11th International Conference on Composites Testing and Model Identification
J. Costa, J. Renart and N. Blanco (Editors)
Girona, 2023

BAYESIAN PREDICTION OF THE LOAD RESPONSE OF COMPOSITE STRUCTURES TO STREAMLINE CERTIFICATION APPROACHES

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Keywords : Polymer composites, Digital image correlation, Finite element analysis

ABSTRACT

The ‘pyramid of tests’ or ‘building block’ approach, consisting of analysis and experimental validation, is currently used to demonstrate the structural integrity of composite aerostructures [1]. The premise is that experiemntally obtained allowable strength limits of small elements (mainly coupons) of a composite structure are combined with knock-down factors to predict performance at higher length scales. The approach is suboptimal, as composite material behaviour is scale-dependent. Therefore, coupon testing does not adequately capture structural scale effects. In the best case, this leads to an overly conservative design, and in the worst to catastrophic failure. Composite structure certification programs of this kind are expensive, time consuming, and therefore inhibitive to innovation [2]. A new methodology that defines the necessary tools for a *holistic* approach that streamlines and optimises the fusion of experimental and simulation data would therefore be desirable. Efficient iteration between physical and numerical tests is required to maximize experimental impact on modelling confidence and to minimize experimental effort, overall reducing cost and time of the certification effort. Therefore, a statistical modelling framework is proposed based on Gaussian processes (GPs) and Bayesian inference using experimental and simulation data to define new efficient ‘pyramid of tests’ approaches [3].

To develop and demonstrate the statistical modelling approach, a set of well-defined experimental data is required as both an input to the process and to validate the output. Hence, it was decided to use data from an extensive testing campaign, described in [4], that provided full-field deformation data obtained from digital image correlation (DIC) of open-hole specimens subjected to combined tension/compression and shear loading. The test configuration is shown in Figure 1 where a modified Arcan fixture (MAF) is used to subject a test coupon to various combinations of tension-shear and compression-shear loading. The combined load case is defined by the choice of a loading hole pair described by the loading angle α, where α = 0° corresponds to tension, α = 15°- 75° to tension-shear, α = 90° to shear, α = 105° - 165° to compression shear, and α = 180° to compression loading. The test specimens were manufactured from IM7/8552 carbon fibre reinforced epoxy constructed to form a quasi-isotropic $[+45/90/-45/0]_s$ laminate. The multidirectional laminate specimen containing a central circular hole produces a ‘mini structure’ that is representative of a larger generic subcomponent. As the MAF allows a series of different loading scenarios to be applied to nominally identical specimens, it makes an ideal simplified basis for demonstration of the statistical modelling approach. Thus, the proposed statistical model is used to determine what load cases to test to demonstrate the ‘structural integrity’ of the open-hole specimen regarding the MAF load envelope with minimum effort. A linear-elastic finite element (FE) solid model of the open-hole specimen was constructed in Abaqus capable to predict elastic deformation and failure initiation. The statistical model is calibrated, satisfying Bayes’ theorem, based on experimental data from the tension-shear (α = 45°) and compression-shear (α = 135°) load cases together with FE model predictions for 100 different combinations of the loading angle, α, and the load magnitude, P. The calibrated statistical model can now be used to predict the load response

and the associated uncertainty of load cases that have not been tested before, as shown in Figure 2. It is observed that the statistical model can predict the initial load response of the open-hole specimen loaded in shear with a high level of accuracy, and in addition provides the associated uncertainty that is a key component in deciding on the next test to conduct/FE model to run.

The next step is to incorporate predictions of the failure initiation into the statistical farmwork and to use it to inform an optimised MAF testing campaign to demonstrate the usefulness of the proposed statistical approach to composite structures validation.

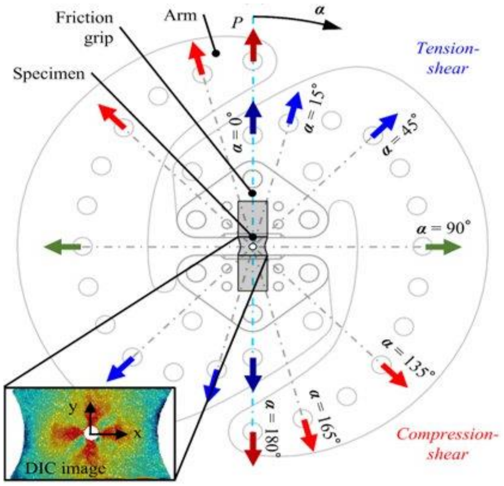

Figure 1: The modified Arcan fixture (MAF) and the open-hole specimen [5].

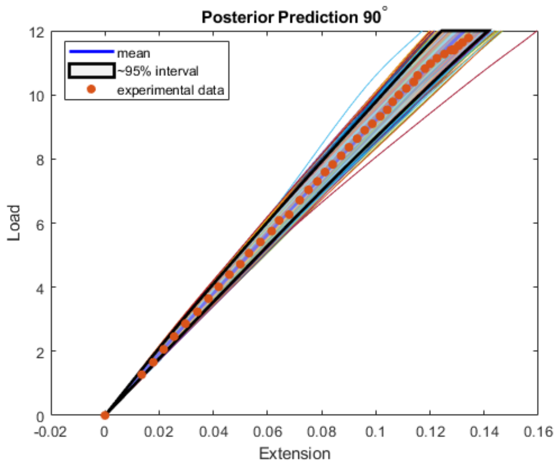

Figure 2: Load-extension curve derived from open-hole specimen subjected to shear loading: posterior statistical model prediction vs. experimental data.

ACKNOWLEDGEMENT

The research presented was supported by the EPSRC Programme Grant ‘Certification for Design – Reshaping the Testing Pyramid’ (CerTest, EP/S017038/1). The support received is gratefully acknowledged.

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