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**Offer of PhD position, University of Southampton**

"Development of a tool for quantitative validation of finite element simulations from full-field optical deformation measurements"

- Supervisor: Professor Fabrice Pierron (University of Southampton), f.pierron@soton.ac.uk
- Studentship: covers registration fees (UK/EU student only) plus maintenance grant of £14,000 per annum, tax free

**Candidate profile:** UK/EU student with a first degree or equivalent. Work will contain elements of numerical simulations and experimental tests using optical full-field techniques. Topic has strong industrial relevance.

**Project description**
The recent and spectacular progress in computational mechanics has enabled to shed a new light on many mechanical engineering problems. It is now possible to simulate in great details very complex configurations such as impact, crash etc.
An important underexplored area of research however concerns the experimental validation of the output of such models. Typical validation includes tests instrumented with dial gauges and/or strain gauges located at a certain number of points on the tested specimen or structure. However, such local strain/displacement measurements may miss out on unexpected behaviour at points where no sensor is located. Alternatives have included 3D photoelastic models with the inconvenience of having to test the structure made out of model photoelastic material, which can only validate loading / contacts but not material behaviour.
The recent development of full-field optical techniques such as digital image correlation (DIC) provides an ideal tool to validate numerical simulations. These imaging techniques provide maps of strain as a function of time which can then be compared to numerical simulations provided by the Finite Element method, for instance. Fig. 1 shows a strain map on a composite panel under bending, and the equivalent map from an FE model. By representing

the data with the same colour scale (as in Fig. 1), visual (qualitative) appraisal of the quality of the fit is possible. However, quantitative match is much more difficult to perform. Indeed, experimental data contain noise, as clearly seen on Fig. 1. But even more difficult is the fact that each strain data point has a certain gauge length over which the strain is averaged. This is called the spatial resolution of the measurement. If this is easy to evaluate for a strain gauge (one can just compare the strain from the FE model averaged over the strain gauge area), it is much more difficult to evaluate for techniques like digital image correlation. Moreover, if extra smoothing is required to filter out noise, this changes the gauge length (makes it larger). As a result, it is difficult to know if differences in strain maps between FE and experiments come from the spatial filtering features of the measurement or from model errors (material model, boundary conditions etc.)

An illustration of this is provided in Figs. 2 and 3. It concerns an Arcan test on a PVC foam specimen, as in Fig. 2. A comparison between the FE strains and that produced by simulating the measurement process (numerical speckle pattern deformation from the FE displacement map) shows differences at strain concentrations (Fig. 3). In other words, the measurement technique acts as a low pass spatial filter of the actual strain data. But this difference could be interpreted as an error in model if the data were experimental.

The objective of this project is to <u>contribute to the definition of a rigorous protocol to quantitatively compare FE models and full-field deformation measurements.</u> This is an essential tool currently lacking in industry to reach the full potential of such strain mapping techniques.

The project will endeavour to simulate experimental date from FE displacement maps in order to generate data that are directly comparable to experimental results (ie, applying the experimental 'filter' to the simulated data). Different case studies will be undertaken to look at how this new tool can then be used to separate experimental measurement uncertainties from material model (damage, etc) and boundary conditions errors.
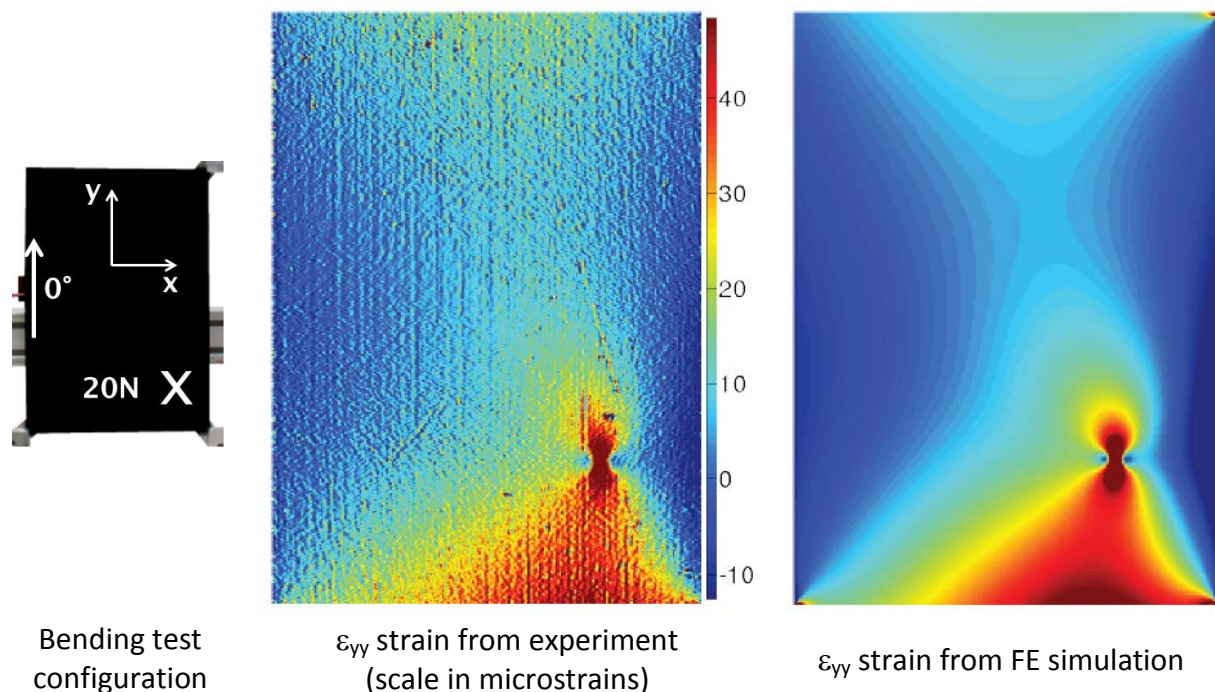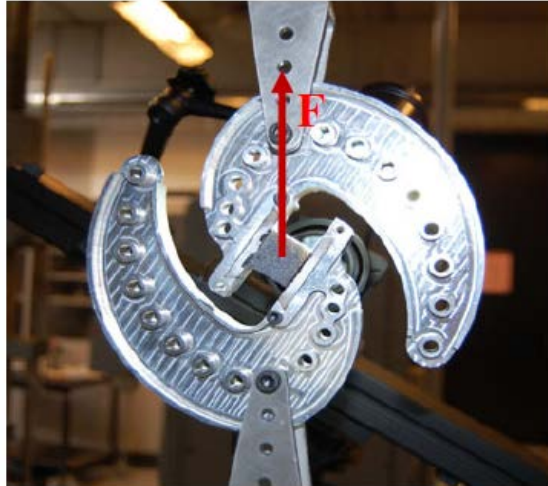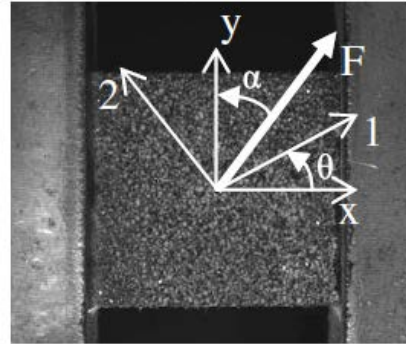


Bending test
configuration

$\varepsilon_{yy}$ strain from experiment
(scale in microstrains)

$\varepsilon_{yy}$ strain from FE simulation

Fig. 1 – Comparison of strain maps obtained from experiment and FE simulation[1]



Arcan test on  foam cubes
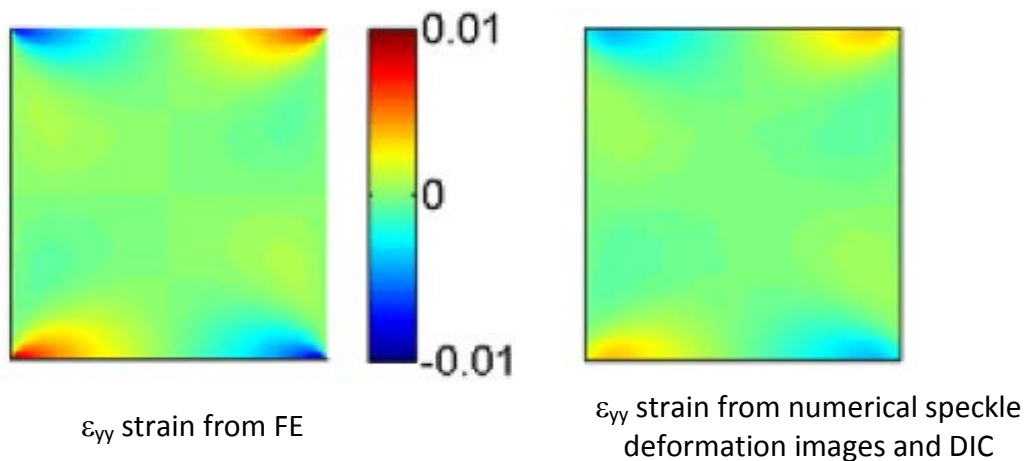


Foam specimen

Fig. 2 – Arcan test on foam cube specimen[2]



$\varepsilon_{yy}$ strain from FE

$\varepsilon_{yy}$ strain from numerical speckle deformation images and DIC

Fig. 3 – FE and speckle deformation strains from FE displacements showing the low pass filtering effect of Digital Image Correlation[3]

[1] Devivier C.,  Pierron F., Wisnom M.R., Damage detection in composite materials using deflectometry and the Virtual Fields Method, *Composites Part A*, vol. 48, pp.  201-218, 2013.
http://dx.doi.org/10.1016/j.compositesa.2013.01.011

[2] Wang P., Pierron F., Thomsen O.T., Identification of material parameters of PVC foams using digital image correlation and the virtual fields method, *Experimental Mechanics*, available online, 2013.
http://dx.doi.org/10.1007/s11340-012-9679-0

[3] P. Wang, Aalborg University, Denmark. Private communication (work underway)