Summary of doctoral dissertation

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A multiscale, statistical approach to model open-hole strength size effect in woven composites

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The variation of strength of composite parts with size is referred to as the size effect, and it can be observed in the presence of notches such as circular open holes. In woven composites, when the characteristic size of the interlocking tows of fibers and the notches is comparable, the material heterogeneity and stress concentration interact, giving rise to a complex stress field. Existing analysis of open-hole strength however focuses on unidirectional composites and does not model this effect. This study proposes to investigate the size effect on circular open-hole strength of a woven twill composite using a novel experimental-numerical approach, capable of preserving the mesoscale material heterogeneity captured by full-field Digital Image Correlation (DIC) measurements, and to use this information as the basis for a statistical reliability method.

An innovative simplified mesoscale model was thus developed, which recaptures the heterogeneity of the woven material. The aim was to obtain a full stress field corresponding to the DIC-measured experimental strain field. First, the experimental strains were obtained via uniaxial tensile testing of open-hole specimens. Local material orientation was mapped in every individual specimen using a semi-automated image processing script, and applied to a shell model of each specimen. The mesoscopic elastic material properties of the material were identified with a data-driven FEMU optimization method, which minimized the difference between the experimental DIC strains, and the one predicted by the model itself. This model was able to replicate the effect of the woven pattern of the fabric in a computationally efficient way.

A probabilistic mesoscale method was then developed to model the size effect. A three-parameter Weibull-based statistical model was devised to model the probability of failure from the mesoscale FEM calculated stress distribution and the volume of the part. An equivalent stress formulation was used to capture the relevant failure modes, and its maximum value within the specimen volume was the random variable of the model. The parameters of the statistical model and of the equivalent stress were calibrated with an optimization process from experimental data.

The methodology was successfully applied to study the effect of specimen width and width-to-diameter ratio on the open-hole strength of a twill CFRP material. The elastic properties identified for the material at the mesoscale were analogous to that of a unidirectional composite. The calibrated model was subsequently used to analyze the stress concentration and localization induced by circular notches with various widths and width-to-diameter ratios. Thanks to the stress data, the macroscale-level behavior was interpreted as the combination of two opposing mesoscale-level effects, stress concentration and stress localization. An observable size effect was produced with varying specimen width, whereas the scaling of width to hole diameter ratio in the range considered

did not. The statistical model was found to accurately describe the experimental observations, efficiently reproducing an inverse size effect: wider specimens lead to a lower probability of failure, regardless of hole size.

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