FE validation from DIC data : a practical case study in bending

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Abstract. The validation of structural models using Digital Image Correlation (DIC) is an emerging field. A very important aspect of this process is to be able to read the maps of strain differences between model and experiments, to isolate the sources of discrepancies. This paper provides a case study for a perforated blade in bending and reviews the different challenges associated with the validation.

Possible Sessions: Model validation, Optical and DIC Techniques

Introduction

Digital Image Correlation (DIC) is an experimental technique used to measure full-field surface deformation using digital cameras. The data-rich nature of the resulting deformation fields makes it an ideal tool for detailed experimental validation of structural mechanical models, most often obtained with the finite element (FE) method. There is however limited literature on this topic. A corpus of work was published by the research group led by E.A. Patterson [1] using low pass spatial filtering in the form of so-called shape descriptors (polynomials of different sorts). The DIC uncertainties are simply approached through a bending test on a beam. This suffers from the fact that it does not include the complex uncertainty quantification (UQ) arising from the highly nonlinear correlation algorithm. In particular, by using a bending test that leads to linear displacement distributions through the width, it ignores the interplay between the spatial frequencies in the model and the limited spatial resolution of DIC. A more advanced approach has been recently proposed, the so-called 'DIC-levelling' method, which uses the model displacements to create a Digital Twin (DT) by numerically deforming the speckle images [2]. These images can then be processed with the same DIC parameters as the experiment to allow for a direct comparison in the form of a validation map. Although very recent, this approach has already been confirmed as an essential tool for model validation by a few studies [3, 4]. However, an underexplored area is the process to use maps of differences between model and measurements to isolate the different sources of model errors. Here, a practical case study is presented.

Experimental setup

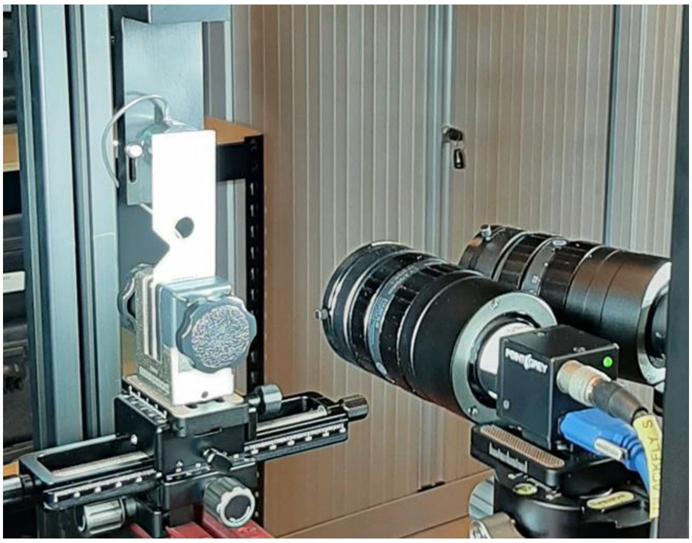

Figure 1 – Experimental setup

The experimental setup is depicted in Fig. 1. The specimen is a PMMA blade with a notch and a hole, clamped at the bottom and loaded in bending using a point load at the top. The load is measured as well as the deformation field using a stereo-DIC system. A finite element (FE) model was built-up, using the elastic properties measured during a monotonic tensile test. Perfect boundary conditions were also applied: clamp at the bottom, point load at the top. The model was then used to deform the experimental reference images, which were then processed with the same DIC parameters as the experiments, creating a one-to-one digital twin of the experiment [2]. This was done using the FEDEF module of the commercial software MatchID. The FEDEF maps could then be subtracted from the DIC maps to create error maps. A full validation is achieved when these maps only contain high frequency random errors within the bounds of the uncertainty evaluated on stationary images.

Results

Fig. 2 shows the longitudinal strain for the experiment, model (FEDEF) and the difference. One sees clearly that there is an error distribution that mimics the actual strain distribution. This suggests that the stiffness is incorrect. Indeed, because of the viscoelastic nature of PMMA, the monotonic loading Young’s modulus € is higher than the long-term one activated in the experiment when load relaxation is left to happen before recording the deformed images. Updating E to itslong-term value, 3 GPa, this error vanishes (Fig. 3).

However, one can see a residual error at the bottom of the blade. This is caused by the fact that a perfect clamp does not reflect reality and in practice, a small rotation is always present. Measured boundary conditions were then applied to the bottom of the blade and this solved that problem. However, some errors still persisted and discussions about Poisson's ratio and how to obtain a realistic noise floor will be addressed in the presentation.

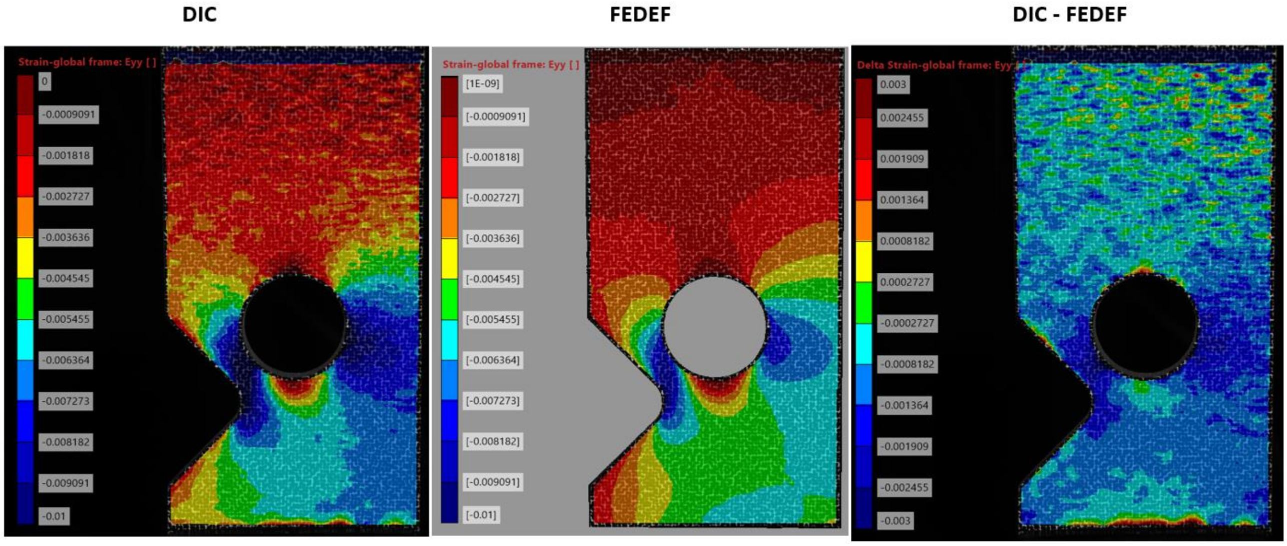

Figure 2 - Comparison between experiment and model (FEDEF), longitudinal strain. Illustration of Young's modulus error (3.7 GPa instead of 3 GPa).

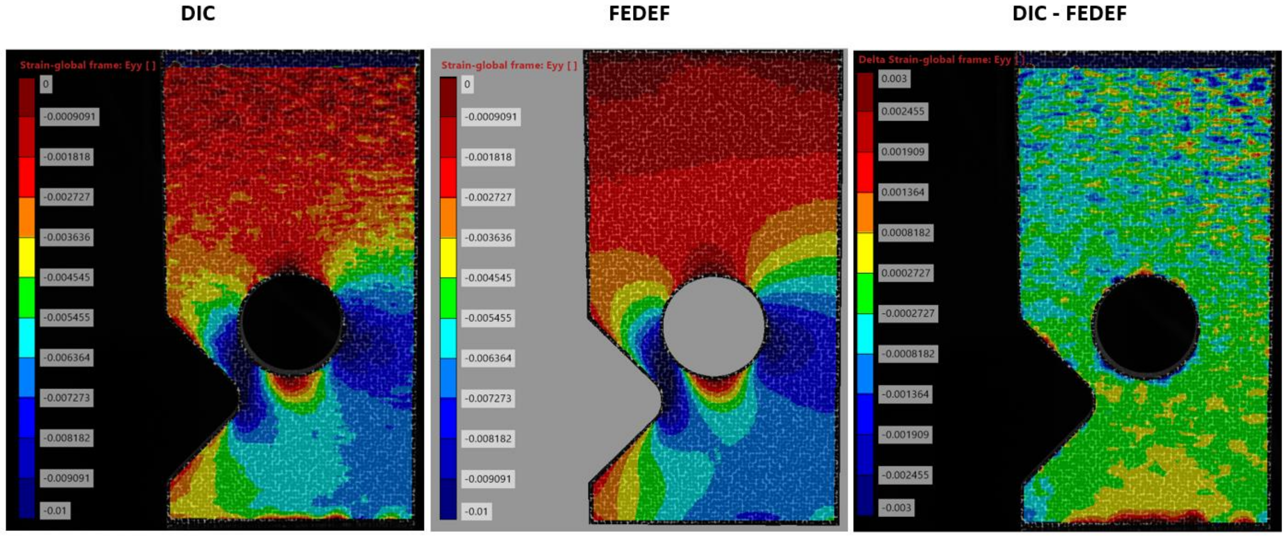

Figure 3 - Comparison between experiment and model (FEDEF), longitudinal strain. Illustration of error on boundary conditions (perfect clamping at the bottom).

References

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