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COMPARISON OF STRAIN FIELD IN SHEAR-LOADED LAMINATE CALCULATED BY FEM AND DETERMINED BY MEANS OF MOIRÉ INTERFEROMETRY

Jaroslav Valach and Jiří Minster

A deformation state of carbon-epoxy laminate is investigated by means of moiré interferometry. Displacement and strain fields are compared to those calculated by FEM. Agreements and disagreements are discussed. The advantage of hybrid experimental-numerical approach concerning for realistic modelling of similar problems is pointed out.

Introduction

To fully utilize advantageous features of composites, they are constructed in the form of sheets or plates making their shape and structure unseparable, that is why composite materials very often posses highly anisotropic features and their behavior under loading is quite complex. As far as there are only a few cases of loading where analytical elastic solution is known and the rest has to be solved numerically, a strong urge exists for a proper experimental technique enabling investigation of stress (strain) state of composites. The range of the technique should cover a field of millimeter to a couple centimeters, the technique should be the whole field and has to be sensitive enough to detect strains of the order of hundredth of per cent. The moiré interferometry technique (MIT) meets such requirements. The presented paper covers a part of our research program devoted to development and application of MIT in strain measurement of loaded composites comparing results obtained by FEM and MIT.

Specimen

Rectangular specimen made of 8 ply carbon fiber/epoxy plate is symmetrically weakened by two circular holes 3 mm in diameter (see fig. 1). Active area of specimen subjected to shearing is 2 x 25 x 100 mm and the size of observed field is 12.6 x 9.4 mm. Effective elastic parameters were estimated from the similar materials used in the previous work [1].

Experimental setup

Loading apparatus is adapted to carry out standard rail-shear test ASTM D4255 (see fig. 1). Both ends of the specimen were fixed in the rigid frame and its middle part, clamped between stiff rods is pushed down. The applied force on the middle rail is measured by calibrated dynamometer Wazau and displacement by dial indicator.

Moiré interferometry

Overlay of two similar grids constitutes a moiré pattern. To get the first one, investigated area of specimen's surface is covered by a very fine rectangular grid (the density of gratings is 1200 lines per mm). The second (virtual) grid (2400 lines per mm) is substituted by standing waves generated by the interference of two coherent plane waves of opposite sense of circular polarization [2].

The complete set of data (using the phase stepping method) necessary for displacement and strain fields determination consists of twelve inteferograms: (horizontal and vertical grid) x (three different phase angles) x (unloaded and loaded state). Interferograms as matrices of intensities are acquired by CCD camera and stored in digitized form in computer for consequent processing.

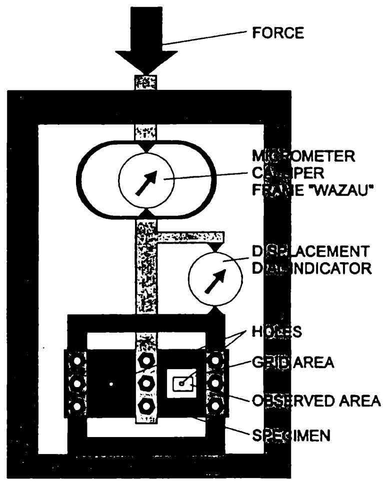


Figure 1 Specimen and experimental apparatus

The processing itself can be divided into two steps: In the first step, the matrices (images) have to be filtered, to remove noise, and in the second step, the proper range of the intensities within image has to be adjusted. The corrected matrices of intensities of no fever than three different phase angles are then used for determination of wrapped (uncorrected) phase function [3]. The discontinuous character of the wrapped (uncorrected) phase function enables individual fringes in the image to be properly numbered. The fringe number and wrapped phase function are then combined in unwrapped (continuous) phase function. The difference between unwrapped functions before and after loading represents increment of phase function due to external tractions which are directly proportional to the displacement. Components of deformation are then calculated by numerical differentiation.

FEM

Finite element package ANSYS 5.3 is used to carry out calculations for the model of the same dimensions as experimental specimen. The automatically generated mesh refined near the central opening is based on four and three node elements and in total contains about 500 elements. Orthotropic elastic parameters of composite are derived from the data of the similar specimens used in previous experiments [1] and are not measured directly. The partial uncertainty about correct reproduction of elastic parameters in investigated specimen and the preference for results related more closely to measured geometry features (displacement and strain field) lead us to avoid solution in known loading force. The solution is obtained for prescribed displacement on the border of the model taken from experimental setup. We have to admit that this is a weak point of the calculation because we don't know exactly how the total displacement is distributed between the specimen and the loading apparatus.

Discussion

The presented comparison revisits the problem of marriage of experiment and calculation - the difficulty to keep them together and impossibility to rely on just one - manifesting a need for the proper experimental technique and qualified level of idealization and simplification of the model. The experiment can't be pushed behind its limitation by model requirements and vice versa.

On one hand, simplified model, offering clear and simple insight into the problem can reveal possible sources of errors in experimental setup. In our case it shows that specimen is not fully clamped in apparatus as can be seen by comparing values for Nx field (see fig. 2) predicted by FEM and those experimentaly measured. Another revealed fact about experiment is, that the technique is applied on its lower limit of resolution: In contrast to a quite pronounced qualitative and quantitative agreement between shear component of deformation (γ, see fig. 3), there is only a 'sign' correspondence between the other two strain components in model and experiment, indicating no meaningful results can be found below 0.005 per cent (other authors [2] state theoretical strain resolution of the method about $3x10^{-4}$ per cent depending upon

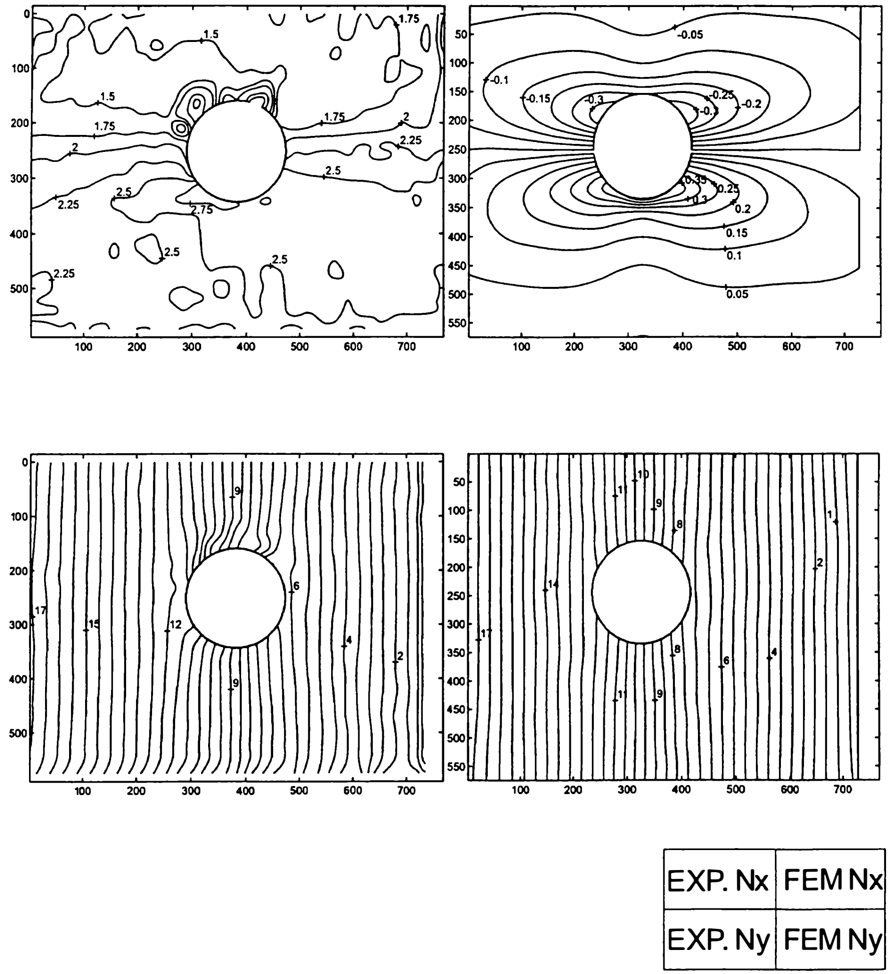
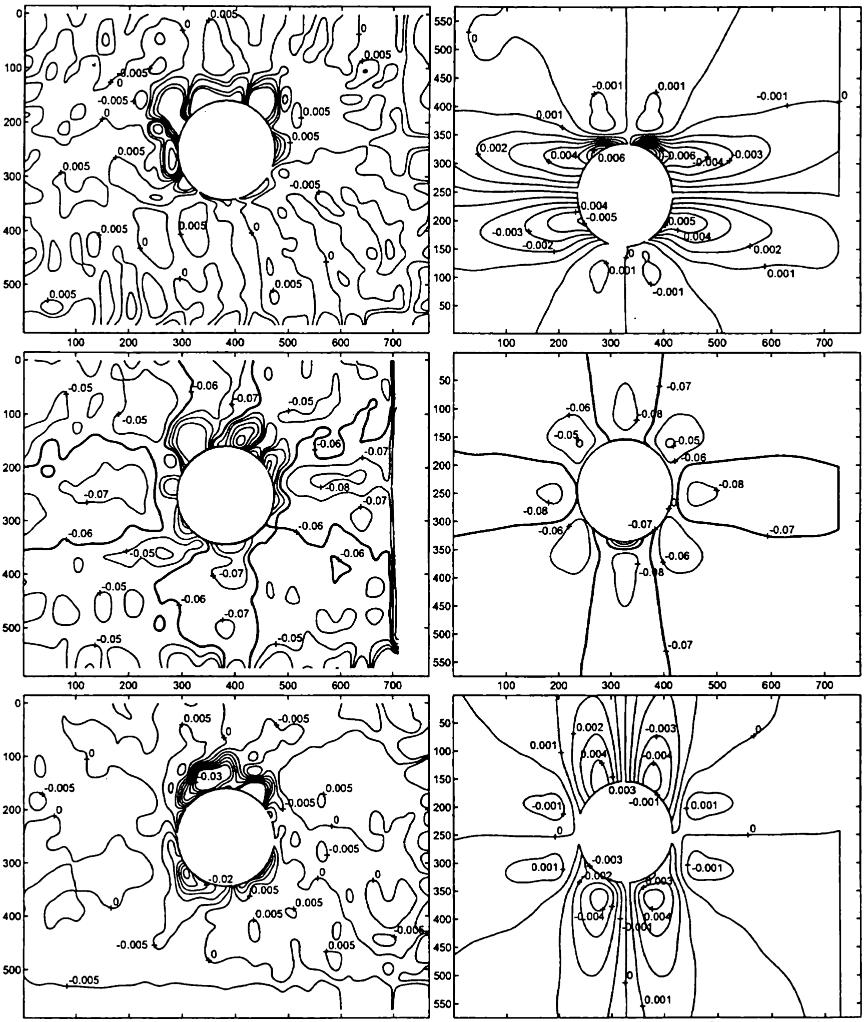


*Figure 2. Comparison of observed and calculated distribution of fringe orders; the contour interval is equivalent to 104 nm and 208 nm for the **u** and **v** fields respectively.*



EXP. ε_{xx}	FEM ε_{xx}
EXP. γ	FEM γ
EXP. ε_{yy}	FEM ε_{yy}

Figure 3. Comparison of strain tensor components calculated and derived from observation

a prescribed 25 mm length) of strain. Finally, anomalous strain peaks near the circular opening indicate debonding between the specimen surface and the grid film.

On the other hand, the same simplified model can neglect substantial features: There is no edge effects on geometrically perfect hole in the center of model, boundary conditions quite differ, showing the loading unevenly spreads the applied force within the specimen. Calculation results depend on availability of data (e.g. effective elastic moduli of the tested composite).

Conclusion

I) regardless the simplicity of the experimental setup the modelling is (could be) difficult considering quantitative agreement between experimental and numerical results;

ii) a simple model does not automatically mean its uncomplicated reproduction in laboratory;

iii) the experiment should be supervised by a model and then experimental results should be incorporated in refined version of the model.

Acknowlegement

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Ing. Jaroslav Valach, *valach@itam.cas.cz*, Ing. Jiří Minster, CSc., *minster@itam.cas.cz;* ✉ Ústav teoretické a aplikované mechaniky Akademie věd České republiky (The Institute of Theoretical and Applied Mechanics of Academy of Sciences of the Czech Republic), Prosecká 76, 190 00 Praha 9; ☎ (02) 88 21 21; fax: (02) 88 46 34.