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Selected Engineering Applications of 3-D Strain Measurements using ESPI

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Abstract: The proposed paper shows the application of the Electronic Speckle Pattern Interferometry (ESPI) strain sensor (Q-100) for 3-D measuring contours of strains and stresses. The article focuses a solution of three selected engineering problems. Firstly, results of calibration verification of a biaxial extensometer used for measurements of shear strain in comparison with the ESPI method measurements are presented. The next task relates to the experimental analysis of stresses in welds. The last application shows the methodology of determining the Poisson ratio of the material from a tensile test. As discussed in the paper, this relatively new technique is very useful for measurements on structural parts in service, as well as for material testing.

Keywords: ESPI Method; Experimental Stress Analysis; Strain/stress Contours; Material Testing; Fillet Weld.

1 Introduction

The ability to determine the values of displacements, strains and stresses is fundamental for a successful strength analysis of structural elements. The analysis is usually performed by means of optical methods or strain gauge measurements. However, the optical methods are applied now more than ever before. One of these methods is the ESPI technique [1]. The Dantec Dynamics Q-100 measurement system uses the principle of electronic Speckle Pattern Interferometry in order to evaluate displacements and contours of a measured field with sub-micrometer accuracy [2]. In the case of an elastic isotropic material with known material properties, stress contours can be determined in the measured area as well [3]. This paper shows some interesting results of 3D strain/stress measurements by ESPI method using the commercial strain sensor Q-100 and presents the way of determining elastic material constants from a preliminary measurement too.

2 Verification of Biaxial Extensometer Calibration

The main goal of this idea was at comparing the results of ESPI measuring with the data gained by the extensometer EPSILON 3550 in order to verify the measurements of shear deformation. The probe was attached to the upper jaw with a simple jig allowing easy assembly and disassembly. The coordinate system was chosen so that the X axis of sensor corresponded to the transversal direction and the Y axis the longitudinal direction of the specimen. The same specimen as in the previous task was used. The calibration was performed only for the load step of 2 Nm. The test was carried out under gradual torsional loading with load step from 2 Nm up to 10 Nm.

The extensometer allowed the determination of the axial strain and the shear strain measured in degrees. These values were the average values for the length of 25 mm, which corresponded to the gauge length of

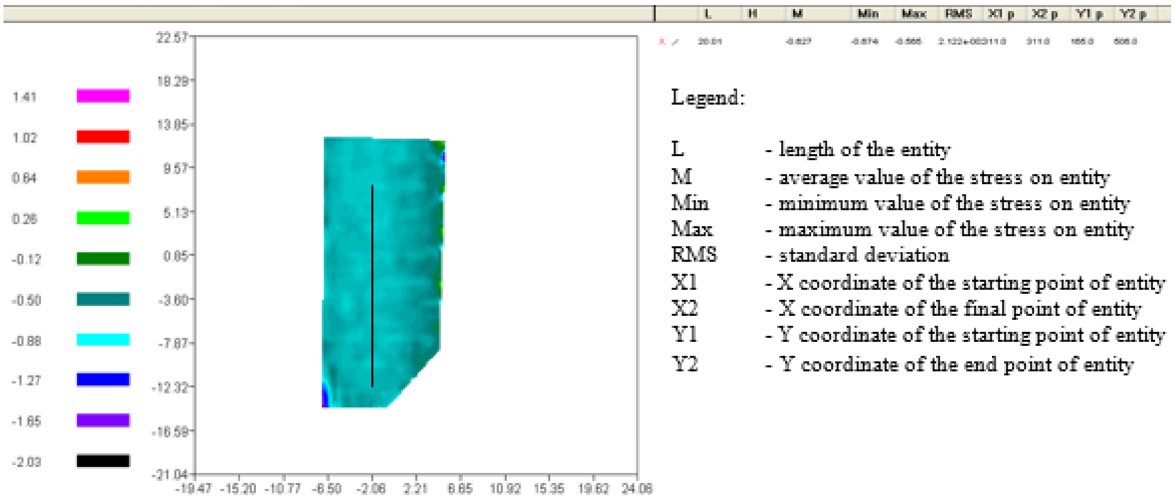


Fig. 1: Contours of shear strain and evaluation of calculated on line (ISTRA - Gauge module).

Tab. 1: Results of verification shear strain measurement.

Loadstep	Torque [Nm]	Shear strain extens. [-]	Shear strain by Q100 [-]	Diff. [%]
1	2.04	0.0001222	0.0001191	2.57
2	4.06	0.0002439	0.0002511	-2.85
3	5.97	0.0003583	0.0003689	-2.87
4	7.99	0.0004774	0.0005004	-4.60
5	10.03	0.0005987	0.0006274	-4.57

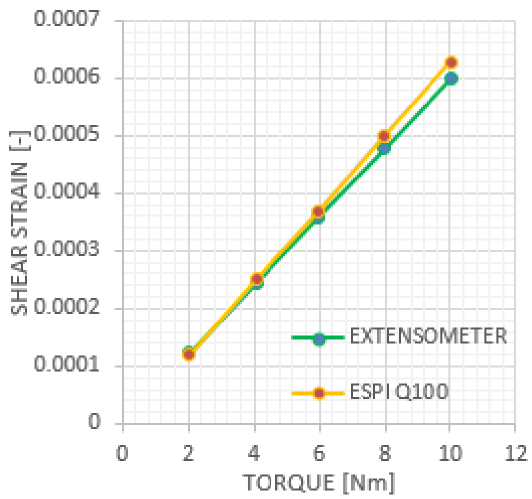


Fig. 2: Calibration curves from both methods.

the extensometer. When evaluating the ESPI measurements the first step was to find a line along which the individual variables are then averaged (Fig. 1). This line was located in points with the smallest values of Z coordinate, i.e. in points which were closest to the sensor, and its length was determined to be 20.01 mm.

Comparison of results of shear strain of both methods is done in the Tab. 1. In calculating relative deviations between the values measured by ESPI and results measured by extensometer the value of ESPI measurements was considered as a reference value.

3 Local Stresses in Welds

The application of the ESPI method is considered suitable in the case of welded structures, because the contours of required quantities can be solved on the actual structural part. This methodology seems to be much easier than the determination of similar quantities using FEM, for example. On the other hand, residual stresses, which play a significant role in welds, could be included in computational analysis. This is not possible in case of the ESPI measurement because of temperature limitations of the sensor head.

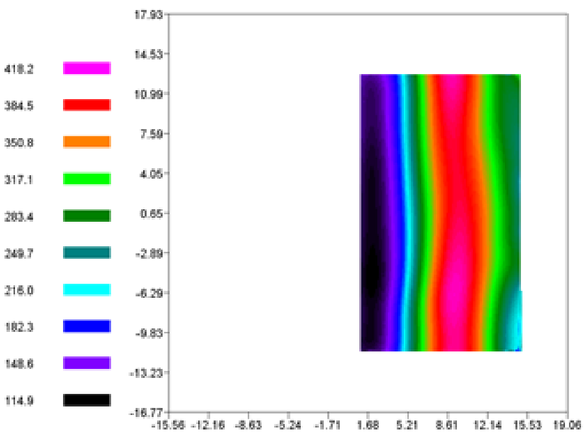
A picture of a cracked specimen and a picture of the stress measurement by means of the Q-100 sensor are shown in Fig. 3. The load was applied to the specimen in a direction parallel to the axes of the welding, so that the shear stress in fillet welds dominated. The loading speed was about 2.5 kN/s. The displacement and the resulting force carried into the specimen were monitored during the test.

(a) detail of cracked specimen

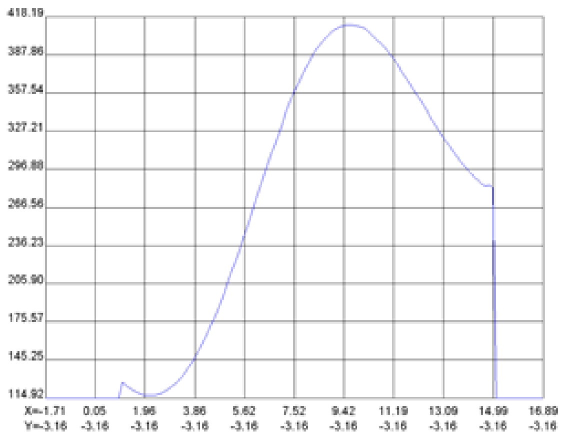
(b) position of the Dantec Dynamics Q-100 sensor

Fig. 3: Pictures from the test of fillet welds.

Von Mises stress contours obtained under the load of 200 kN are shown in the Fig. 4a. As it is clear from the Fig. 4b, the maximal von Mises stress was measured close to the place of the weld crack occurrence.



(a) von Mises stress contours in fillet welds



(b) von Mises stress profile along line Y= -3.2 mm

Fig. 4: Results of 3-D stress measurement in fillet welds using ESPI.

4 Poisson Ratio Determination

Elastic material constants of specimen were determined using a Q-100 device and a universal testing machine, see Fig. 5. In this case, measurements were carried out on the machine LABCONTROL 100 kN / 1000 Nm, in the Laboratory of mechanical properties of advanced materials and non-destructive testing at the Department of Applied Mechanics VSB - Technical University of Ostrava. In this particular case, it is necessary to glue the sensor to the stationary jaw by means of special glue. The coordinate system of the sensor has been turned to 45 degrees to the longitudinal axis of the sample. Prior to the measurement enlightenment of the surface was carried out and a picture of the area was taken. The calibration procedure followed [1]. A specimen of 12.5 mm outer diameter was gradually quasi-statically subjected to a tensile force of 2 kN and interference fringes were stored. As this was the 3-D measurement, the scanned area was subsequently unloaded and its coordinates were determined. Finally, the measurement was carried out under the axial force of 2 kN (the same load as for the calibration).

Fig. 5: Picture of 3-D strain measurement.

The graph in Fig. 6 presents the correlation of the obtained ratios of principal strains and the principal stresses, the value of the Poisson ratio can be inferred (by linear regression μ = 0.2991 - SS316L material) for the zero value of the minimum principal stress.

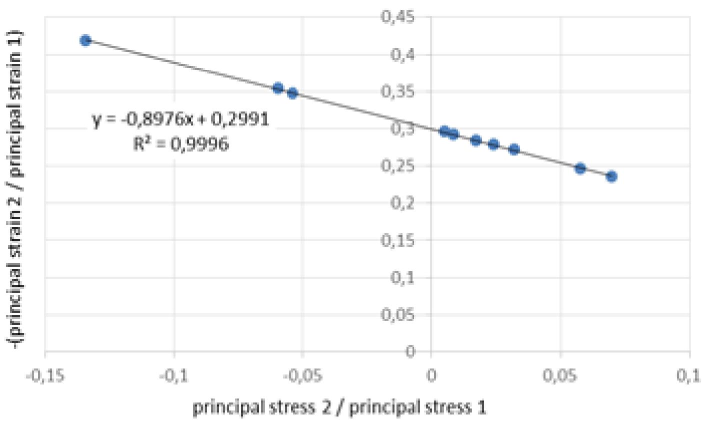


Fig. 6: Dependency of negative ratio of principal strains on the ratio of principal stresses in selected points.

5 Conclusion

This study has been focused a solution of selected engineering problems using ESPI strain sensor (Q-100). All measurements and computations have been performed in elastic domain only. The sensor is driven by a ruggedized electronic control system with the complete software package ISTRA for Windows. It offers quantitative data analysis of 3D-displacement and strain/stress fields [3].

Due to the accuracy of the method, sensor can be used for material research, for example, for elastic constants determination and verification of extensometer calibration as presented. The ESPI system used in the experimental study offers relatively accurate and complete stress/strain analysis of parts with complex geometry which were made of a wide variety of materials. Also one of mentioned application was the stress analysis of fillet welds [4]. Hot spots of welding structures were correctly determined.

Acknowledgement

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