Deformation and Strain Field Analysis on Spot Welded Joints with 3D-Speckle-Measuring Techniques

Introduction

Spot welding is used primarily in mass production of thin sheet metal structures, e.g. automobile bodies. In order to calculate fatigue life of spot welded joints, strain and stress distribution at the spot is required. Advanced Finite Element Analysis (FEA) of such designs enables the determination of deformation, strain and stress distribution at the spot weld and the resulting forces and moments. In turn fatigue calculations are easily obtained [1].

In the frame work of a research project, presented by the Forschungsvereinigung Automobiltechnik e.V. (Society for Research on Automobile Technique) new measuring techniques have been developed [2].There, new approaches using strain gauges and optical measuring techniques have produced surprising results.

Strain gauge technique

The experimental determination of the local loads at the spot weld requires measuring techniques for fast and accurate strain analysis from a single of the component. The application of traditional strain gauge techniques allows only in unique cases the determination of strain and stress distribution and the forces at the spot weld.

ESPI-Measurement

Electronic Speckle Pattern Interferometry (ESPI) allows full field, non-contact and highly sensitive measurement of deformations of components [3]. This is an entirely new solution for the determination of the deformation and strain field at spot welds. The applicability of the ESPI technique at the spot weld was accomplished with a miniaturized 3D-ESPI system, fig. 1.

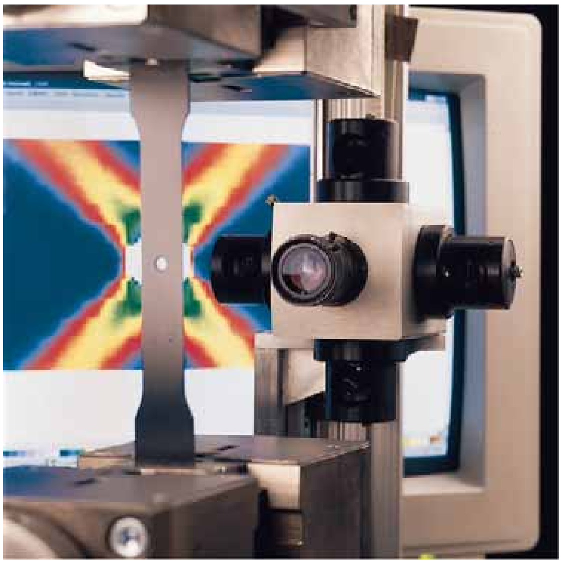

Fig. 1: 3D-ESPI-system for deformation and strain analysis in a tensile testing machine. The figure shows the strain distribution on a tensile specimen with central hole.

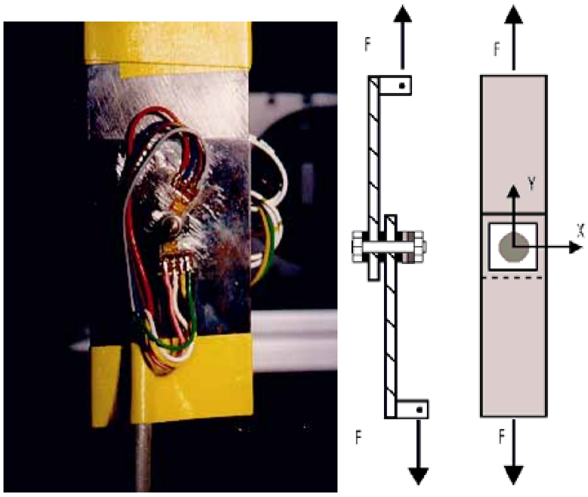

Fig. 3: View of a shear tensile specimen with simulated spot weld. The drawing shows the coordinate system and the measuring field for a specimen with 9 mm cross bar similar to a bolt or rivet.

Measurement on shear tensile specimens

A shear tensile specimen was loaded axially with both, force and moment, fig. 2. This shear tensile specimen is formed by two overlapping sheets which are connected by a spot weld. In order to eliminate influences of variations in processing of the joint the spot weld was simulated by a screwed joint, fig. 3. Additionally, strain gauges were installed for direct measurement of the strains around the spot weld. The measured strains were then compared with the results of the laser speckle measurements.

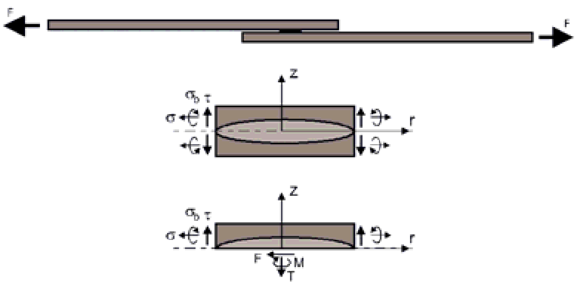

Fig. 2: Structure of a shear tensile specimen

In the following example, a series of measurement on a shear tensile specimen is presented. The tensile load ranged between 60 N and 400 N over a cross bar of 9 mm length.

Measurement of deformation fields

The measuring field was determined in the overlap area of the specimen. Its dimensions are 16 x 24 mm^2 (0,65" x 1"). Fig. 4 shows the resulting relative deformations in the x-, y- and z-coordinate directions, as measured with the ESPI system. The rigid body displacement has been subtracted from the total displacements.

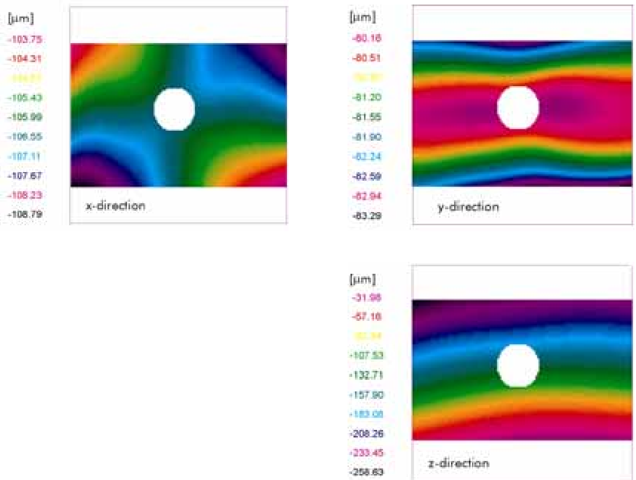

Fig. 4: Deformation components of the shear tensile specimen with 9 mm crossbar

Strain calculation

The strain components can be calculated from the complete three dimensional deformation field according to the standard mechanical equations (plane stress model):

$$\varepsilon_x = \frac{\partial u}{\partial x}, \qquad \varepsilon_y = \frac{\partial v}{\partial y}, \qquad \gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}$$

The flexible components are calculated as:

$$\varepsilon_{xb} = -\frac{t}{2}\frac{\partial^2 w}{\partial x^2}, \qquad \varepsilon_{yb} = -\frac{t}{2}\frac{\partial^2 w}{\partial y^2}$$

$$\gamma_{xyb} = -t\frac{\partial^2 w}{\partial x \partial y}$$

The results of the strain calculations are presented in fig. 5 for the tensile component and in fig. 6 for the flexible component.

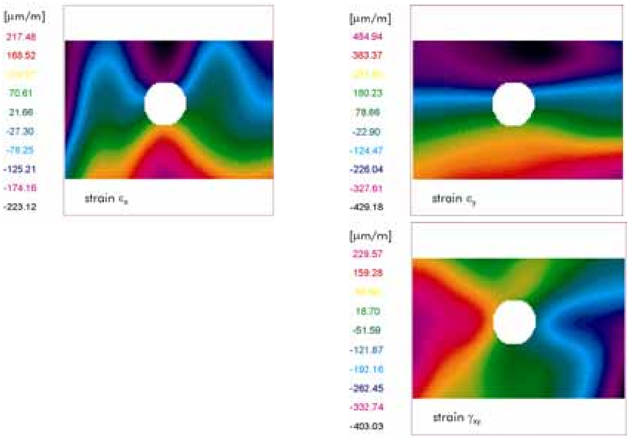

Fig. 5: Strains ε_y, ε_y and shear strain γ_{xy}

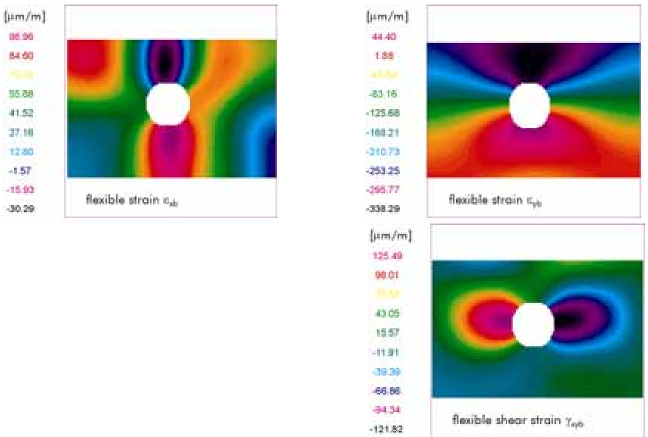

Fig. 6: Flexible strains ε_{xb}, ε_{yb},, γ_{xyb}

Verification of the results

The strain values were transformed into its tangential and radial components and compared with strain gauge measurements and FEA results. Fig. 7 shows the radial strains at a radial distance of 5,6 mm from the spot weld and fig. 8 the tangential strains at a distance of 4,3 mm from the spot weld. The results of the ESPI measurement, the strain gauge measurement and the FEA compare favourably, especially in tangential direction. In the radial direction the high strain gradients lead to greater deviations.

By comparison, fig. 9 and fig. 10 show the results of a measuring series, which were obtained on a shear tensile specimen loaded on a 3 mm crossbar with forces between 50 N and 700 N. The results correspond very well to the experiment with the 9 mm shear tensile specimen. The reason for the larger radial strain amplitudes of the ESPI measurement in comparison with the strain gauge measurement and the FEA could not be determined and will be the subject of further investigations.

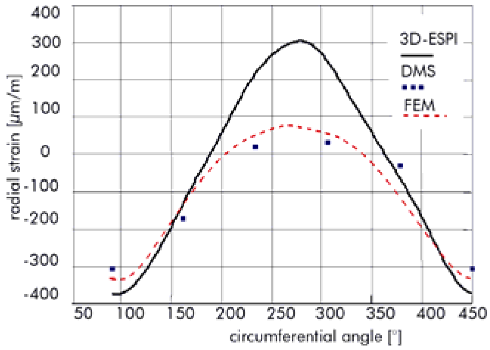

Fig. 7: Shear tensile specimen, cross bar 9 mm: radial strain at 5.6 mm distance, compared with strain gauge measurement and FEA

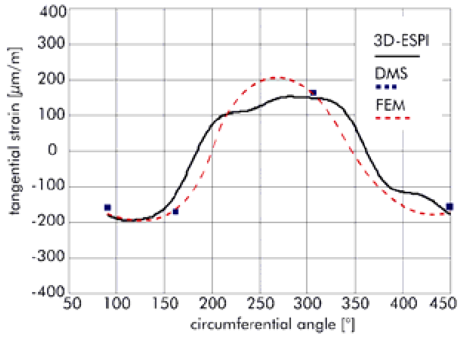

Fig. 8: Shear tensile specimen, cross bar 9 mm: tangential strain at 4.3 mm distance, comparison with strain gauge measurement and FEA

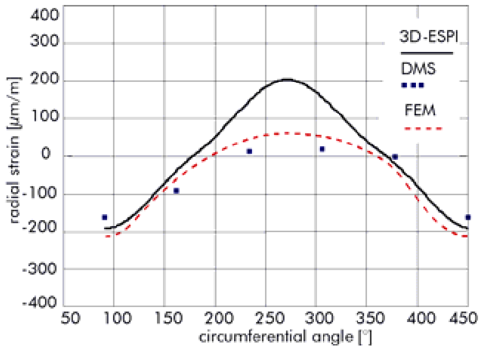

Fig. 9: Shear tensile specimen, cross bar 3 mm: radial strain at 5.6 mm distance, comparison with strain gauge measurement and FEA

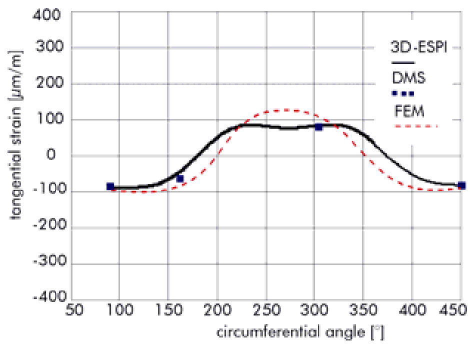

Fig. 10: Shear tensile specimen, cross bar 3 mm: tangential strain at 4.3 mm distance, comparison with strain gauge measurement and FEA

Summary

The use of the speckle measuring technique for investigations of the load on spot welds offers several positive features, especially:

The complete area around the spot weld is analyzed. Therefore, defective spot welds will be detected by disturbed strain fields.
The measurement can be carried out from just one side of the component. Nevertheless, flexible components can be identified.
The measurement is fast and does not require complicated preparation of the component.
The use of the miniaturized ESPI measuring system permits the use "in the plant", e.g on car bodies, etc..

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[2] Stoppler, W., A. de Boer, Messverfahren für Kräfte und Momente an strich- und punktgeschweißten Überlappverbindungen, Abschlußbericht der Forschungsvereinigung Automobiltechnik e.V., Schriftenreihe 134, 1997
[3] Ettemeyer, A., Miniaturized 3D-ESPI-Sensor for Material Testing, 1997 SEM Spring Conference, June, 02-04, 1997, Bellevue, Washington, USA

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