Parameter fitting algorithm for composite laminates using a new material model with fiber reorientation

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Introduction

Continuous fiber-reinforced composites are increasingly used as structural components due to their high strength-to-weight ratio. To reduce development time, advanced simulation techniques are essential, especially because composites show highly non-linear mechanical behavior. Accurate material models are therefore crucial for reliable predictions. However, identifying and tuning model parameters is still a challenge, particularly when fitting data extends beyond the range of standardized tests where the available analytical solutions are valid. One particular phenomenon, which restricts the application of analytical formulae is the fiber reorientation process due to mechanical loads by making the material appear stiffer or softer compared to the applied constitutive equations. Fiber reorientation or draping arises from the orthotropic nature of composite materials and is always present, although it may be negligible in some cases. Fig. 1. presents the fiber reorientation effect. In critical applications, however, neglecting this effect can lead both qualitative and quantitative discrepancies. Apart from the actual simulations of composite tools or structures, the fiber reorientation affects the parameter fitting techniques of constitutive or failure models, as the stress states are modified due to the scissoring process taking place in the specimens with symmetric layup of ±θ degree. This contribution aims to cope with the above mention problem using a previously developed and implemented orthotropic material model with an in-house developed parameter fitting framework to achieve a more accurate set of parameters

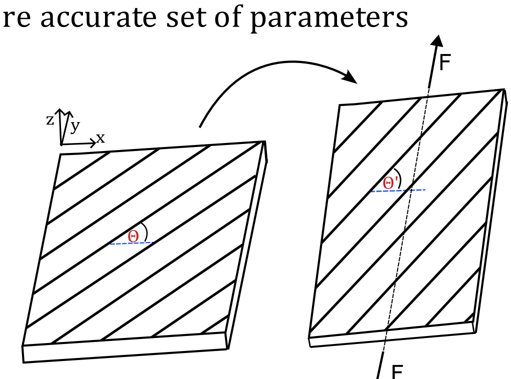

Figure 1. Deformation induced fiber reorientation

A non-linear orthotropic material model with fiber reorientation effect

The developed material model utilizes in-plane non-linear elastic constitutive laws and can distinguish between tensile and compressive directions. Moreover, the fiber reorientation is also incorporated into the model. The following adopted version of the Ramberg-Osgood equation [1] is applied for the transverse and shear directions, while the fiber direction is assumed to be linear (but with different tensile and compressive moduli),

$$\sigma = E\varepsilon\left(\left(\frac{E\varepsilon}{Y_0}\right)^p + 1\right)^{-1/p}, \tag{1}$$

where σ can stand for σ_2 or τ_{12} and ε for ε_2 or γ_{12}, meanwhile the set of Ramberg-Osgood parameters is the initial modulus E, asymptotic stress value Y_0 and the shape parameter p. Furthermore, since the tensile and compressive loading directions are distinguished, the total number of parameters corresponding to the transverse direction is six, i.e. two sets of parameters. In addition, the model is implemented in LS-DYNA finite element solver for explicit and implicit simulations with thin shell and solid formulations.

Developed parameter fitting framework

The proposed algorithm can determine the parameters of the above introduced constitutive laws by running the finite element models of the measurements and optimizing the parameter set of Eq (1), until the results of the simulations match with the measured curves. The next step of the fitting process is to obtain the best fitting first ply failure model with its appropriate parameters. This is done via gathering the critical stress states of the elements of the simulations at the failure load of the measurements, then using a developed data-driven technique the best failure model is characterized. This technique involves a nominal fit of the preselected models, followed by parameter identifiability and robustness check. This decides upon the best model for the available data. The fitting is finished by a numerically approximated Bayesian fit of the expected strength probability distribution functions.

Results

The experimental results show, that the draping effect is a significant contributor to the measured data. Moreover, the proposed algorithm with the material model is capable to characterize such behavior, as Fig. 2. presents the fitted curves to ISO14129 measurement data.

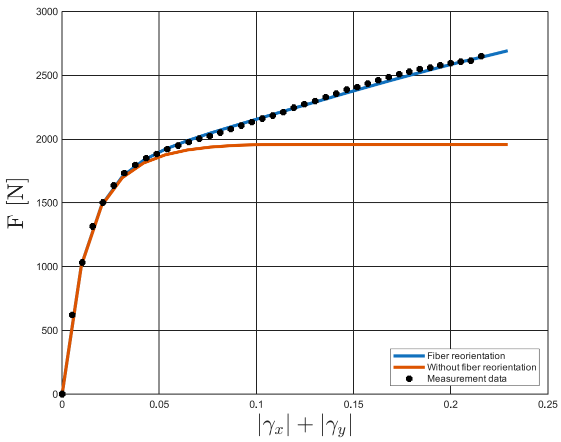

Figure 2. The difference, that draping makes to the fitted curves

References

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