A whole-field measurement based identification procedure for polymer composites

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Introduction

Numerical simulation of composite materials is of industrial interest, as these materials are increasingly used in critical load bearing applications due to a favorable combination of low weight and good mechanical properties. A key part of the numerical models is the constitutive model (material description) containing parameters that have to be determined through mechanical testing. Several shortcomings of traditional equipment and test techniques make materials property assessment difficult and costly.

Objective, challenges and approach

- Several shortcomings of traditional test techniques and equipment, e.g. strain-gauge transverse sensitivity and misalignment, as well as industrial fibre reinforcements with heavy tows, make materials property assessment difficult and costly.
- Current test standards originally developed for aerospace materials applied on industrial (e.g. marine construction) materials do not always yield realistic measured properties with low experimental scatter.
- High experimental scatter affects the statistically established dimensioning allowables, which makes the composite material less attractive as a construction alternative.
- Numerical methods, e.g. Finite Element Methods, are well established within the industry. Combination of this method by so-called inverse modeling with the whole-field digital image correlation measurement technique, has disclosed a new area of testing procedures to identify constitutive equations for composite materials.
- The present work aims at establishing a method to identify the elastic constants of a polymer composite using fewer tests than what is standard today.

Identification procedure

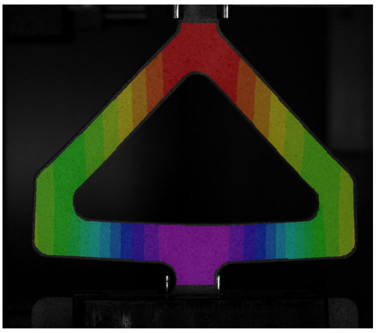
- Each ply was assumed to be transversely isotropic and only plane stress states were considered → Five non-zero elastic constants (four are independent, the last one can be determined from the other constants):

$$E_L, \upsilon_{LT}, E_T, \upsilon_{TL}, G_{LT}$$

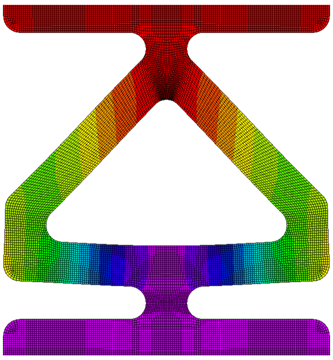
- A specimen geometry was designed to achieve several different stress states simultaneously in one specimen. The complex shape was cut using a water jet.
- The entire displacement field was measured during loading using 3D Digital Image Correlation.
- A finite element (FE) model of the test was made using LS-DYNA. The discrepancies between the predicted nodal displacements and the measured displacements of the corresponding points on the test sample at the same applied force were used to construct a "cost function" to be minimized. Linear elasticity was assumed, and therefore only one state of loading was used.

$$J_u\left(\mathbf{P}\right) = \sum_{n=1}^{N_n} \sum_{k=1}^{2} \frac{\sqrt{\left(u_{k,n}^{eksp} - u_{k,n}^{sim}\right)^2}}{\left\| u_n^{eksp} \right\|}$$

- LS-OPT (a standalone Design Optimization and Probabilistic Analysis package with an interface to LS-DYNA) was used to minimize the cost function and determine the optimal set of elastic parameters. A quadratic metamodel and D-optimal sampling was used.
- Several iterations were required and the total number of FE simulations was quite large. The optimization process turned out to be computationally demanding and time consuming.



Contours of vertical displacement measured during a test using DIC



Contours of vertical displacement calculated by the finite element model

Materials

- Two different laminates were tested: Glass fiber reinforced epoxy and carbon fiber reinforced epoxy.

<u>Glass fibre reinforced laminate (GRP-laminate)</u>

The composite laminate consist of 12 layers of Interglas 92112 woven roving with a weight of 200 g/m2 in an R&G L20 epoxy resin with the EPH161 curing agent. Fibre orientation was 0/90°. Hand lamination was used yielding a fibre volume fraction of 0.38. The laminate was cured over night at ambient temperature, and then post cured for 16 hours at 80°C.

<u>Carbon fibre reinforced laminate (CFRP-laminate)</u>

The laminate consists of 12 layers in a symmetrical 0/90° lay-up of an UD-tape with a weight of 125 g/m2. The reinforcement is Udo UD CST 125/300 using the Tenax UTS E5631 12k 800 tex carbon fibre and is made by SGL epo GmbH. The matrix was the R&G L20/EPH161 combination. Hand lamination and post curing as for the GRP-laminate which resulted in a fibre volume fraction of 0.35.

Principle behind 3D Digital Image Correlation (DIC)

Single camera DIC systems are limited to planar specimens that experience little or no out-of-plane motion. This limitation can be overcome by the use of a second camera observing the surface from a different direction. 3-D DIC is based on a simple binocular model. In principle, the binocular vision model is similar to human depth perception. By comparing the locations of corresponding subsets in images of an object's surface taken by the two cameras, information about the shape of the object can be obtained. In addition, by comparing the changes between an initial set of images and a set taken after load is applied, whole-field, three-dimensional displacement can be measured. Both the initial shape measurement and the displacement measurement require accurate information about the placement of the cameras being used and of the distortion characteristics of the lenses. To obtain this information, a camera calibration process must be used to accurately determine the model parameters.

Validation tests

- Tensile tests in three in-plane directions (0°, 45° & 90°) according to ASTM D3039 and D3518 were used to validate the identification procedure.
- The laminates were assumed to be generally orthotropic and the stress was assumed to be planar. Then there are 9 non-zero elastic constants (four are independent, and the remaining can be determined from these).
- Finite element simulations of the tensile tests were carried out to predict the laminate properties from the lamina properties identified through inverse modeling.
- Four independent elastic constants predicted from the finite element simulations were compared to the corresponding constants calculated from tensile test results.
- A reasonable agreement was observed, but the experimental scatter was significant.

Conclusion

- There are several challenges associated with identification of model parameters for composite materials.
- Whole-field strain measurements and inverse modeling may help reduce the number of mechanical tests. Preliminary results are promising, but the experimental scatter, especially for the verification tests, is significant. More tests are therefore needed to say anything conclusive.
- The reduced number of tests required to determine the elastic constants can not at the present time justify the amount of material needed to manufacture the complex test sample and the time required to run numerous simulations to optimize the set of material parameters.

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