Damage identification in composite structures using full-field strain data

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Abstract

Damage assessment of composite materials is crucial for health monitoring of engineering structures. It is particularly important to detect damage invisible to the human eye caused e.g. by low speed impact. Optical non-contact sensing techniques enable full-field measurements from structural responses. In the present work, a methodology for delamination damage identification by its local effect on surface strain pattern potentially measured by full-field optical strain measurement methods is proposed. The surface strain of a delaminated composite panel under tensile loading is considered to be the measured structural output. The Zernike moment descriptor is applied to extract a small number of features from the full-field strain map. An Artificial Neural Network (ANN) is trained to map the damage parameters to shape features of the strain distribution; consequently the ANN is applied in the determination of location and size of the delamination region.

1. Numerical simulation model of the delaminated plate

A composite panel having the configuration shown in fig. 1, including two circular delaminations of different size and position, loaded by uniform tensile load as, well as by a concentrated out-of-plane load is selected for the method development.

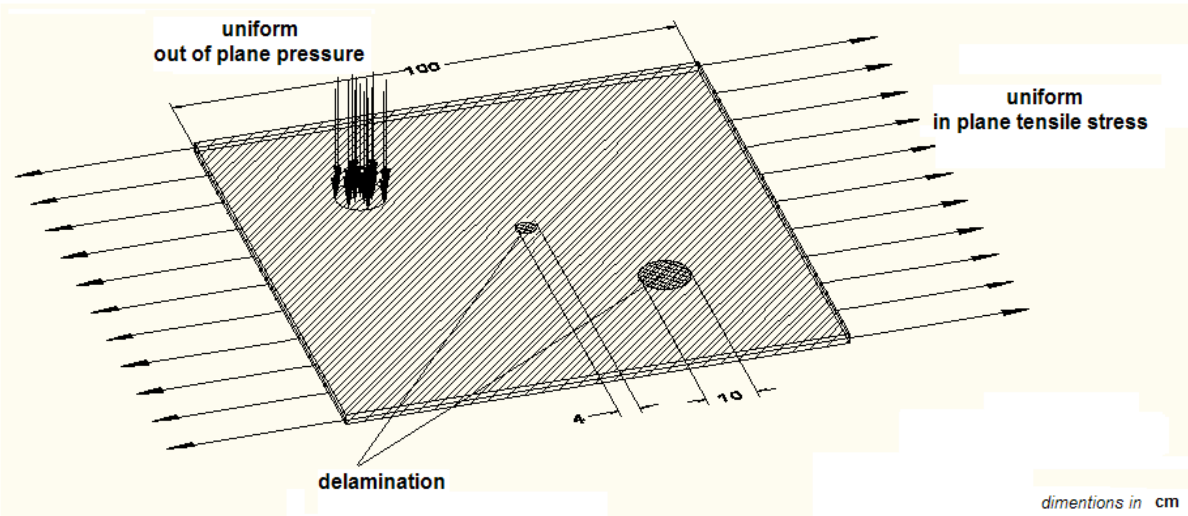
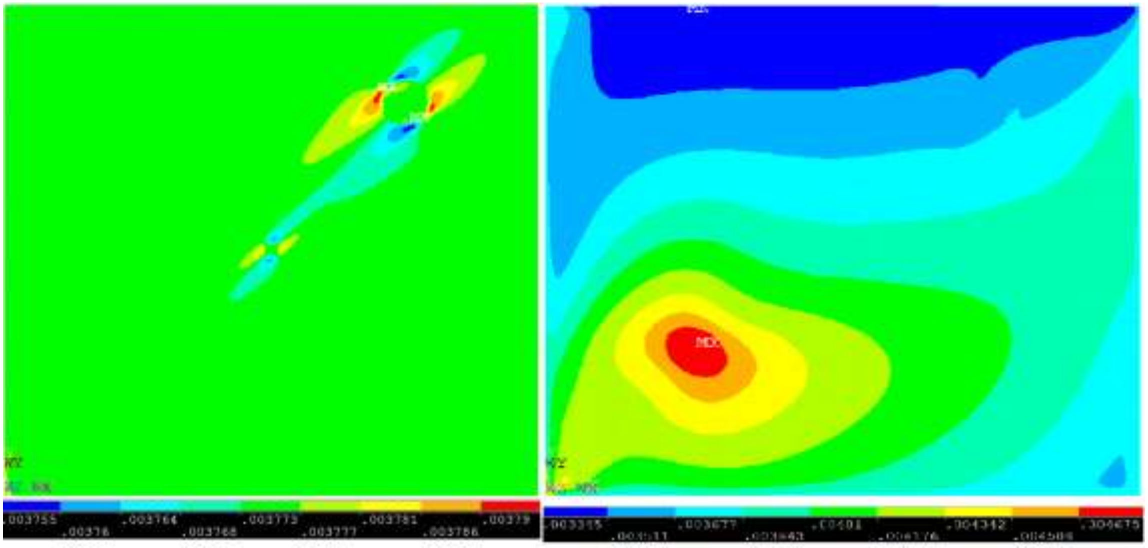


Fig.1 Geometry, loading conditions and damage of the composite panel (delaminations between the 3rd and 4th layer)

The mechanical response of the above delaminated panel is numerically simulated using the ANSYS commercial FE code. In fig. 2, the surface strain is plotted; in the left plot of fig. 2, only the in plane uniform tensile load is applied and the strain field disturbance due to the delamination existence is obvious, while in the right plot of fig. 2, the same inplane load together with an out of plane load is applied; as it may be observed, in the latter case, the disturbance of the delamination has been obscured by the much more intense strain field produced by the out of plane load, therefore, the existence, position and magnitude of the delamination is not anymore obvious.



(a) *(b)*

Fig 2 Contour plot of elastic strain along the surface layer, (a) in plane loading only, (b) both out of plane and in plane loading

2. Damage detection methodology via Shape Descriptors and ANN

Progress has been made in the frame of project ADVISE [1] in the use of reduced or decomposed data. Different shape descriptors (Zernike moment, Discrete Fourier transform (DFT), Tchebichef features, etc) can be used to reduce the amount of the data in order to simplify the data handling.

Presently, the Zernike polynomials, shown in the following equations (1), are used to perform decomposition of a strain image plots taken from the DIC measurements or simulation results at a specific time interval.

$$Z_{n,m} = \frac{n+1}{\pi} \int_0^{2\pi} \int_0^1 I(\rho, \vartheta) V^*_{n,m}(\rho, \vartheta) \rho \, d\rho \, d\vartheta$$

Eq. (1a)

$$R_{n,m} = \sum_{s=0}^{(n-|m|)/2} (-1)^s \cdot \frac{(n-s)!}{s!\left(\frac{n+|m|}{2} - s\right)!\left(\frac{n-|m|}{2} - s\right)!} \rho^{n-2s}$$

Eq. (1b)

$$V_{n,m}(x,y) = V_{n,m}(\rho, \vartheta) = R_{n,m}(\rho) e^{im\vartheta}$$

Eq. (1c)

The Zernike polynomial terms calculated from the decomposition of the simulation plot image are used to train an ANN which maps the damage parameters to shape features of the strain distribution. Zernike moments of the surface (top layer) maximum strain at the principal material directions are used in the ANN training. 71 Zernike moments terms Rm,n for m, n =1 to 15 are used. The training includes the radial and angular position of the delamination on the Zernike circle, as well as its size and is performed for 1245 different randomly generated examples.

3. Methodology results

In figures 3, 4 and 5 regression plots (R = regression factor) including: (a) the sample used for ANN training, its outcome obviously correlates perfectly; (b) the validation sample, which indicates if training is sufficient and should stop, the outcome of which also indicates a good correlation, but the mean square error is higher than in the case of sample; (c) an unknown sample; (d) the simultaneous plot of (a), (b) and (c).

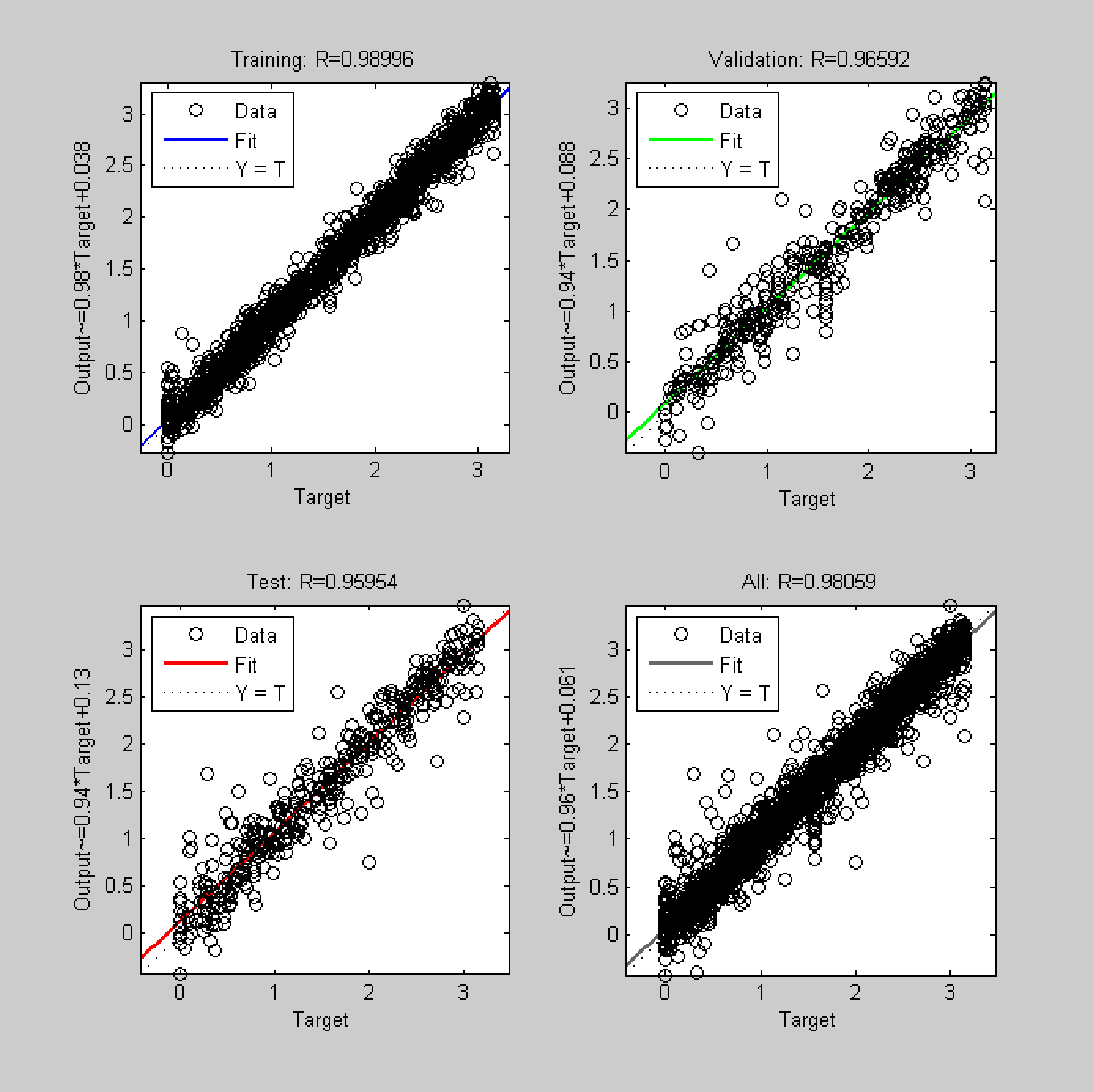


Fig 3: Regression plots of the delamination angular position on the Zernike circle

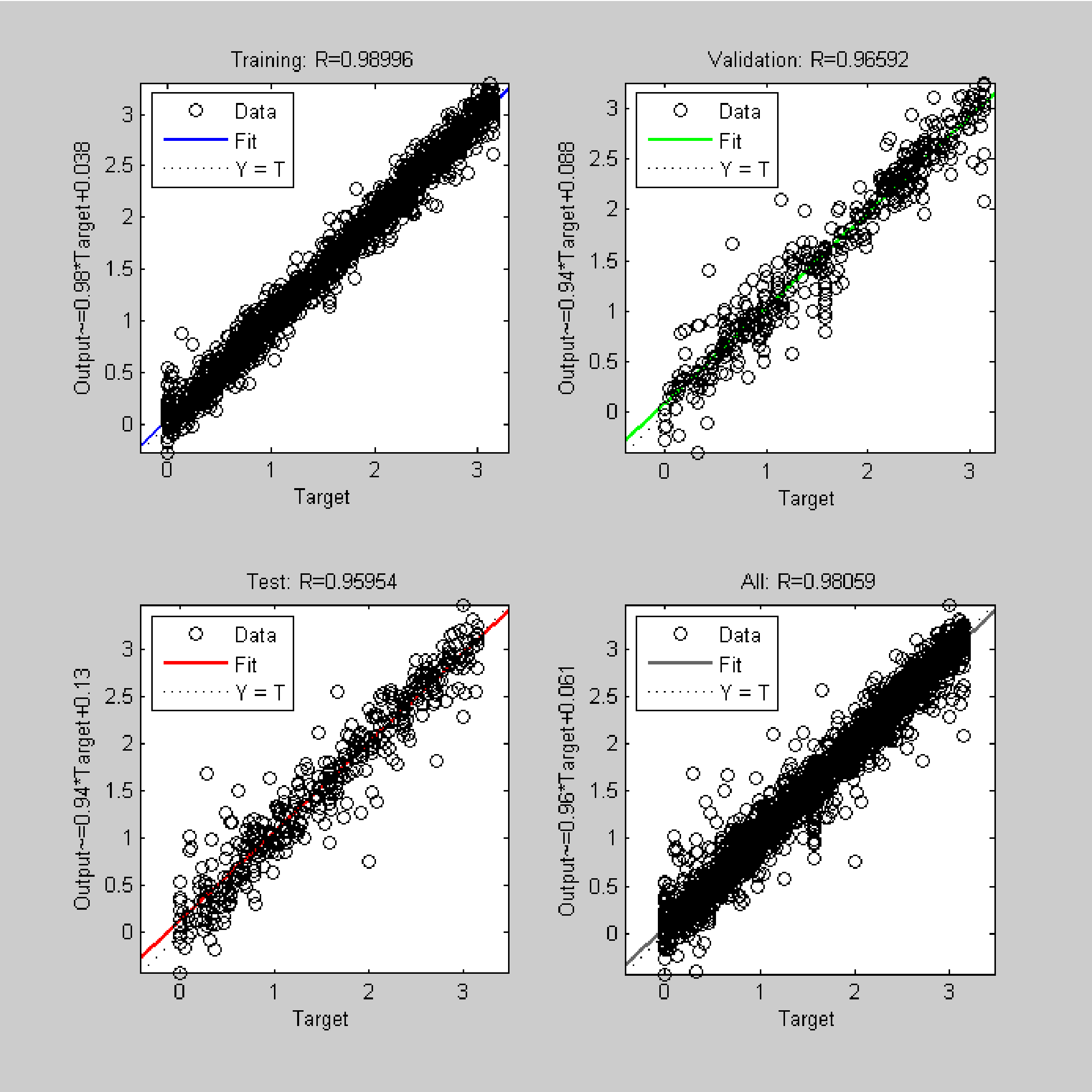


Fig 4: Regression plots of the delamination radia position on the Zernike circle

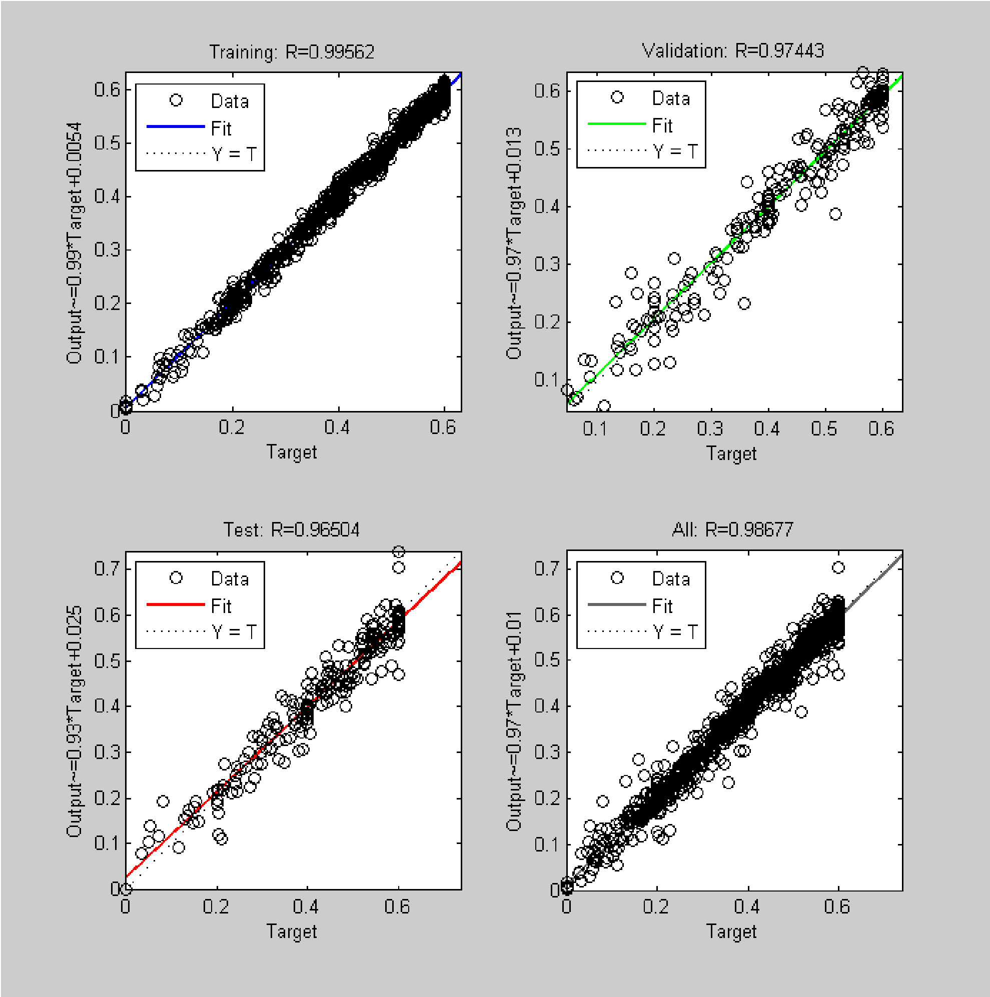


Fig 4: Regression plots of the delamination size

4. Conclusions

In the present work, full-field strain data of a delaminated plate have been used in the training of an ANN in detecting the location and size of delamination. The 'shape descriptor' approach seems to be a powerful tool with main advantage the radical data reduction. The combination of ANN and Zernike factors looks promising in the delamination detection of damaged composite panels.

Acknowledgements

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References

[1] ADVISE – Advanced Dynamic Validations using Integrated Simulation and Experimentation, FP7 project SCP7-GA-2008-218595