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INVESTIGATION OF FAILURE MECHANISMS IN L-ANGLE COMPOSITE LAMINATES

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ABSTRACT

Highly curved composites such as L-angle composite laminates, used at the junction between two perpendicular panels experience unfolding failure. These laminates are typically used in critical components such as aircraft wing spars, hence understanding of their failure mechanisms becomes crucial. Unfolding failure is typically associated with the interlaminar stresses, eventually leading to sudden delamination, in the curved sections when they are loaded under an opening bending moment. However, depending on the stacking sequences, failure mechanisms experienced in curved composite laminates, may have different causes. This study addresses the two prominent failure mechanisms occurring in L-shaped composite beams.

1. Introduction

Generally, the interlaminar properties in composite laminates are relatively weak, leading to interlaminar delamination failures under certain loading conditions. Unidirectional (UD) curved composite laminates exhibit pure delamination dominated failure when they are subjected to opening bending moments. This classical failure mechanism occurring in UD curved laminates is termed as traditional unfolding failure. Interlaminar tensile strength (ILTS) is one of the interlaminar properties that provides information about the delamination onset in the thickness direction.

Four point bending tests (4PBT), according to test standards AITM1-0069[1] or ASTM D6415[2], can be used to obtain the ILTS values. Both the test standards are designed to obtain ILTS values in UD curved composite specimens. When this test is applied to curved composite laminates with different ply orientations, then it has been observed that the damage is initially initiated by intra-laminar matrix crack which propagates as a delamination under the presence of high interlaminar stresses [3]. This type of failure occurring in non-UD curved laminates is termed as induced unfolding. Cross-ply (CP) and Quasi-isotropic (QI) laminates with specific stacking sequences are used to highlight this induced unfolding failure.

2. Test results

A test campaign comprising three sets of specimens has been carried out. The specimens were manufactured and tested according to the AITM1-0069[1] test standard for five different thicknesses.

2.1. Traditional unfolding failure

Test data obtained from the series of four point bending tests on UD curved specimens with 8, 16, 24, 32 and 48 UD plies was used to obtain the corresponding ILTS values following AITM1-0069 procedures. Fig.1a represents the ILTS values obtained for all the specimens with various thicknesses. ILTS value obtained for the specimens, except for the ones with 8 plies, is around 100 MPa. This difference is due to the higher impact of manufacturing defects in the thinner specimens. Fig. 1b. represents the delamination in a specimen with 24 plies. The delamination locations in the tested samples are in line with the ones obtained in [4].

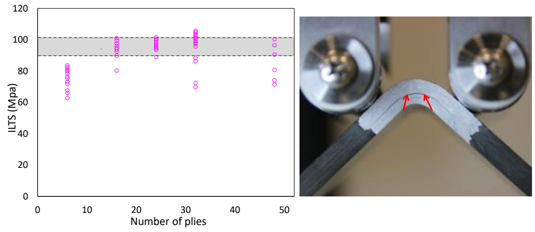

Figure 1: UD[0º] test results (a) ILTS plot (b) Delamination

2.2. Induced unfolding failure

Specimens with 8, 16, 24, 32 and 48 plies and $[0,90_2,0_n]_S$ stacking sequences were subjected to 4PBT. Here, `n` indicates the number of 0º plies between the two 90º plies on both sides. This stacking sequence is chosen to illustrate the existence of induced unfolding phenomenon. Fig.2a represents the obtained ILTS vs. number of plies. It is very clear that the apparent ILTS for CP specimens is around 50MPa, which is significantly lower than the ILTS of UD specimens.

Fig.2b represents the matrix-dominated initial cracks in the innermost 90º plies, which might have further propagated to form interlaminar cracks between 90º//0º interface. This initial matrix crack doesn´t result in the total failure of the specimen but leads to very low load drop that can be recovered. The second load drop leads to delamination dominated crack as highlighted in the Fig.3b. Induced unfolding failure locations compared with the ones obtained from [4] are in good agreement.

Test campaign of Quasi-isotropic layup laminates with [10/80/10] % of [0º/±45º/90º] stacking sequences, similar to spar/rib configurations, are tested to precisely analyze the induced unfolding failure and the interaction between intra-laminar matrix cracking and interlaminar delamination.

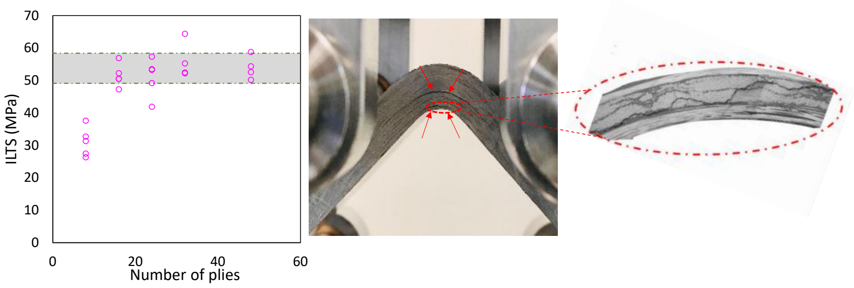

Figure 2: CP test results (a) ILTS plot (b) Cracks

3. Conclusions

Two main failure mechanisms, traditional unfolding occurring in UD and induced unfolding occurring in non-UD laminates are analyzed thoroughly using the test results of UD, CP and QI specimens. The failure locations are compared with the ones obtained using the stress analysis methods from [4].

Furthermore, a detailed ongoing finite element study is expected to provide a complete understanding of both the failure mechanisms and their interactions. Abaqus models combining cohesive elements with bilinear traction separation law to simulate the interlaminar delamination and phase-field for modeling intralaminar matrix failure are being used. The effect of residual stresses is being considered during the simulations.

REFERENCES

[1] ASTM D 6415/D 6415 M-06a, *Standard test method for measuring the curved beam strength of a fiber-reinforced polymer matrix composite*, ASTM, 2007.

[2] AITM1-0069 issue-02, *Determination of curved beam failure load of fiber reinforced plastics*, AITM, 2011.

[3] J.M.González-Cantero, E.Graciani, B.López-Romano, F. Paris, *Competing mechanisms in the unfolding failure in composite laminates*, Compos Sci Technol, 156:223-230, 2018.

[4] J.M.González-Cantero, *Study of the unfolding failure of curved composite laminates*, PhD Thesis, University of Seville, Spain, 2017.