SIMULATION OF OFF-AXIS FRACTURE OF THIN-PLY COMPOSITE LAMINATES USING PHASE FIELD

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Abstract

Thin-ply laminates can offer significant advantages for aeronautical design, however, obtaining design allowables for such laminates requires efficient simulation tools. Previous simulation methods used for standard composites pose significant drawbacks when it comes to thin-ply composites, and therefore motivate the advent of new numerical techniques. The Phase Field method, a possible solution, is applied here, in an equivalent single layer approach, to simulate the fracture of multidirectional thin-ply laminates subjected to off-axis loading. The anisotropic nature of the fracture energy multidirectional laminates present is considered through an analytical formulation that feeds the inputs of the method. It is shown that accurate predictions can be obtained compared to experiments for off-axis open-hole tension (OHT) of a hard laminate. But this does not mean the same accuracy will be achieved regardless of the laminate type and lay-up. The issue is nicely illustrated considering a cross-ply laminate that presents the peculiarity of having the same translaminar fracture toughness in the two principal material axes. This creates some inaccuracies in the simulation due to the way the phase field model is formulated. A discussion on this issue and possible ways to circumvent it, under current development, will be presented.

1. Introduction

Failure in composite laminates consisting of thin-ply layers (thickness <0.1 mm) macroscopically occurs with the form of a single crack on a single fracture plane. This plane though is not known a priori. So, methods that alleviate themselves of this restriction, like the Phase Field (PF) method, are a good option to model such laminates at the macroscale level in an Equivalent Single Layer (ESL) approach.

When using an ESL approach, properly incorporating consideration of the anisotropic nature of the laminate becomes tedious. Anisotropic fracture energy can be considered using a structural tensor defined based on scaled directional vectors (Teichtmeister et al., 2017). The scaling constants used in this definition can be considered in a way to properly capture the toughness of the laminate in the two principal directions of the orthotropic laminate. Here, a 2nd order tensor is considered for the structural tensor.

2. Results

The toughness in the two principal directions can be calculated using analytical equations developed by Camanho & Catalanotti (2011) and based on this, the scaling constants for the anisotropic PF model can be defined analytically. The validity of the assumptions made would more easily be understood through off-axis testing. For that reason, some results from the experimental work of Furtado et al. (2021) are used in this case. Taking the respective results for the UD-75 laminate mentioned in their work we can obtain the satisfactory strength predictions that all lie under 5% relative error to the experimental results. Another interesting observation is the fact that the crack path is not aligned with the horizontal axis something also observed in the experiments, and a comparison of both is shown in Figure 1. The good accuracy is attributed to the fact that the fracture toughness distribution considered by the PF model matches reasonably well the off-axis fracture toughness of the orthotropic laminate, here determined using the virtual crack closure technique (VCCT), see Figure 2.

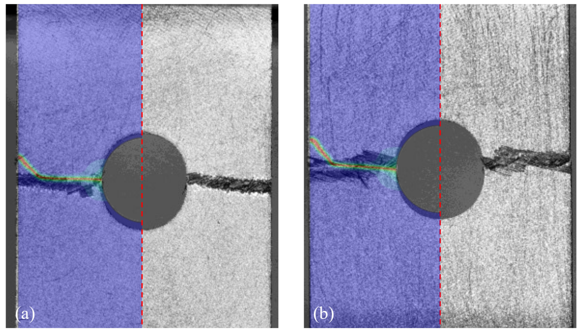

Fig.1 – Comparison of experimental and numerical crack paths for (a) 30° off-axis loading and (b) 60° off-axis loading.

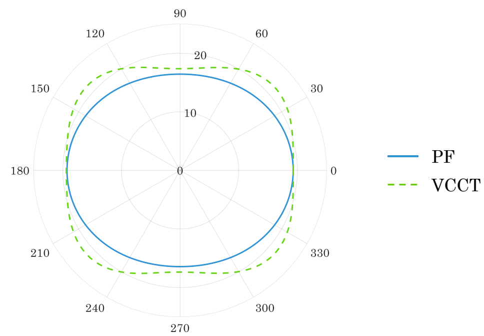

Fig.2 – Comparison of the fracture toughness distribution considered in the PF model with that obtained by VCCT for the hard laminate

3. Conclusions

A way to apply the PF method to simulate the macroscopic failure of thin-ply laminates has been implemented. Successful strength predictions were obtained for engineering laminates. However, the present formulation cannot accurately capture off-axis strengths of highly orthotropic laminates, such as cross-ply laminates. This is attributed to the fact that the 2nd order approximation leads to an elliptical inverse toughness distribution, something that for the cross-ply laminate lies far from actuality. Future work includes the extension of this methodology, e.g., using higher order methods, to accurately capture the anisotropic fracture energy required to model in full the off-axis behavior of general multidirectional laminates of any level of anisotropy.

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