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MITSUBISHI HEAVY INDUSTRIES

ON PREDICTING TRANS-LAMINAR FRACTURE OF QUASI-ISOTROPIC CARBON/EPOXY LAMINATES USING R-CURVES

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bristol.ac.uk/composites

EPSRC
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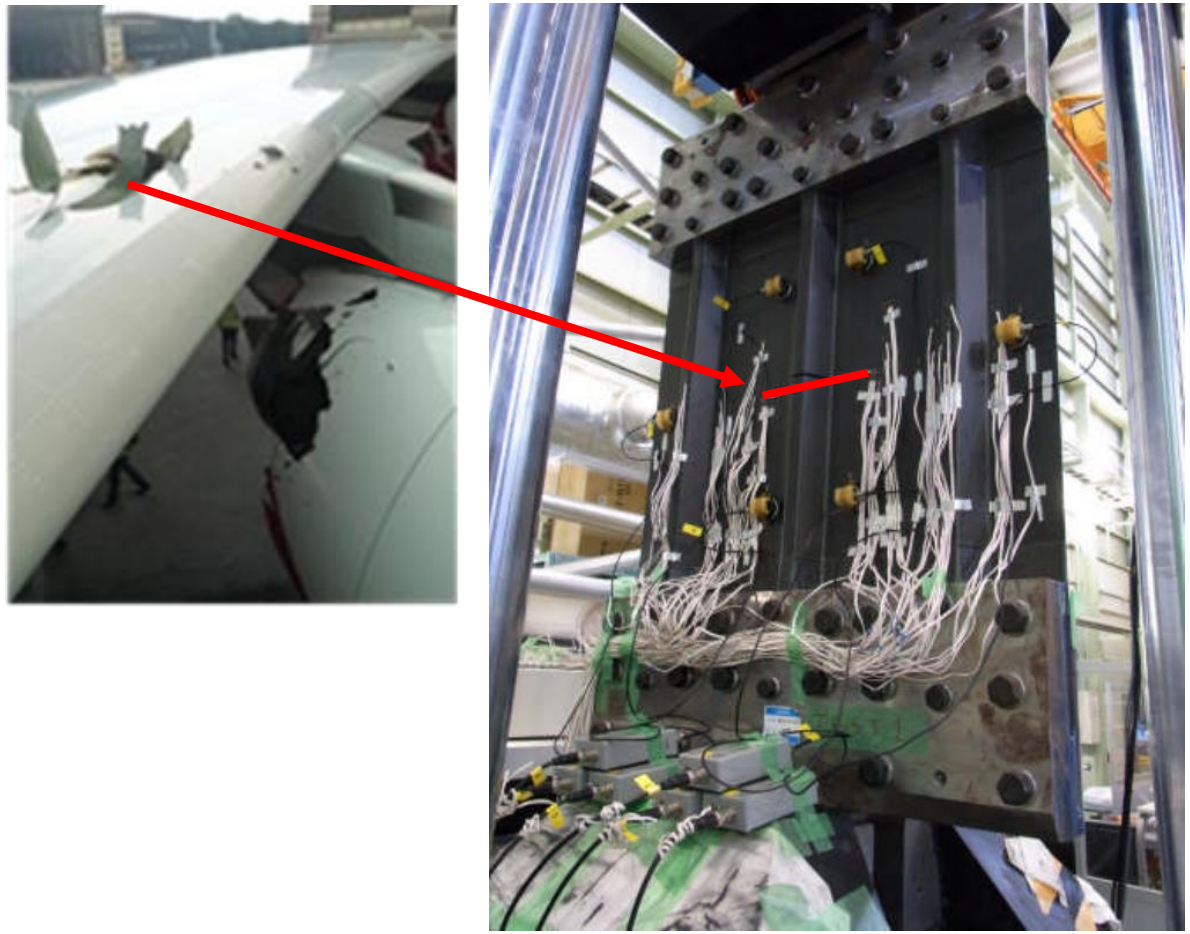
Background

- **In full-scale test**, stiffened composite panel behaves differently from small coupons

- Key contributing factors:

  Material properties *e.g. existence of R-curve*

- Contributions made so far have mainly been limited to academic problems not directly relevant to the scales used in the industry.

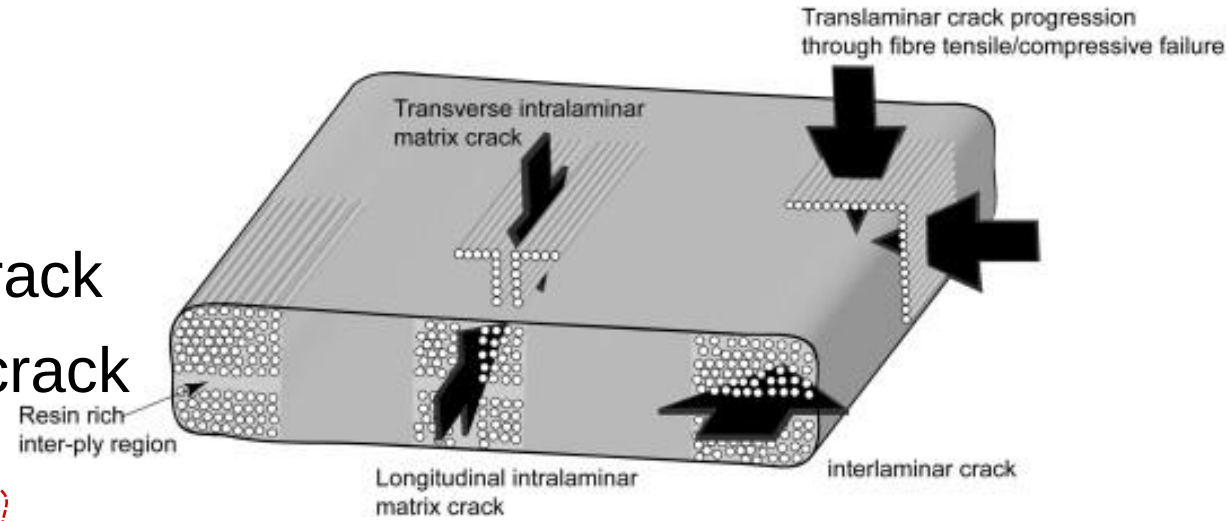


Aoki Y et al. 2012.

Failure of Composites

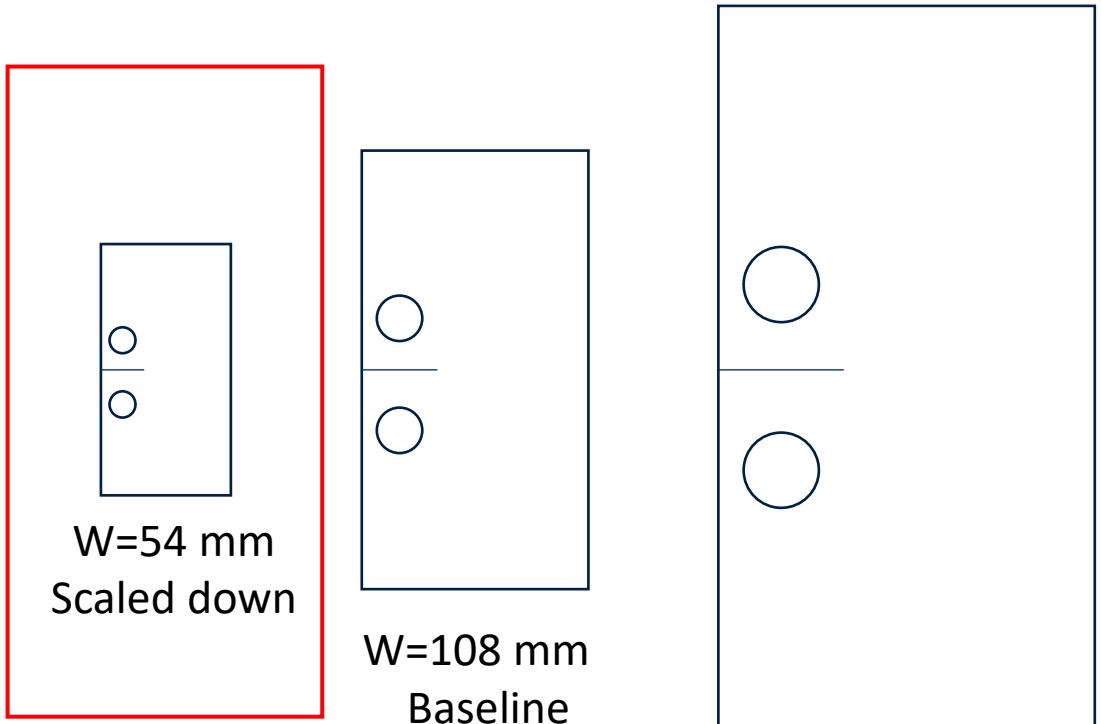
- Overview of composite failure modes
  - Interlaminar failure
  - Intralaminar failure
    - Transverse intralaminar matrix crack
    - Longitudinal intralaminar matrix crack
  - Translaminar fibre failure
    - Translaminar fibre tensile failure
    - Translaminar fibre compressive failure

Focus of the work



Laffan MJ et al. 2012.

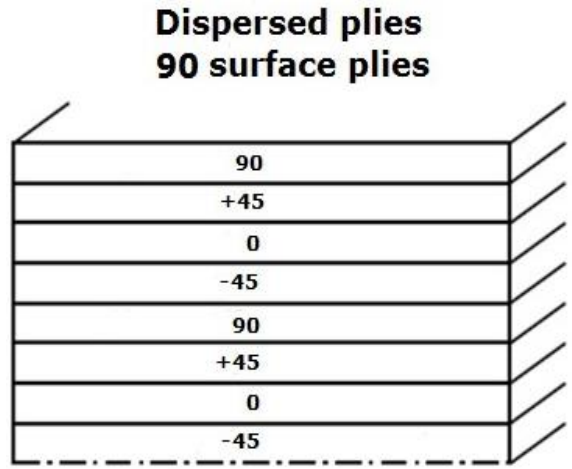
Over-height Compact Tension Specimen Configuration



Selected case for modelling with low computational costs

Xu X et al. 2021.

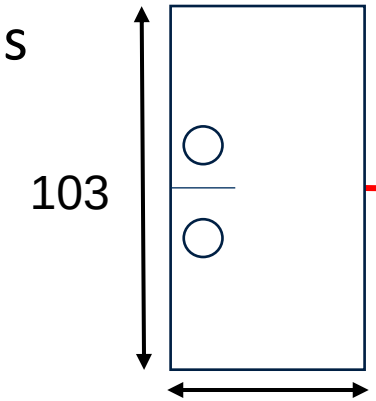
Scaled OCT specimens



Stacking sequence

Methodology

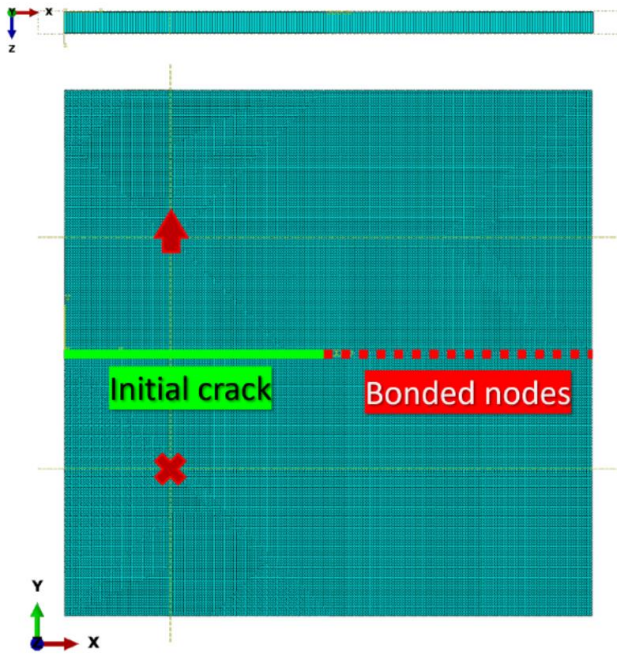
- The ultimate goal of this research is to be able to predict the damage process of stiffened composite panels using VCCT technique.
- The first step is to carry out VCCT analysis of a small specimen and validate it using experiments.
- The second step is to compare VCCT method against a previous High-fidelity Finite Element method.
- Finally, some recommendations are given for the simulation of large panel.



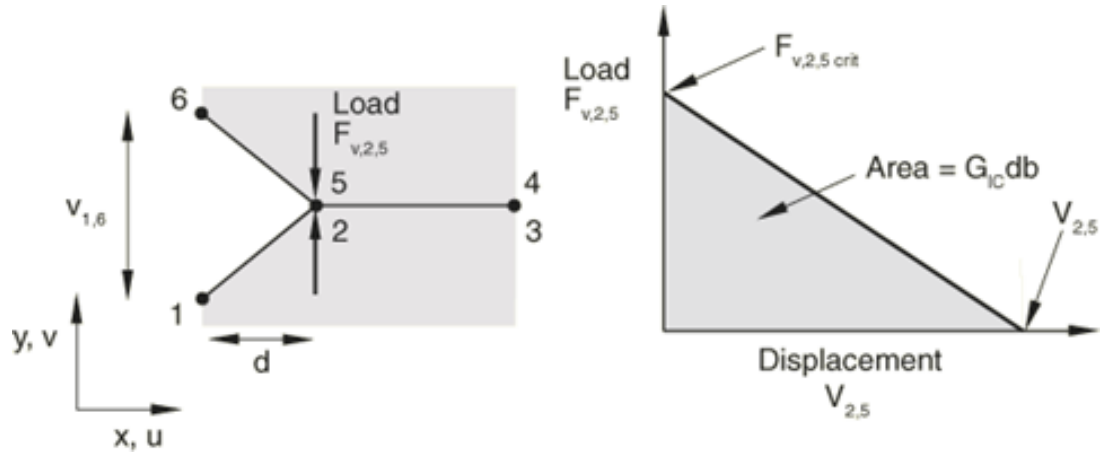
Scaled-down OCT

Virtual Crack Closure Technique

- Virtual Crack Closure Technique (VCCT) criterion suitable for evaluating brittle crack propagation along a predefined surface
- VCCT assumes that the strain energy released when a crack is extended is the same as the energy required to close the crack by the same amount.



VCCT analysis in ABAQUS

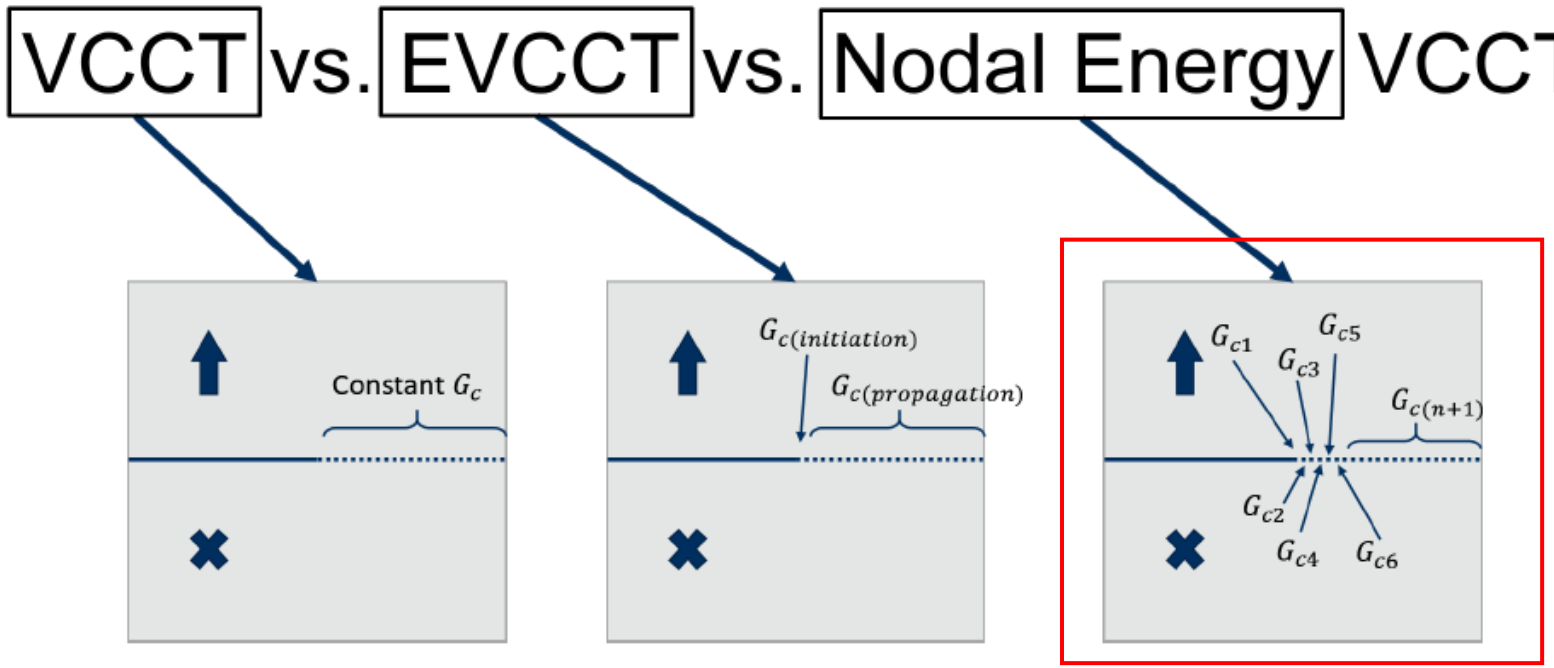


$$G_I = \frac{1}{2} \times F_{v,2,5} \times v_{1,6} \times bd$$

VCCT analysis theory

ABAQUS VCCT Analysis

- Three propagation criteria: VCCT, extended VCCT and nodal energy VCCT
- Input parameters for VCCT include: critical energy release rate (Mode I, II, III), exponent (value of 1 used here) .

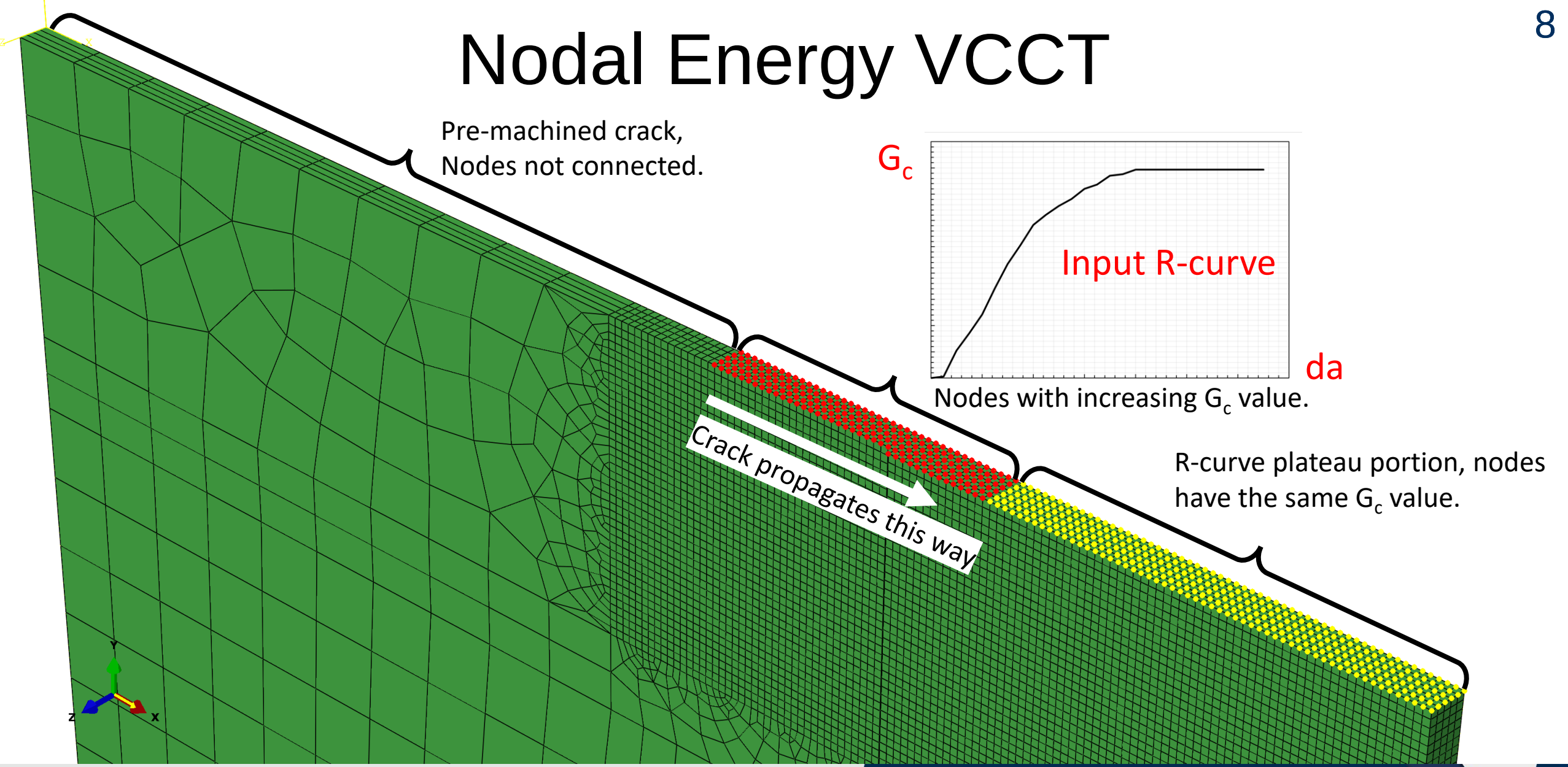


Nodal Energy VCCT to represent R-curves

ABAQUS VCCT fracture criteria

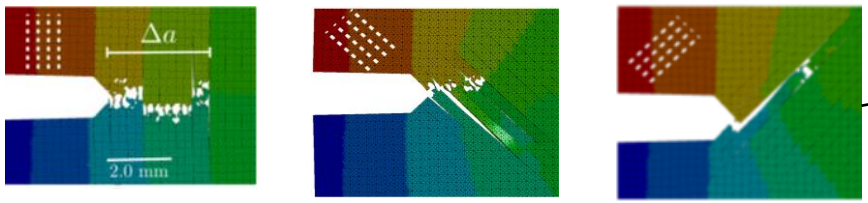
Nodal Energy VCCT

Pre-machined crack,
Nodes not connected.

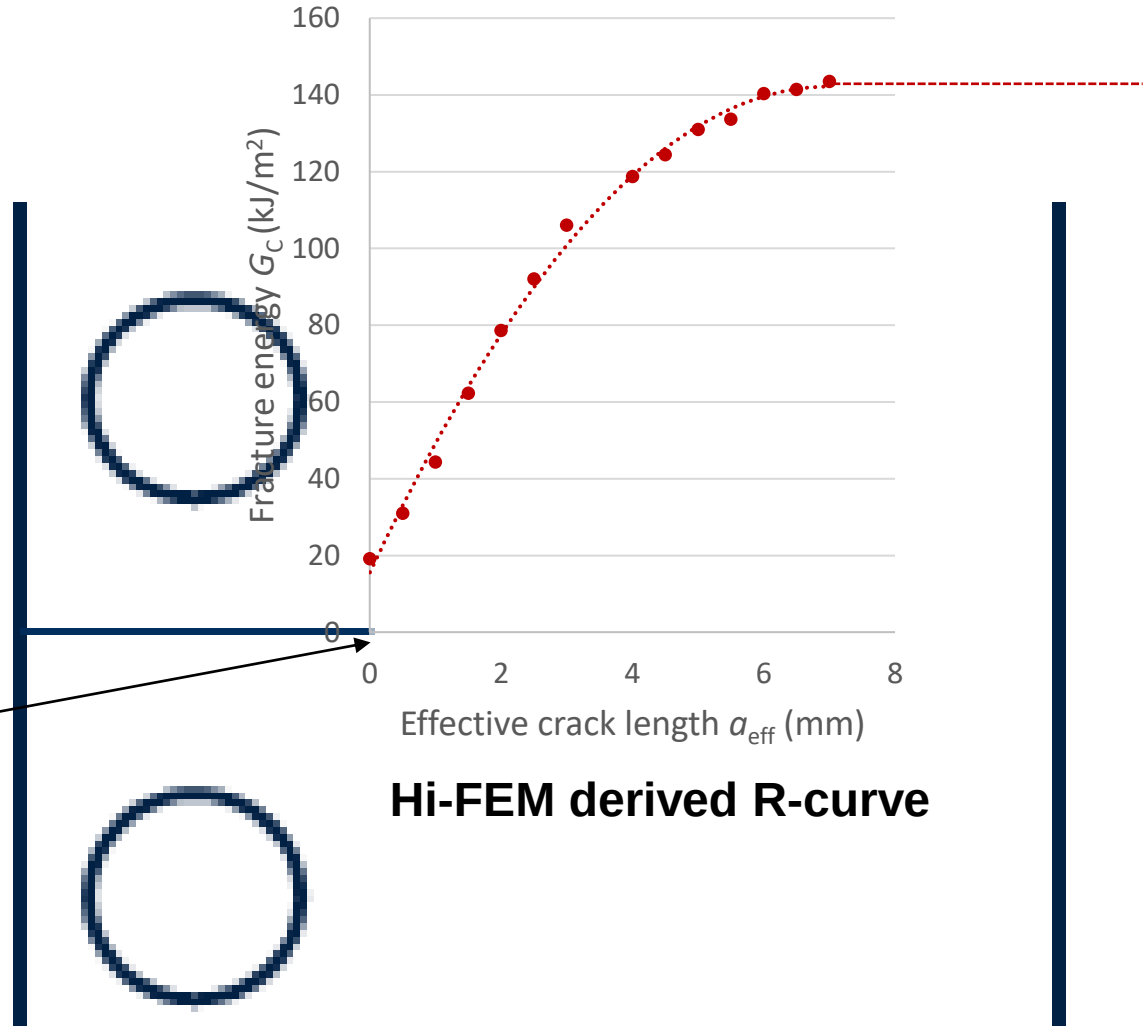


Nodal Energy VCCT

- Gc values were taken from a Hi-fidelity Finite Element Model (Hi-FEM) of the same OCT specimen
- The plateau value of 143 kJ/m_2
- Hi-FEM R-curve implemented via a list of Nodal Energy Rates in ABAQUS



Fibre breakage in Hi-FEM in LS-Dyna

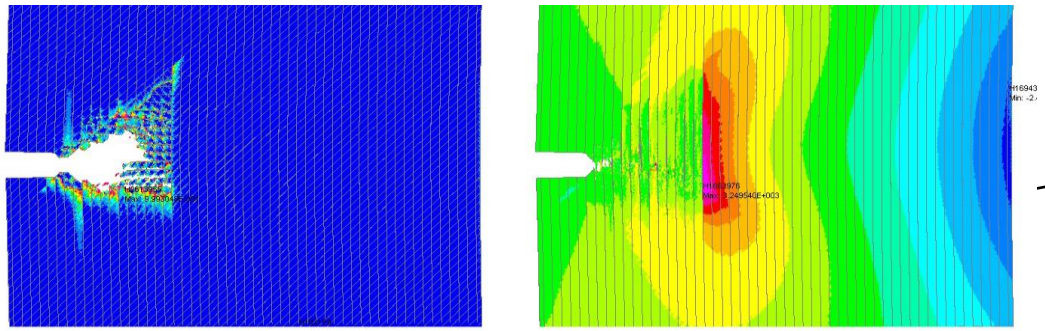


Hi-FEM derived R-curve

Xu X et al. 2019.

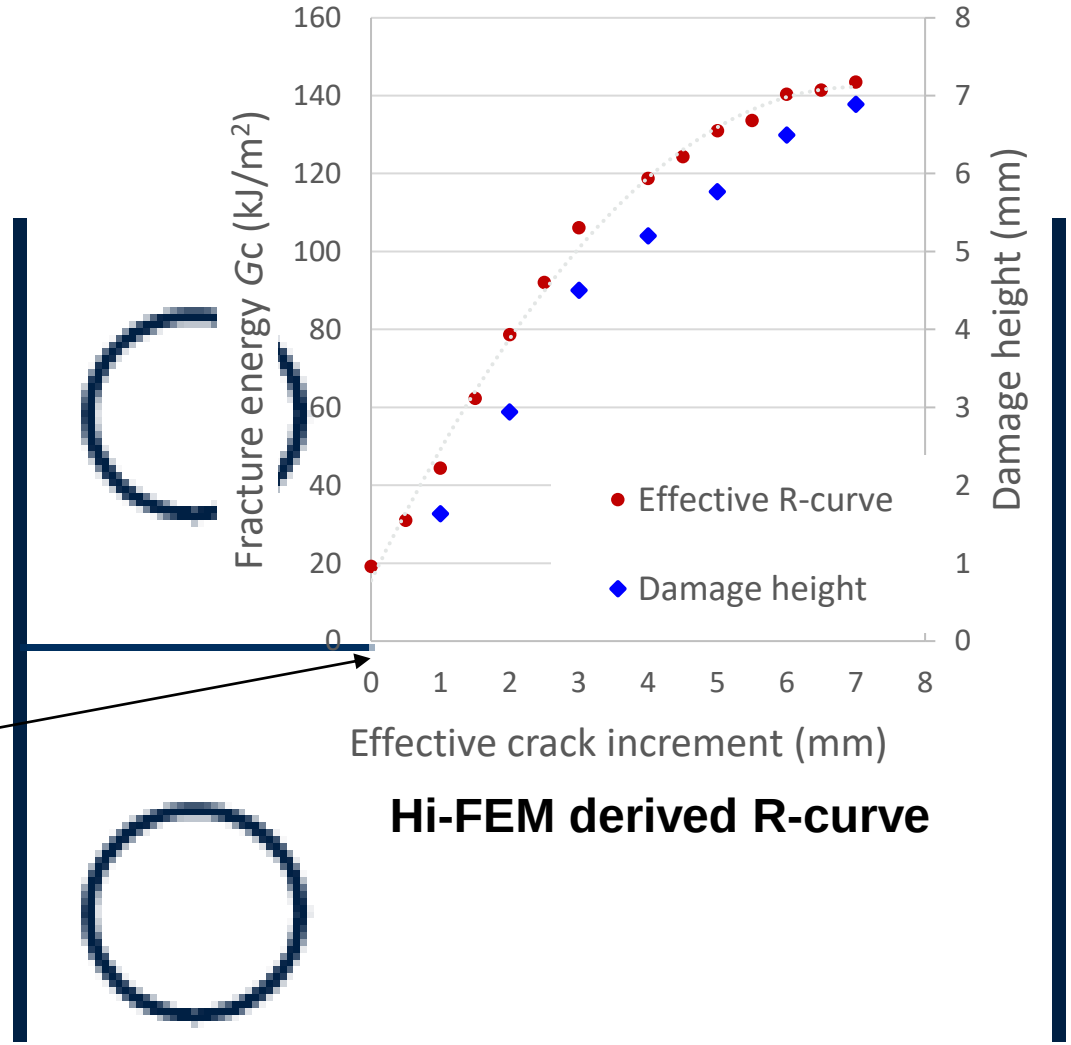
Nodal Energy VCCT

- Hi-FEM analysis showed that damage height increases with Gc
- Damage height is significant (up to 7 mm) as crack propagate
- Such damage height cannot be represented in ABAQUS VCCT analysis



Damage height from Hi-FEM in LS-Dyna

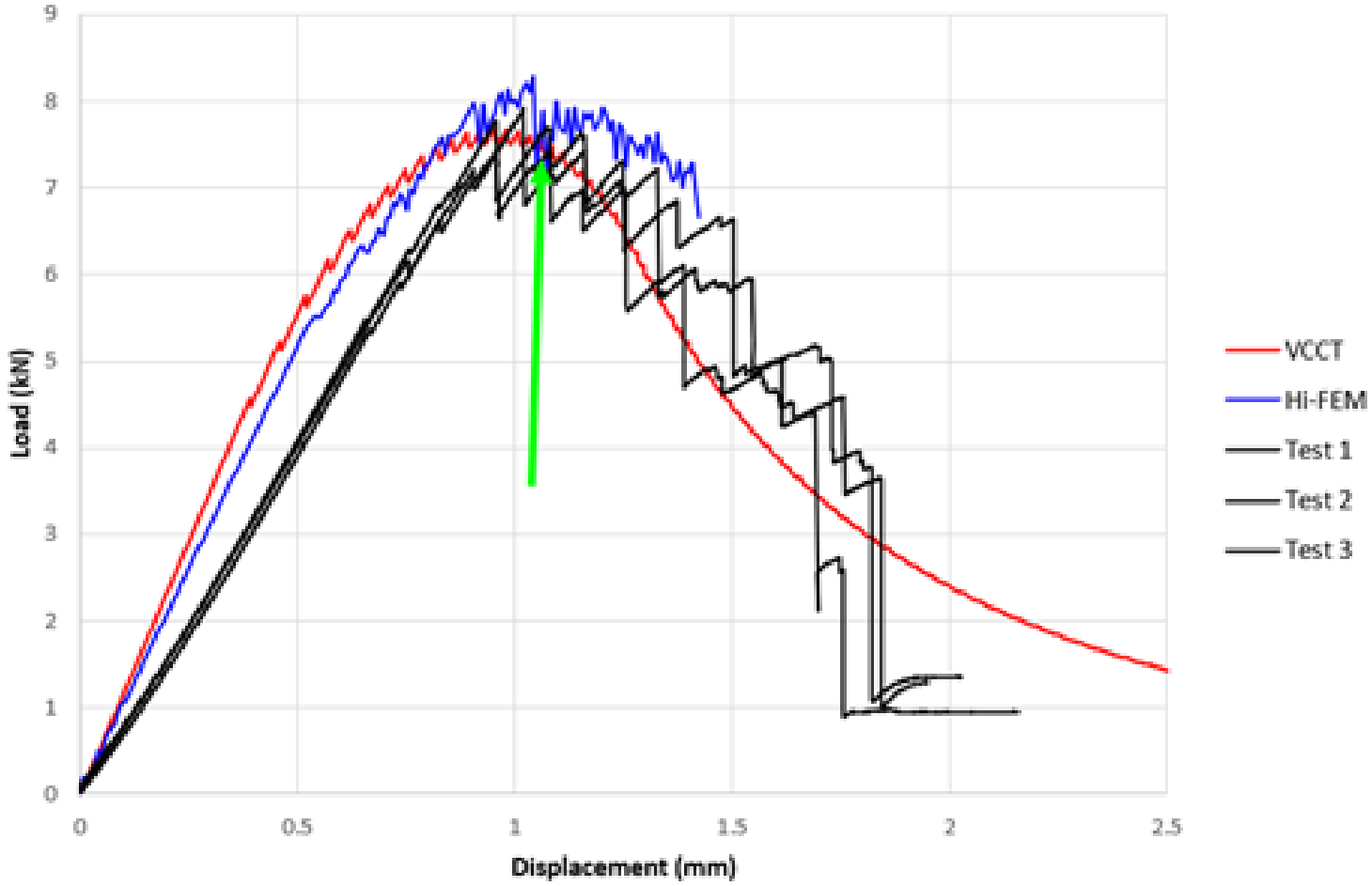
Xu X et al. 2019.



Hi-FEM derived R-curve

Results Comparison

- VCCT prediction approximately captured the lower bound of the experimental results
- VCCT analysis runtime is much shorter than Hi-FEM's, so it is more suitable for composite structures
- VCCT result deviates from Hi-FEM result as the damage height increases
- VCCT is much more efficient



Load-displacement curves comparison

Conclusions and Future Work

- ABAQUS VCCT successfully implemented for predicting trans-laminar fracture propagation
- Nodal Energy VCCT can represent R-curves
- Local Hi-FEM model bridged with VCCT analysis via R-curves
- VCCT analysis much more computationally efficient for large structures
- VCCT analysis will be done on full-scale panels

References

1. Aoki Y, Takeda S, Shoji H, Sugimoto S, Iwahori Y. Evaluation on discrete source damages of CFRP stiffened panels, *28th International Congress of the Aeronautical Sciences*, Brisbane, 2012.
2. Laffan MJ, Pinho ST, Robinson P, McMillan AJ. Translaminar fracture toughness testing of composites: A review, *Polymer Testing*, 31(2012) (3):481-489.
3. Xu X, Sun X, Wisnom MR. Initial R-curves for trans-laminar fracture of quasi-isotropic carbon/epoxy laminates from specimens with increasing size. *Composites Science and Technology*, 216 (2021): 109077. https://doi.org/10.1016/j.compscitech.2021.109077
4. Xu X, Wisnom MR, Hallett SR. Deducing the R-curve for trans-laminar fracture from a virtual Over-height Compact Tension (OCT) test. *Composites Part A: Applied Science and Manufacturing,* 118 (2019): 162:170. https://doi.org/10.1016/j.compositesa.2018.12.027

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