University of BRISTOL

Open Hole Tension-Tension Fatigue in Composites

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ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

Project Outline

- An extensive experimental program has been carried out to understand the sequence of damage events throughout the life of notched composite laminates loaded in tension-tension fatigue.

- Several tests were interrupted during the decrease in stiffness for both ply and sublaminate configurations.

- X-ray CT scans were carried out for all interrupted tests to determine the level of damage in each specimen.

Open Hole Test Program

- Specimens were loaded to failure in static tests.
- Based fatigue load levels both experimentally and numerically on the average of their respective static failure loads.
- Fatigue tests were ran at various load levels at 5Hz up to 1E6 cycles or until failure.
- Each test is at constant amplitude with an R ratio of 0.1.
- Failure is taken as a 15% reduction in stiffness.

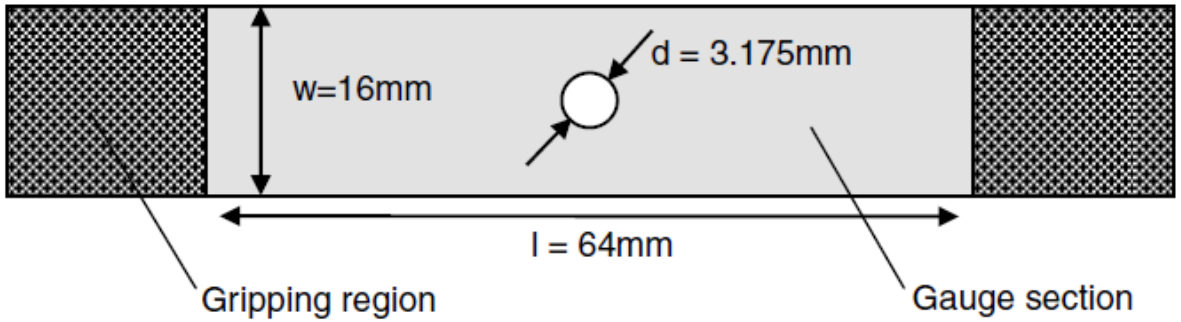

Figure 1. Specimen Geometry

Ply Scaled Testing

- Hole size of 3.175 mm, ply level scaling, symmetric quasi-isotropic layup with ply orientations $[45_2, 90_2, -45_2, 0_2]_S$
- Tests were carried out in fatigue at 40%, 50%, 60%, 70% and 80% of the static failure load for ply level laminates.
- The same mode of failure is observed for specimens in fatigue to that of the static specimens which is delamination dominated. Dominant failure mode is the delamination at the 0/-45 interface.
- Runouts to 1E6 cycles are observed at 40% severity.

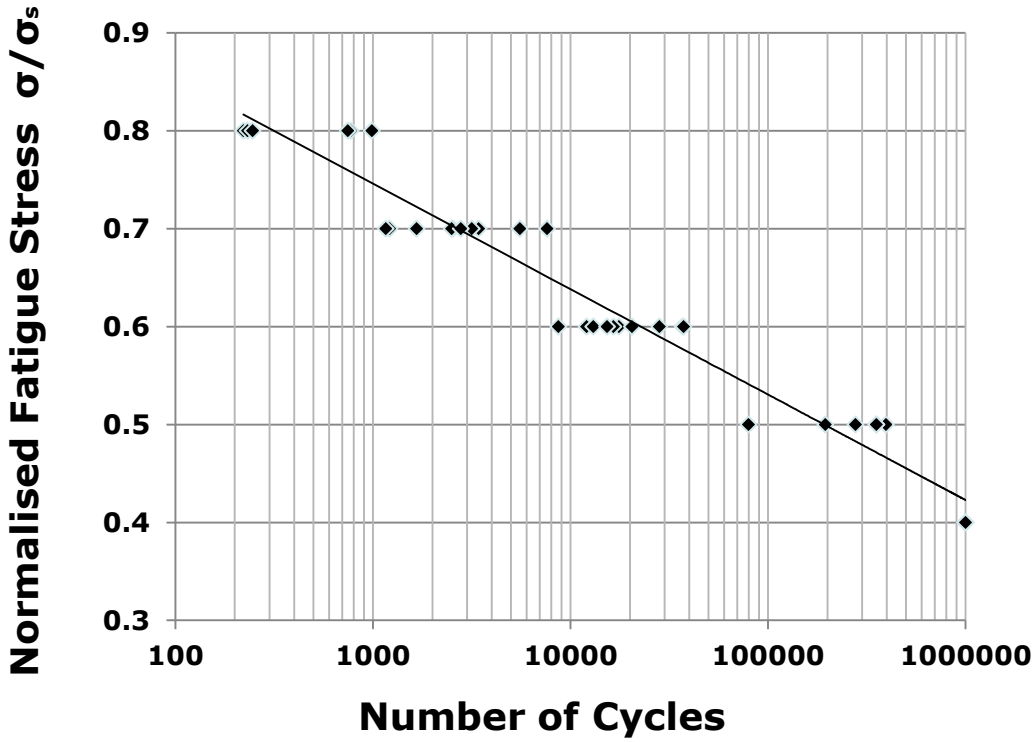

Figure 2. shows SN Curve for ply scaled Specimens

Ply Scaled Interrupted Testing

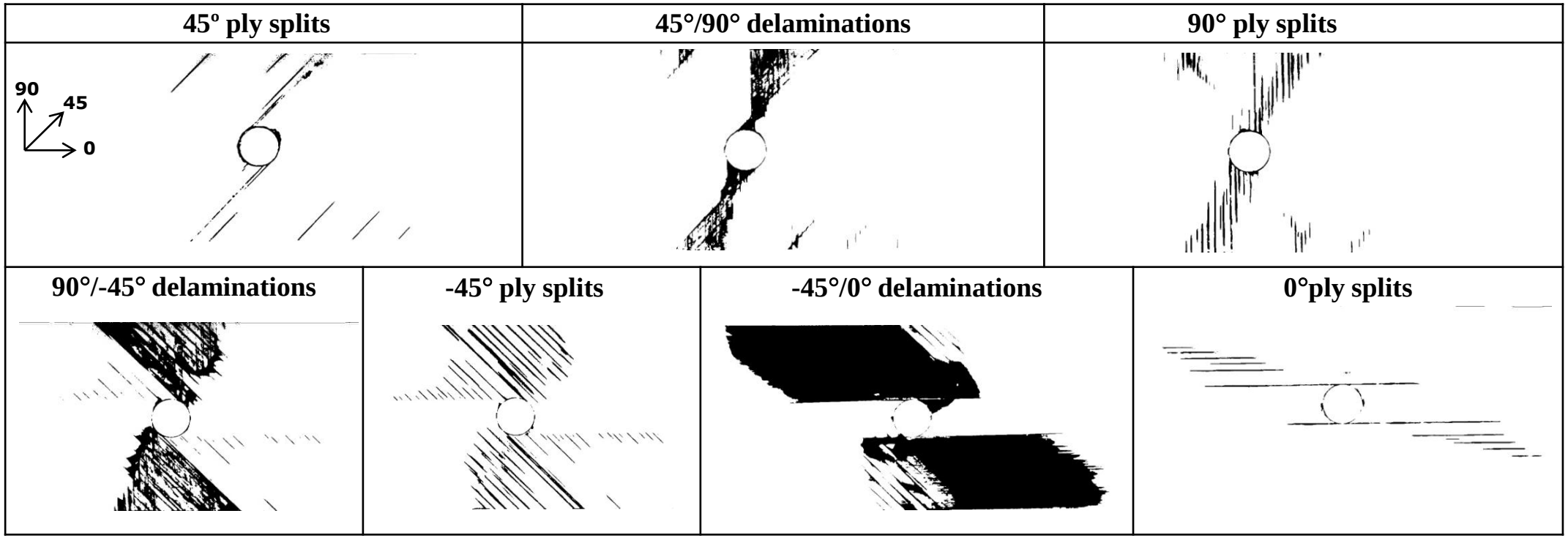

Figure 3. Shows Interrupted test (b) sample 033, X-Ray CT Images.

Figure 4. Showing the progression of the delamination at the 0/-45 interface for several interrupted tests of increasing levels of damage.

Sublaminate Scaled Testing

- Hole size of 3.175 mm, sublaminate level scaling, symmetric quasi-isotropic layup with ply orientations
  $[45, 90, -45, 0]_{2s}$
- Tests were carried out in fatigue at 55%, 60%, 65%, 70%, 80%, 85% and 90% of the static failure load for sublaminate level laminates.
- Mode of failure in static tests defined as 'pullout', a fibre dominated failure mode. However for specimens in fatigue there is a change to a delamination dominated failure mode.
- Runouts to 1E6 cycles is observed consistently at 55% severity.

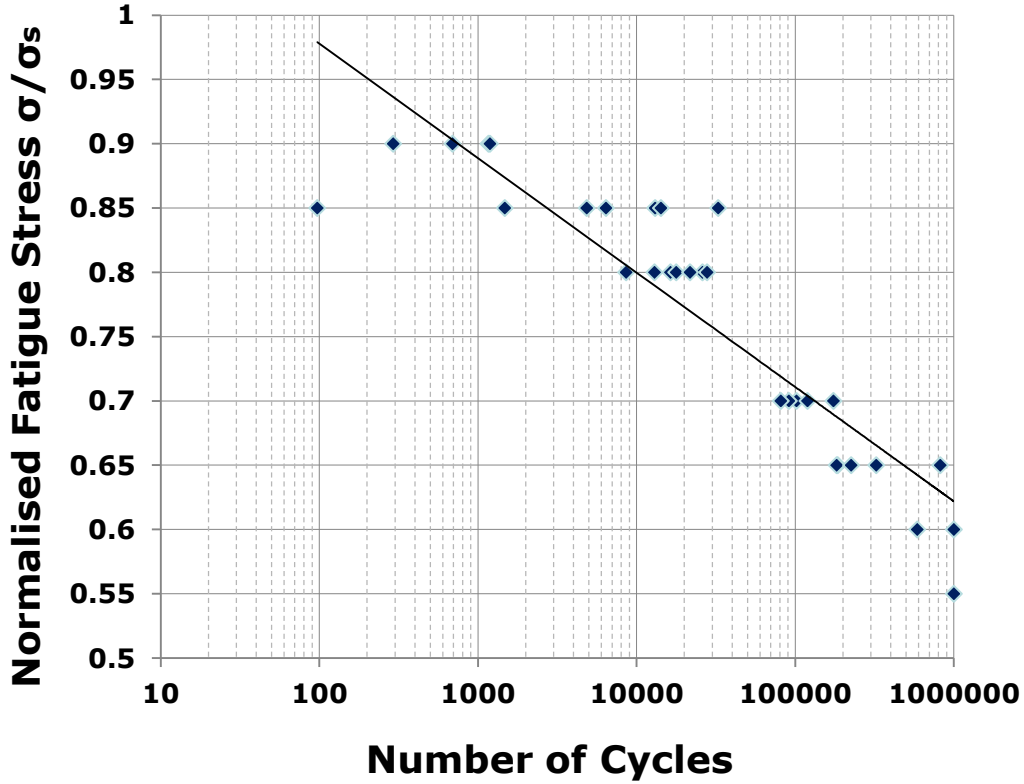

Figure 5. show SN Curve for sublaminate scaled Specimens

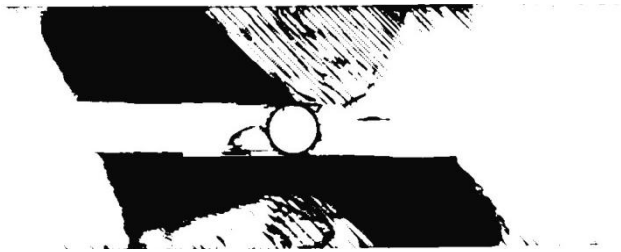

Figure 6. X-ray CT image of the 0/-45 delamination of an interrupted test specimen from the fatigue sublaminate scaled program.

FE Modelling

- Fully integrated solid interface elements were placed between coincident nodes in order to predict the initiation and propagation of subcritical damage.
- Previous experimental observations had shown that these were the major splits that are significantly involved in specimen failure.
- Quasi-static numerical failure loads agree well with static experimental failure loads.
- A half model through thickness is used as the layup under investigation is symmetric about the centreline.
- Thermal residual stresses were included in the model to simulate cool-down from the 180^0C processing temperature to room temperature.

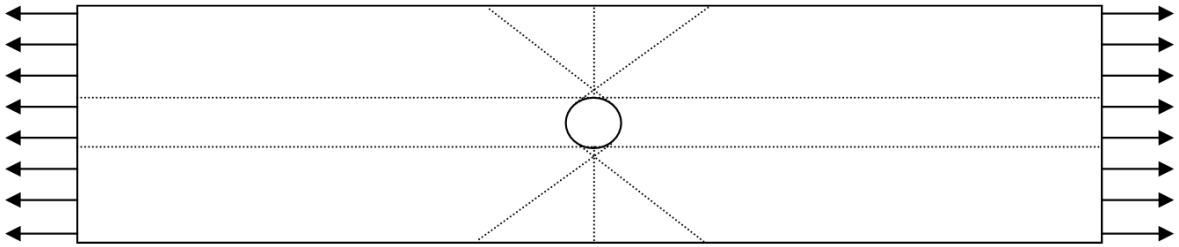

Figure 7 showing location of inserted splits within the model and loading condition.

FE Modelling

- The model is mode I and II maximum interfacial strength dominated where mode I strength is 60 MPa and mode II strength is 90 MPa.
- A crack tip tracking formulation is used for accurate determination of crack fronts.
- The fatigue FE Modelling results also agree well to that of the experimental results (figure 8).

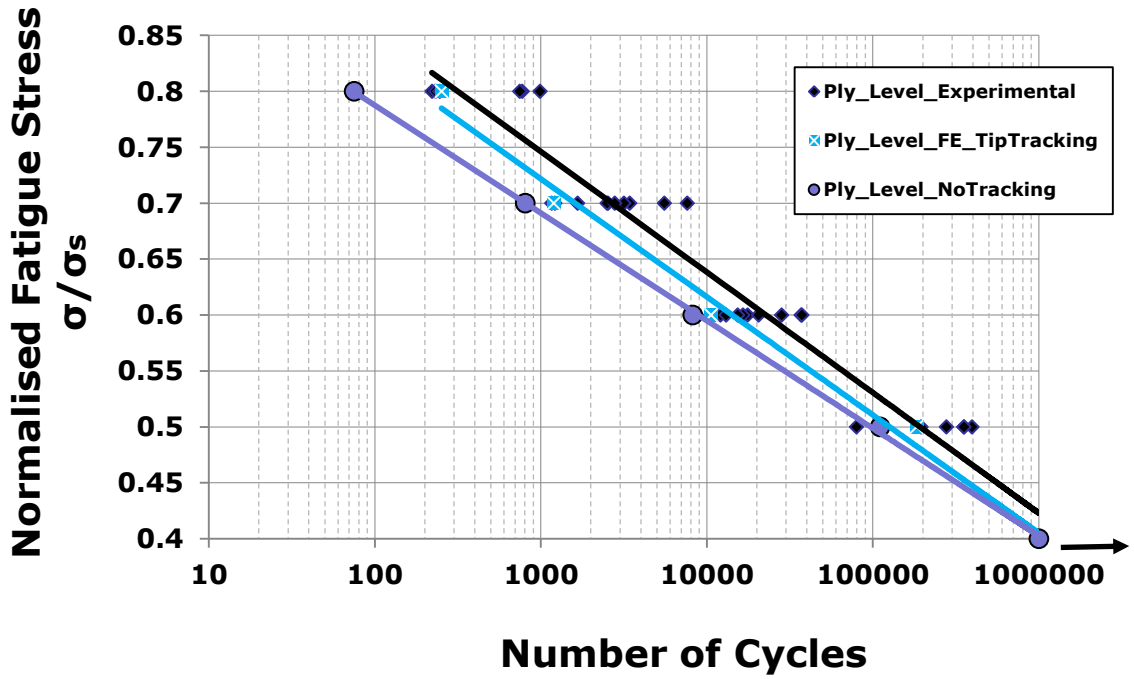

Figure 8 Shows FE results for the ply scaled program with the experimental results superimposed.

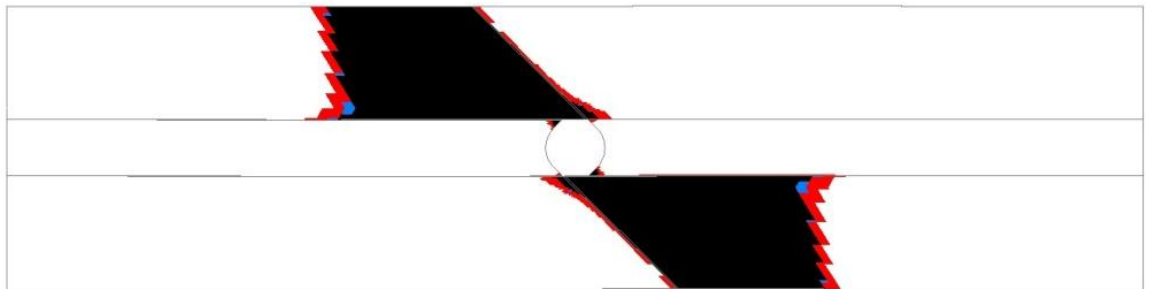

Figure 9. Progression of the delamination at the 0/-45 interface in the FE model.

Conclusions and Further Work

- Ply-level Specimens failed with a delamination dominated mode in both quasi-static and fatigue tests.
- Sublaminate Specimens failed with a fibre dominated mode in quasi-static tests, but in fatigue testing a delamination dominated failure mode is observed.
- The location and sequence of failure events from FE modelling agreed well with those of the experimental results.
- Future objectives includes a pilot study recently started on a new sublaminate configuration which is shown to give a brittle failure mode in static tests.
- Residual strength testing for runouts on recent sublaminate study plus the new configuration.

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Any questions?