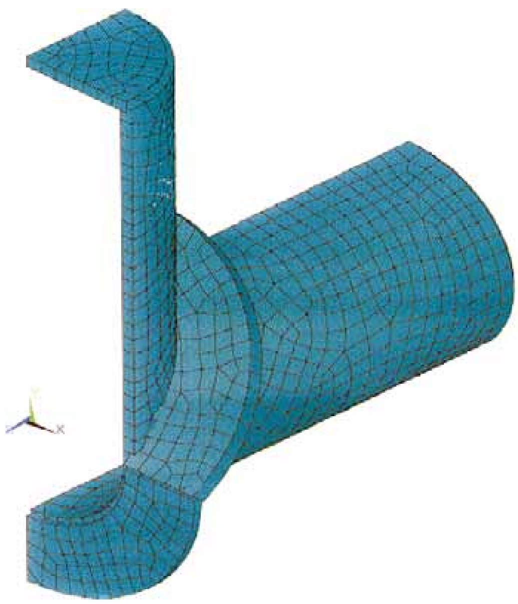

Fig. 2: FE model for simulation of triform T-branch

Quantitative analysis of ESPI-data

The 3D-ESPI system at first provides deformation data in the x-, y- and z-coordinates of the sensor head. In order to achieve quantitative surface strain values from the 3D-displacement values the object geometry has to be known. As the object is a cylinder in the observed area, the geometry could easily be introduced into the calculation program. Then the deformation data were transformed to the object's coordinate system. In the present case, a cylindrical coordinate system was chosen with a circumferential direction, an axial direction (according to y-direction of sensor) and a normal direction of the main pipe, fig. 4. Fig. 5 shows the circumferential component of the transformed 3D-deformation field as measured with the 3D-ESPI system.

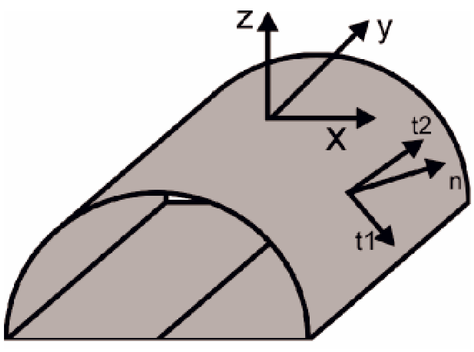

Fig. 4: Coordinate system for strain calculation

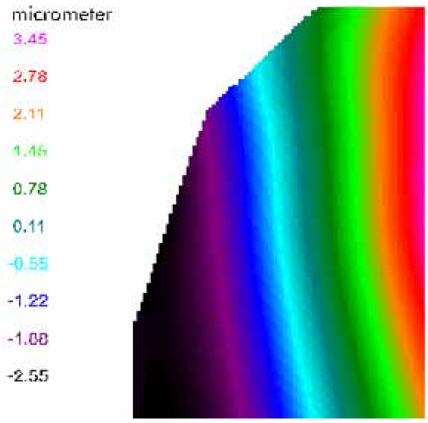

Fig. 5: Measured deformation field in circumferential direction (pressure difference 40 to 2.5 bar)

Quantitative strain analysis

The strain fields in circumferential and axial direction were calculated by numerical differentiation of the deformation vectors in both directions. As the numerical differentiation of measured data often produces some accuracy problem a special filter procedure has been used to obtain the correct values. A quadratic best fit approximation was carried out for small rectangular areas of the data field. This algorithm proved to be very effective without reducing the maximum strain peaks too much. Fig. 6 shows the circumferential strain field as determined with the 3D-ESPI system.

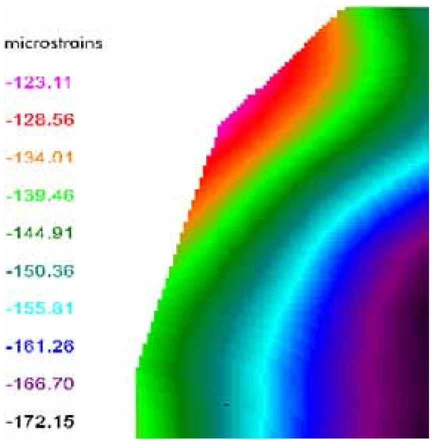

Fig. 6: Circumferential strain field as measured with the 3D-ESPI system (pressure difference 40 to 2.5 bar)

In comparison fig. 7 gives the same presentation for nearly the same measuring field. The data are inversed, because in FE-calculation a pressure increase was assumed, while the 3D-ESPI-measurements were carried out with decreasing pressure. The maximum strain amplitude is 158 microstrains in the FE-simulation, while the 3D-ESPI result shows -172 microstrains.

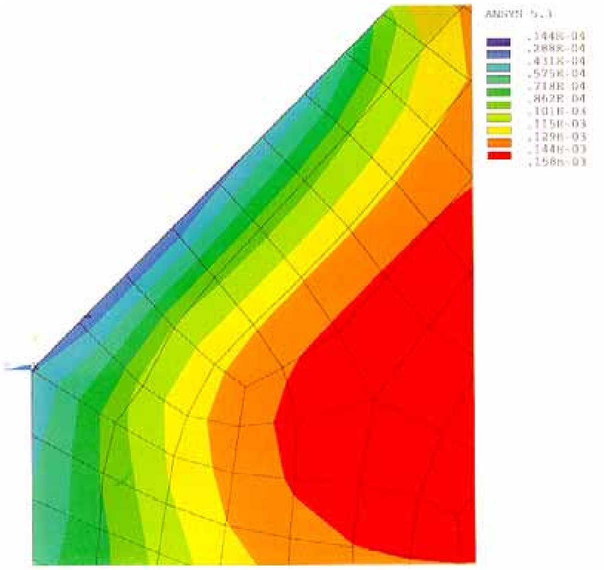

Fig. 7: Circumferential strain field as computed with FE simulation (pressure difference 2.5 to 40 bar)

Strain gauge comparison

At certain positions, the strain field was additionally measured with strain gauges, fig. 8. The comparison is carried out at a center line through the measuring area and shows good agreement between the ESPI measurement and the strain gauge results.

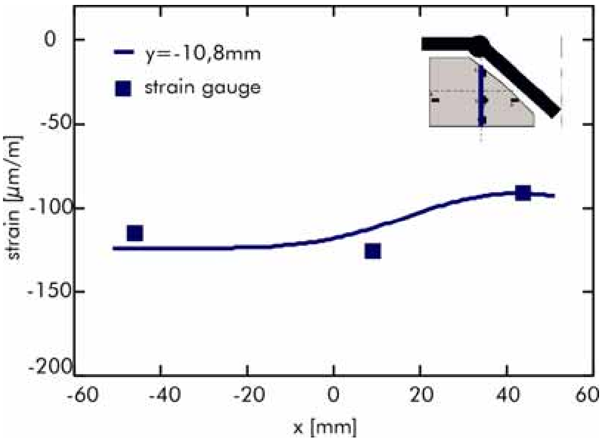

Fig. 8: Circumferential strain values measured with strain gauges and with 3D-ESPI at the indicated line.

Outlook

The quantitative analysis of strain fields with 3D-ESPI proves to be efficient not only on flat specimen, but also on components. Recent improvements at numerical strain calculation and geometry considerations make 3D-ESPI a versatile engineering tool for stress/strain analysis. The full field measurement with 3D-ESPI gives very similar presentations of deformation and strain results as the Finite Element calculation. Therefore, 3D-ESPI can be used with advantage for verification of FEA results.

References:

[1] A. Ettemeyer, Non contact and whole field strain analysis with a laseroptical strain sensor, VIII International Congress on Experimental Mechanics, June, 10-13, 1996, Nashville, Tennessee

[2] A. Ettemeyer, Z. Wang, T. Walz, Applications of speckle interferometry to material testing, presentation at KSME conference, Nov., 1st, 1996, Seoul, Korea

For more information please contact:

Dantec Dynamics GmbH
Kaessbohrerstrasse 18
89077 Ulm
Germany

Tel.: +49-731-933-2200
Fax: +49-731-933-2299

E-mail: product.support@dantecdynamics.com
Internet: www.dantecdynamics.com

Partners for progress