Performance of Thin Walled Composite Beams with Stochastic Properties under Matrix cracking Damage

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Introduction

Thin walled composite beam structures are used in several engineering applications. The composite materials, despite of their significant advantages, prone to complicated damage mechanisms are compared to metals due to their heterogeneous composition and directional properties [1]. Matrix cracking is the first failure mode which leads to the severe damage modes such as debonding, delamination and fiber breakage. Therefore, matrix crack detection is a useful approach to monitor structural health and identify the point where more dangerous damage mechanisms begin. However, matrix crack detection problem becomes complicated in reality due to involvement of various uncertainties in the composite structures. The uncertainties range from the statistical nature of the material properties of constituent ingredients (e.g., fibers and resin) to the randomness in the fabrication (e.g., layup and curing) and manufacturing processes [2].

In this paper, the behavior of damaged thin walled composite beam having material uncertainties is studied. The matrix crack damage is modeled through the extension, bending and extension–bending stiffness matrices. The material uncertainties are introduced using Monte Carlo simulation using the stochastic properties obtained from previous experimental work. The cross-sectional stiffness properties are obtained using mixed beam approach. The effects of matrix cracking are under uncertainties are studied on the cross-sectional stiffness properties and beam responses.

Cross-Sectional Stiffness Properties:

The matrix cracking in the composite is inserted through the extension (A), extension–bending (B) and bending (D) stiffness matrices [2]. Material and fabrication uncertainties are introduced using the Monte Carlo simulation (MCS). The stochastic behaviors of material properties E_1, E_2, G_{12} and υ_{12} are obtained from the earlier experimental studies [2,3]. Thin walled composite beam is modeled as a single-cell box beam with outer width= 203.2 mm and outer depth=38.1 mm, having 28 plies with ply thickness=0.127 mm and a balanced layup as $[0_4/(15/-15)_3/(30/-30)_2]_s$ in all the walls. The beam length is considered as 5 m.

The cross-sectional stiffness properties for the 6000 samples with damage levels of matrix crack densities of zero, 1.0, 2.0 and 3.0 are obtained using thin walled beam analysis and matrix crack model. Figure 1 shows the histograms of out-of-plane bending and torsion cross-sectional stiffness properties of the beam with damage level with crack densities of zero, 1.0, 2.0 and 3.0.

Beam Response

While developing the beam damage detection system, beam stiffness cannot be measured directly. The effect of matrix cracking on the slopes of the beams for unit bending and torsion loading with material uncertainty are studied here. Figure 2 shows the plots of lower (min) and upper (max) limits of the beam bending slope and twist responses of the beams at different crack densities.

Conclusion

The following conclusions are drawn from the numerical results:

1. Bending stiffnesses are useful for distinguishing the damage of crack density of 3.0 from undamaged beam.
2. Torsion stiffness indicates that beams with crack density of 1.0 can be well separated from the undamaged beams and also beams with crack density of 3.0 can be well separated from beams with crack density of 1.0.
3. The bending and torsion responses can be jointly used for predicting crack density of 1.0 which indicates crack initiation and crack density of 3.0 which indicates initiation of higher damage levels.

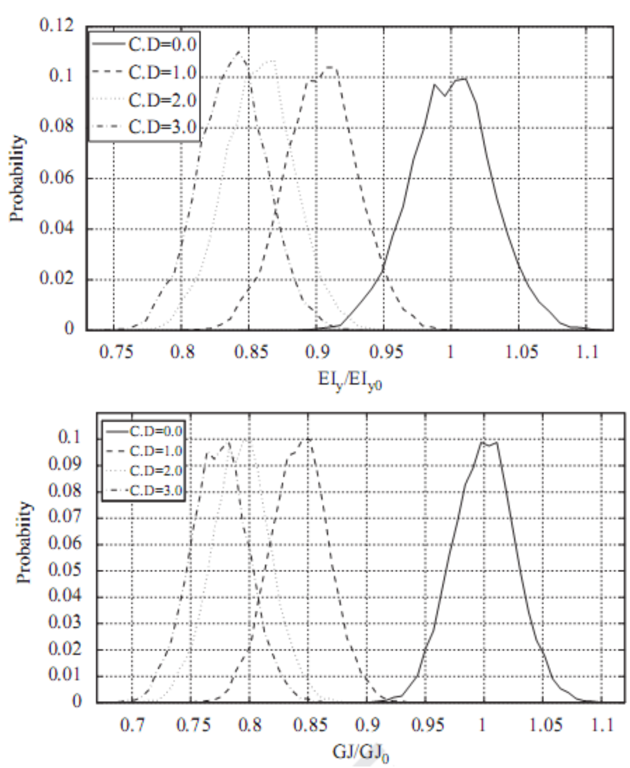

Figure 1: C/S stiffnesses at different crack densities.

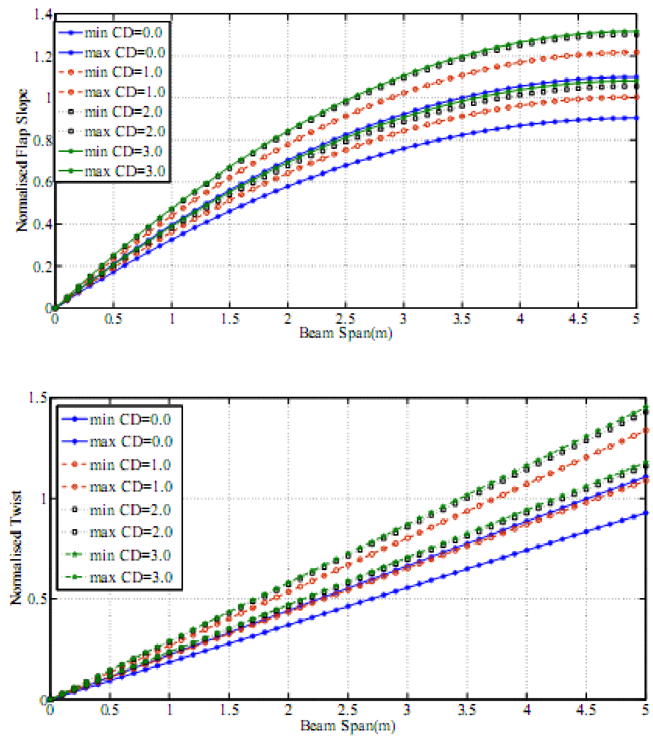

Figure2: Tip deflections for different crack densities

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