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OPEN-HOLE TENSION ANALYSIS OF CFRP COMPOSITE USING PROGRESSIVE DAMAGE MODELLING

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ABSTRACT

This study aims to develop a 3D progressive damage model (PDM) for analyzing the behavior of fiber-reinforced plastics (FRP) laminates using the open-hole tension test. The proposed PDM is based on a linear damage propagation law and Hashin's 3D failure criterion. To analyze composite laminates, the VUMAT subroutine is incorporated into an Abaqus/explicit™ program. Where, finite element analysis reveals that the strain accumulation around the hole closely resembles the observations made in the experimental study, indicating the presence of stress concentration near the hole. The results demonstrate that the multi-directional $[45/-45/0/90]_4$ ply sequence experiences strain accumulation and crack propagation primarily in the 45-degree direction. Interlaminar shear and transverse cracking are identified as the primary failure mechanisms in multi-directional ply composite materials.

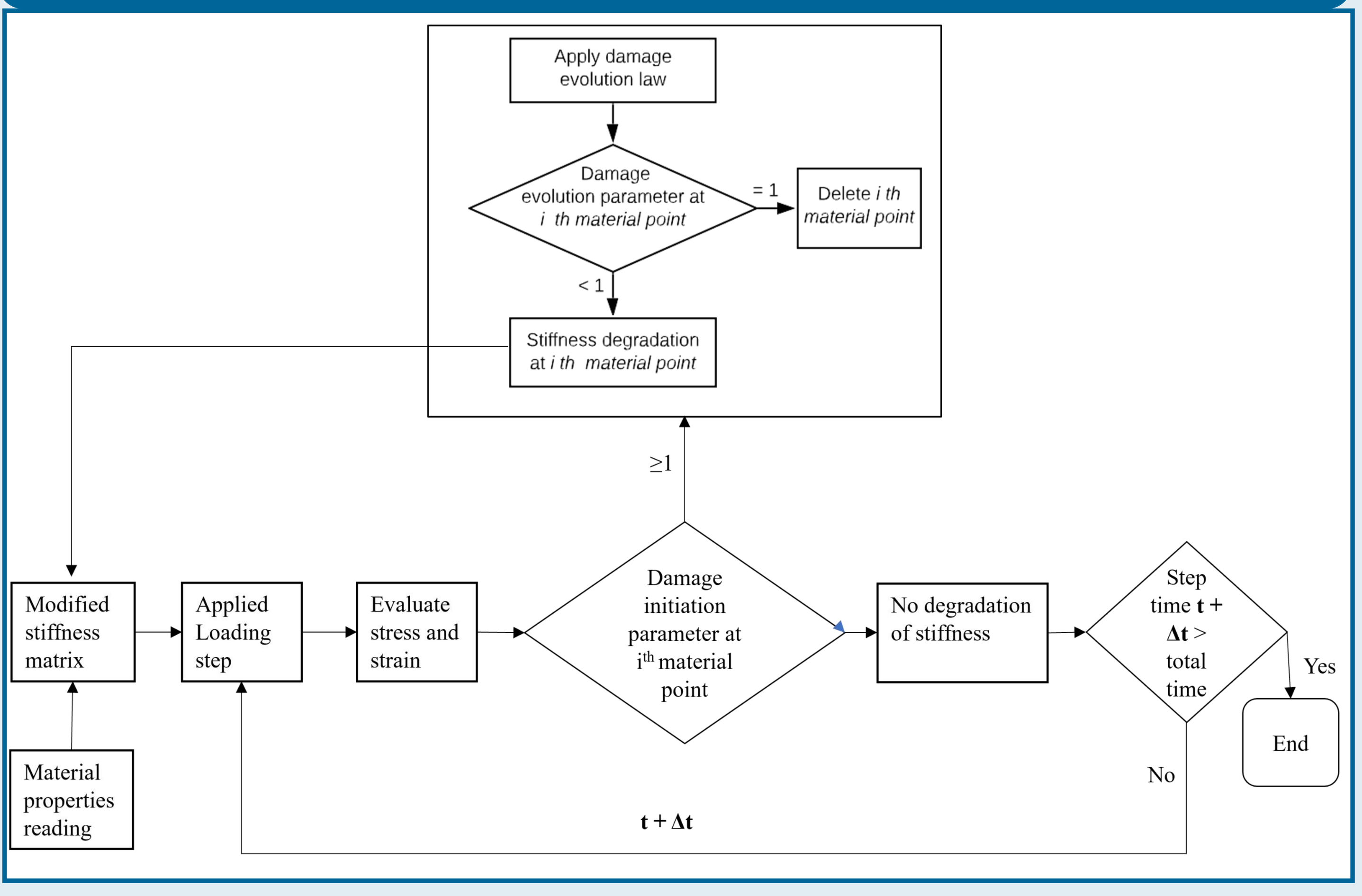
INTRODUCTION

- FRP composite materials are widely used in aerospace, automobile, defense, marine, sports, and biomedical applications [1].
- They offer better mechanical properties, including high specific stiffness, strength, and corrosion resistance.
- However, FRP composites exhibit complex failure under structural loading conditions due to their non-homogeneous and anisotropic behavior.
- Progressive damage models (PDM) are commonly employed to analyze FRP failure [2].
- PDMs help predict damage initiation and evaluation under complex loading conditions.
- For laminates made of unidirectional fiber-reinforced plastics (UD-FRP) [3], several failure theories exist.
- The Hashin [4], LaRC04 [5], Puck [6], and LaRC05 [7] failure criteria are widely accepted for their reasonably precise outcomes.

OBJECTIVES

The objective of this study is to develop and validate a predictive model by numerically and experimentally investigating the damage behavior and strain fringes on the tensile properties of multilayer carbon fiber reinforced plastic (CFRP) composites during drilling.

PDM FLOW CHART



CONCLUSIONS

The experimental study validated the results obtained from the FE analysis, leading to the following conclusions.

- Firstly, strain accumulation around the hole is similar in the FE and experiment analyses. This is due to stress built-up near the hole.
- Secondly, in the multi-directional $[45/-45/0/90]_4$ ply sequence, strain accumulation and crack propagation occur in the 45-degree direction.
- Finally, interlaminar shear and transverse cracking are the primary causes of failure for multi-directional $[45/-45/0/90]_4$ ply composite materials.

The results from the experiment can be further used to determine the tensile strength, stiffness, and strain of the composite material. Through the proper understanding of stress concentration spreading around an open hole in a particular sequence of CFRP composite, it is possible to prevent damage initiation and evolution through the proper selection of geometric and process parameters.

RESULTS

- A finite element model is created to incorporate in-plane progressive failure.
- The 3D Hashin's criteria are utilized to identify the initiation of damage in the in-plane failure.
- A linear softening law is employed to represent the evaluation of the damage.

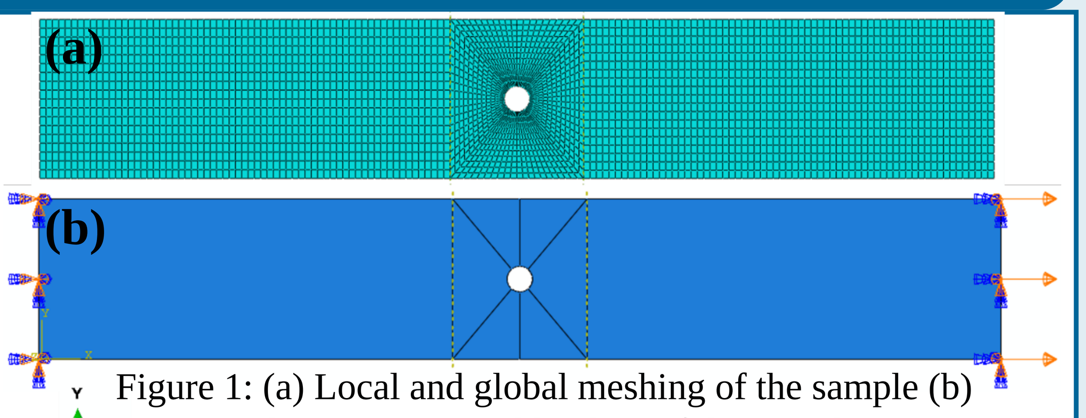


Figure 1: (a) Local and global meshing of the sample (b) Displacement-control loading of the sample.

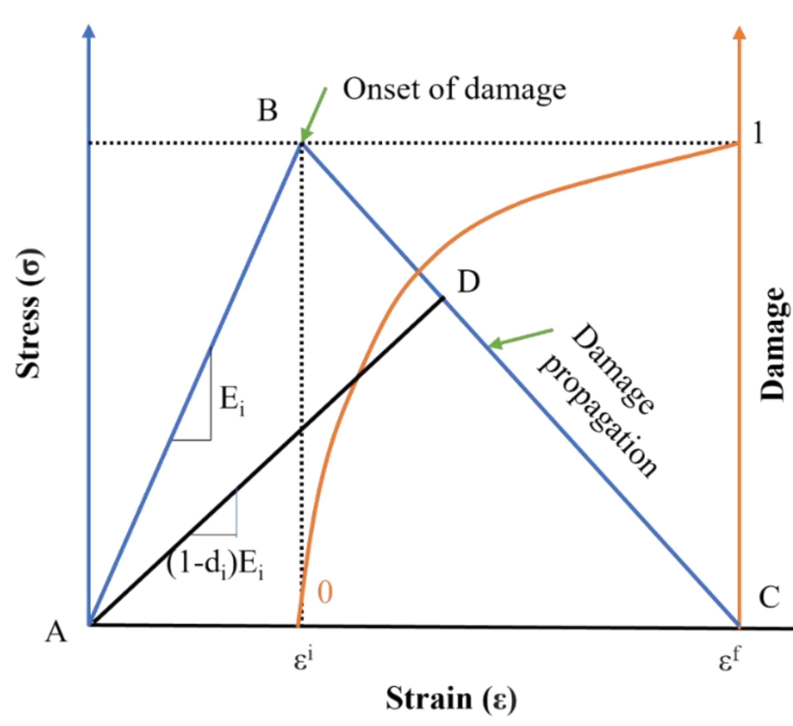


Figure 2: Schematic of stress and damage parameters response with changes in strain.

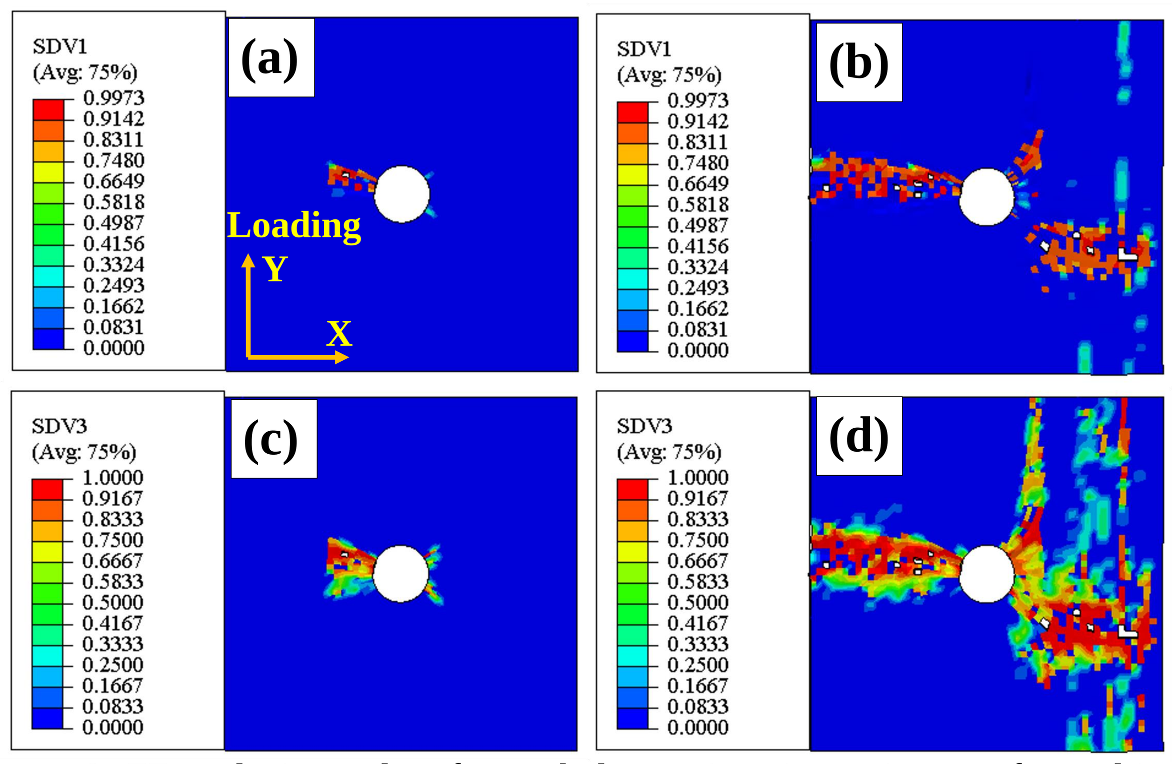


Figure 3: FE analysis results of open-hole quasi-static tension test for multi-directional $[45/-45/0/90]_4$ ply sequence (a) Fiber damage initiation (b) Fiber damage evolution (c) Matrix damage initiation (d) Matrix damage evolution.

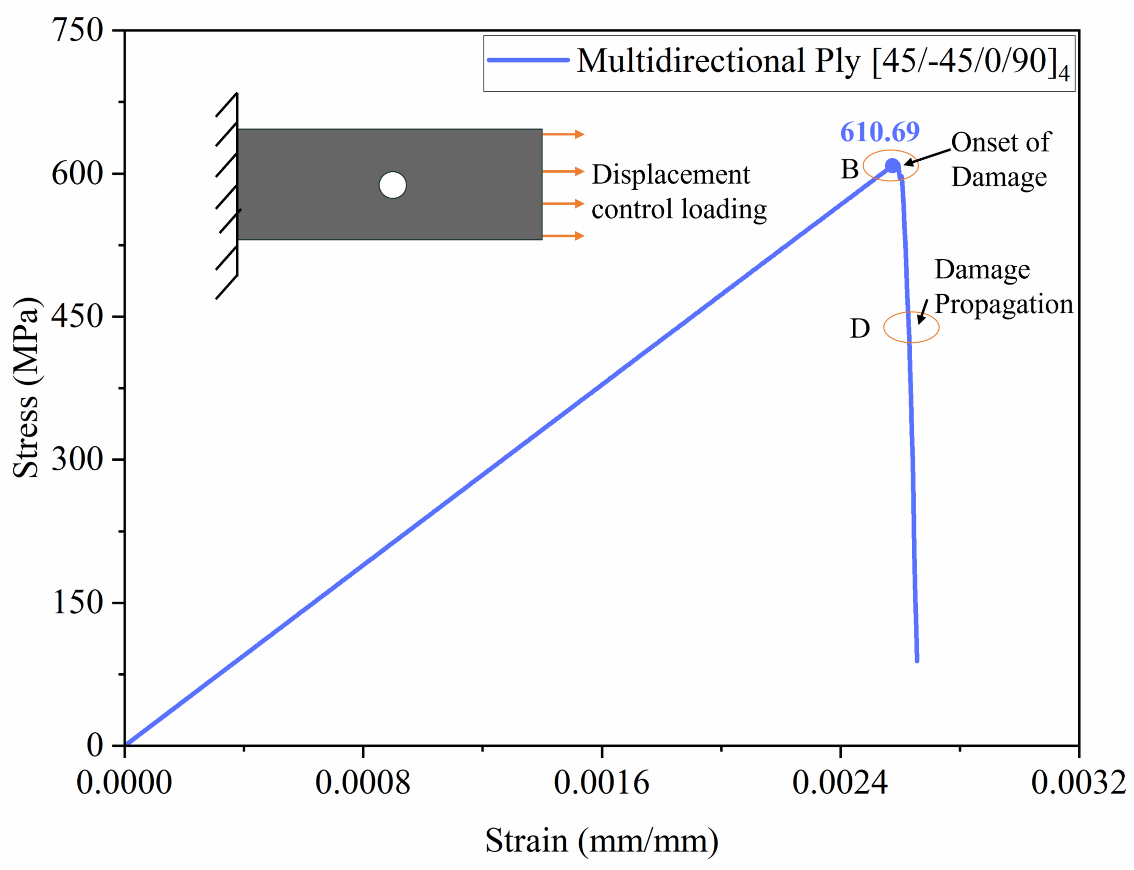


Figure 5: *FE* results for stress variation with strain during uniaxial tension.

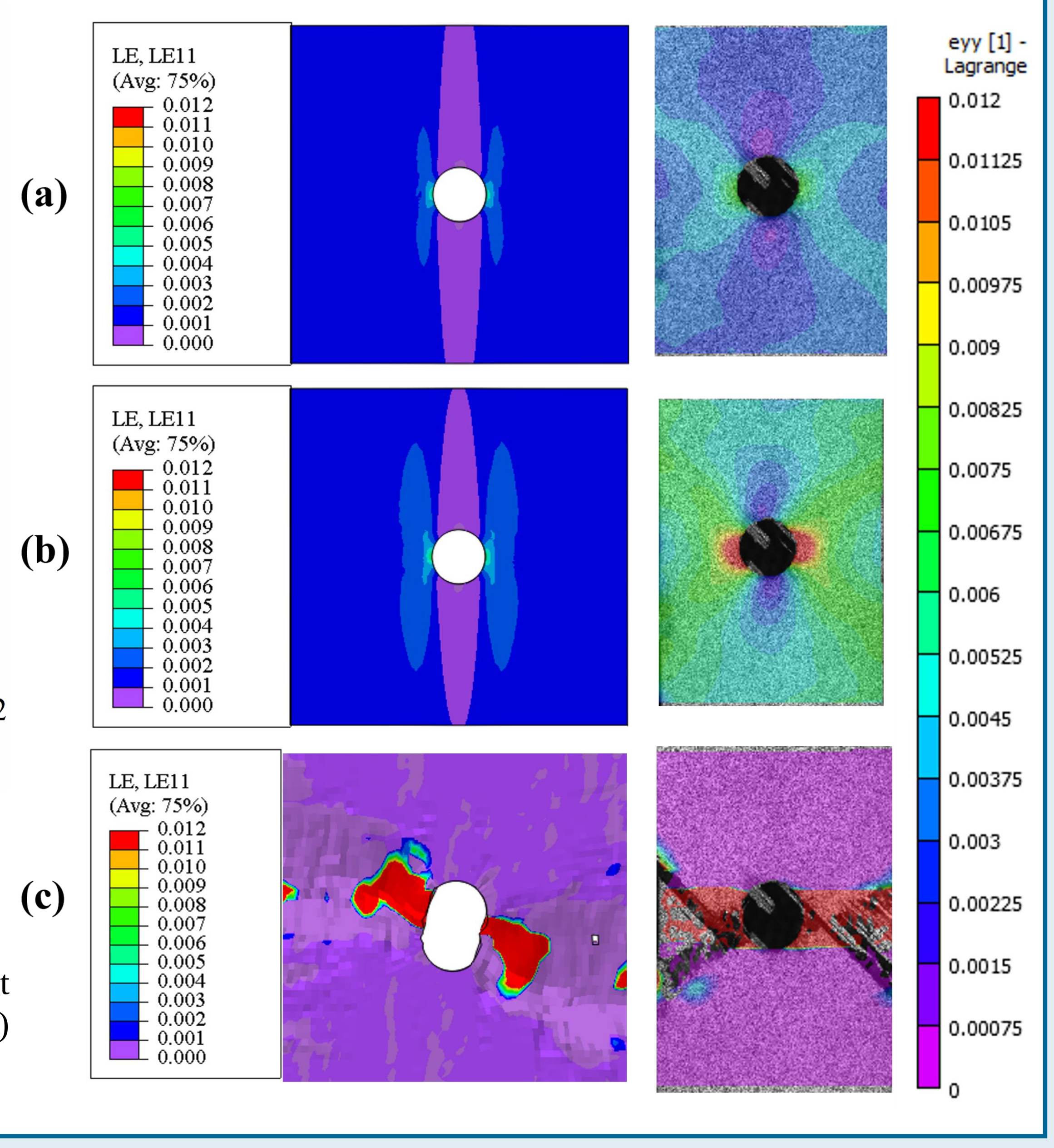


Figure 4: Strain mapping of multi-directional ply at different phases (a) localize strain concentration (b) damage initiation (c) fracture condition.

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