A METHODOLOGY TO GENERATE DESIGN ALLOWABLES OF COMPOSITE LAMINATES USING MACHINE LEARNING

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ABSTRACT

This work represents the first step towards the application of machine learning techniques in the prediction of statistical design allowables of composite laminates. Building on data generated analytically, four machine algorithms are used to predict the notched strength of composite laminates and their statistical distribution, associated to material and geometrical variability. Very good representations of the design space (relative errors of around \( \pm 10\% \)) and very accurate representations of the distributions of notched strengths and corresponding B-basis allowables are obtained. The Gaussian Processes models proved to be the most reliable, considering their continuous nature and fast training process. This work serves as basis for the prediction of first-ply failure, ultimate strength and failure mode of composite specimens based on non-linear finite element simulations, providing further reduction of the computational time required to virtually obtain the design allowables for composite laminates.

Keywords: polymer-matrix composites, machine learning, design allowables.

INTRODUCTION

The generation of design allowables for composite laminates is of utmost importance for the design and certification of the composite structures used in the aerospace industry. The determination of these design allowables, which account for the variability associated with curing procedures, geometrical features and defects, usually relies on expensive and time-consuming experimental test campaigns. With the increase of computational power, and the development of high-fidelity numerical models that accurately represent the response and failure of composite materials, alternatives to generate design allowables based on finite element simulations have also been sought out to reduce the certification costs. However, these solutions are still computationally expensive, especially if uncertainty is accounted for. The recent advances on machine learning techniques opens a new window of possibilities for the faster prediction of the structural response of materials and their optimization, by allowing the definition of surrogate models that continuously and analytically describe the design space [1].

In this work, a feasibility study on the application of machine learning techniques for predicting a design allowable, the notched strength of multidirectional composite laminates, is presented, with the main goal of presenting the challenges of applying machine learning techniques for composite laminates and of evaluating the most appropriate algorithms for the determination of composite design allowables.
RESULTS

The data-driven framework is divided into:

i) design of experiments: the input descriptors that describe the specimens geometry (diameter of the hole and the width-to-diameter ratio), material properties (longitudinal Young’s modulus, fracture toughness for longitudinal tensile failure and longitudinal tensile strength) and stacking sequence (two laminate parameters for conventional laminates and two ply angles for double-double laminates) are selected, comprising a total of 7 input descriptors. A more compact description of the problem is obtained using the Buckingham’s \( \pi \) theorem, reducing the 7 input descriptors to 4.

ii) data generation: the design space for open-hole strength is populated using the analytical model described in Ref. [2];

iii) model training and testing: the machine learning models for open-hole tensile strength are trained and their ability to capture the overall response of the design space is evaluated. In this work, four machine learning models (Random Forests, XGBoost, Artificial Neural Networks and Gaussian Processes) are optimized, trained and tested.

iv) generation of design allowables [3]: the ability of the trained machine learning models to capture the variability associated to the uncertainty of material properties and geometrical descriptors [4] is evaluated.

CONCLUSIONS

Regarding the representation of the design space, Gaussian Processes were able to achieve the best performances for very small number of data points, whereas Artificial Neural Networks outperformed all the algorithms for increasing number of data points. The continuous nature of these methods provided a more accurate representation of the design space. The models were shown to accurately represent the statistical distribution of open-hole strength, thus giving good estimation for the B-value design allowable. The Gaussian Processes models proved to be the most reliable, considering their continuous nature and fast training process. This work serves as basis to tackle a more demanding future challenge: the prediction of first-ply failure strength, ultimate strength and failure mode of composite materials based on finite element simulations.

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