MODELING FAILURE MECHANISMS OF 3D ORTHOGONAL INTERLOCK HYBRID TEXTILE COMPOSITES IN FLEXURE

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Summary The flexural response of a three-dimensional (3D) orthogonal interlock hybrid textile composite has been investigated under quasi-static three-point bending. Fiber tow kinking on the compressive side has been found to be a strength limiting mechanism for this class of material. An architecture based 3D finite element model that implements Schapery Theory (ST) in conjunction with the Discrete Cohesive Zone Model has been proposed to predict the damage characteristics of the composites.

INTRODUCTION

Textile Composites are increasingly becoming a viable alternative to other types of high performance composites in industrial applications. Owing to the reinforcement through the thickness, 3D textile composites offer increased resistance to delamination that often occurs in layered pre-preg tape type laminated composite materials. Various analytical models have been proposed in the literature to study the elastic properties of textile composites. It has been pointed out that though the geometric distortions resulting from curing and consolidation have little effect on elastic moduli, these manufacturing induced imperfections can greatly affect damage progression and the resulting mechanical properties such as strength, strain to failure, and fatigue life. The focus of this paper is to investigate the strength limiting mechanism in flexural response of quasi-statically loaded 3D composite panels through validated, mechanism based modeling.

MATERIAL SYSTEM

The material studied in this research is a 3D through-the-thickness orthogonal interlock hybrid textile composite that consists of SC-15 matrix, carbon fibers, glass fibers, and Kevlar fibers. Kevlar is used as Z-fibers running parallel to the warp direction and drawn from top to bottom and over the weft fibers, as schematically shown Fig. 1. Measurements were taken from optical micrographs to characterize the geometry. The fiber volume fraction in a fiber tow is determined by analyzing scanning electron microscopic (SEM) images of tow cross-sections.

EXPERIMENT

Three-point flexure tests were performed on a hydraulically activated MTS machine at a loading rate of 0.0004 in/sec to achieve a quasi-static loading condition. The outer surface of the specimen was implemented with a speckle pattern using an air brush. The full-field surface strain histories were obtained via the digital image correlation (DIC) technique. A representative experimental load-displacement curve is shown in Fig. 2, where the observed damage events are annotated. The material exhibits a "plastic-like behavior", more representative of a metal, indicating considerable damage tolerance. It is noted that the peak load is determined by the onset of tow kinking on the compressive side. This agrees with the findings reported in [1, 2] that kink band formation is the strength controlling mechanism of failure. The final failure of the specimen is governed by tow rupture on the tensile side. Figure 3 shows a photomicrograph of the kink band formation observed under a SEM.

NUMERICAL MODEL

The tow kinking phenomenon and the surface strain patterns suggest that the geometric characteristics of textile reinforcement play a key role in influencing the mechanical response of this type of material. Hence an architecture based finite element (FE) model that incorporates constitutive relations that encompass damage is proposed to predict the failure modes observed in the experiment. The proposed finite element (FE) model is composed of a series of representative unit cells (RUCs) that account for a quarter of the specimen. Displacement continuity is enforced on the common boundary of the two adjacent RUCs. Quarter-symmetric boundary conditions are imposed to achieve a quasi-static three-point flexural loading condition as illustrated in Fig. 4.

The properties of fiber tows are determined based on a nonlinear version of the composite concentric cylinder model (CCM) [3], resulting in a transversely isotropic solid. The SC-15 matrix material is modeled as an elastic-plastic solid obeying J2 incremental theory of plasticity. The computed surface strain fields are compared against the experimental

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DIC results in the pre-damage region as shown in Fig. 5. It can be concluded that the proposed FE model can successfully capture the strain localizations when the textile composite deforms elastically. To predict the critical tow kinking stress, a fiber tow is modeled as an inelastic degrading transversely isotropic solid based on Schapery Theory (ST) [4]. These features are built into a user-defined material subroutine that is implemented through the commercial FE software ABAQUS. This subroutine is called at each material point and the material incremental constitutive matrix is updated accordingly. The key to success is that all the calculations are performed in the instantaneous material frame by tracking the rotation of the principal material axis. Discrete cohesive elements [5] are inserted between fiber tows and matrix to allow for debonding which occurs after tow kinking.

CONCLUSIONS

The flexural response of 3D orthogonal interlock hybrid textile composites has been examined experimentally and modeled via an architecture based FE model. Fiber tow kinking on the compressive side of the bending specimen has been found to be the strength limiting mechanism. The proposed FE model has successfully captured the surface strain localizations in the pre-damage region. The computational model that implements ST as a tow damage constitutive relation in conjunction with Discrete Cohesive Zone Model (DCZM) between the fiber tows and matrix provides insight into mechanisms that control final collapse and failure of the 3D composite.

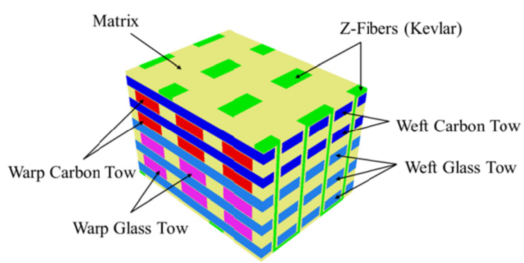


Fig. 1. Ideal architecture.

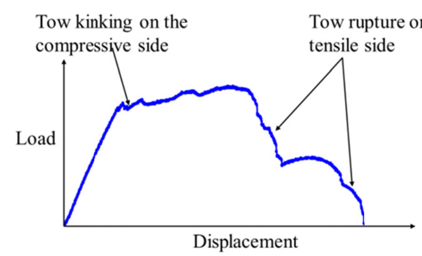


Fig. 2. A representative experimental load-displacement curve with annotated damage events.

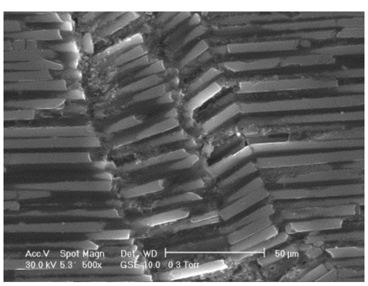


Fig. 3. Kink band formation on the compressive side of the specimen.

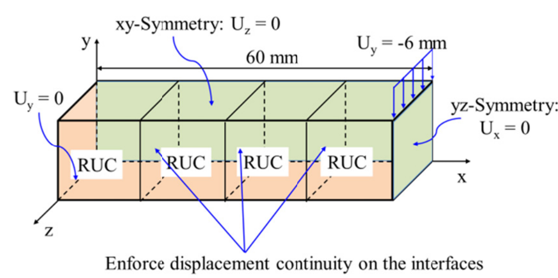
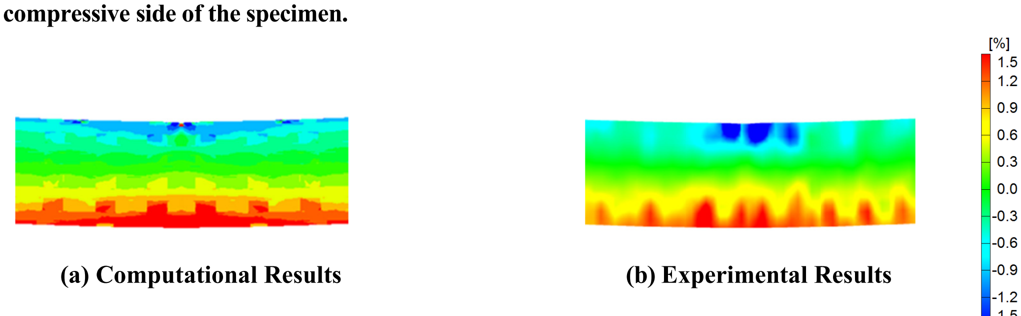


Fig. 4. Boundary conditions of the FE model.



(a) Computational Results **(b) Experimental Results**

Fig. 5. Comparison of the axial strain fields.

References

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