A S-N-based Cohesive Element for Delamination Propagation in Composite Materials

Ανάπτυξη Συνεκτικών Στοιχείων (Cohesive Elements) Βασισμένων σε Αποτελέσματα Καμπυλών Κόπωσης S-N για την Μοντελοποίηση Διαστρωματικής Αποκόλλησης σε Σύνθετα Υλικά

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Diploma Thesis

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OBJECTIVE

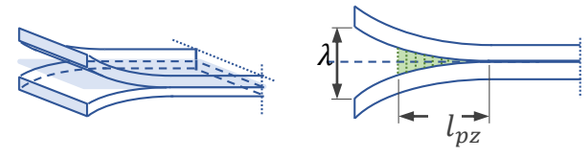
Delamination in composites is accompanied by complex damage mechanisms such as fiber bridging and matrix cracking. These mechanisms increase the critical energy release rate, G_c, required to propagate the crack. This increase in G_c when plotted against the crack extension Δa is referred to as the resistance curve (R-curve).

An experimental study was conducted by Yao[1] to quantify the significance of fiber bridging in the delamination growth in multidirectional composite laminates by comparing quasi-static and fatigue R-curves.

The objective of this thesis was to verify the capabilities of a recently proposed cohesive fatigue damage model[2] by comparing the numerical predictions of Yao's experiments to the test data.

Cohesive Zone Model

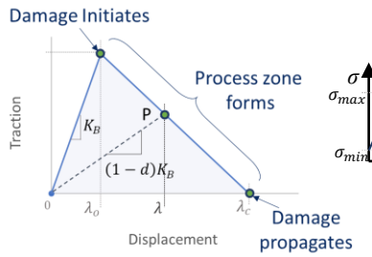
Cohesive elements, are zero thickness interface elements that represent the separation with a traction-separation law.

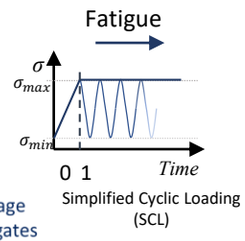


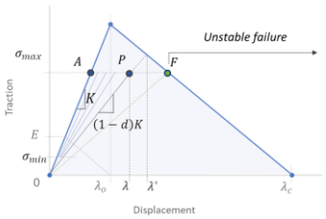
Fatigue Damage model:

- Same damage envelope for QS and fatigue
- Based on normalized S-N Curve
- Damage accumulates at rate dictated by a function:

$$\frac{dD}{dN} = C\left(\frac{\lambda}{\lambda^*}\right)^{\beta}$$





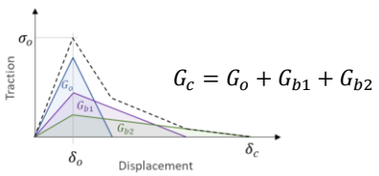


The CZM is implemented in a UMAT in Abaqus for FE analysis

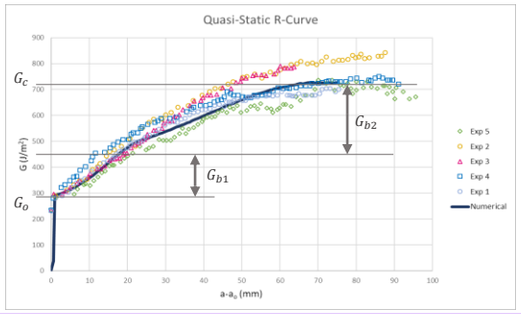
MAIN WORK

1. Programmed a UMAT user-written subroutine of Dávila's model.
2. Developed an FEM model of a double cantilever beam specimen.
3. Performed analyses for:
   - QS characterization of interfaces (QS R-curve)
   - Fatigue propagation rates and R-curve modeling for R=0.1 and R=0.5

Quasi-static characterization:



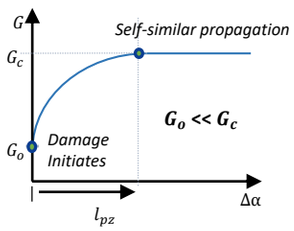
$$G_c = G_o + G_{b1} + G_{b2}$$

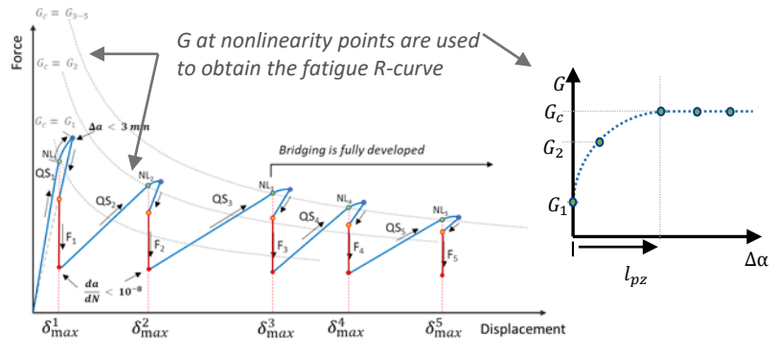


R-Curves

Fatigue fracture: Experimental procedure described by Yao

Quasi-static fracture:





G at nonlinearity points are used to obtain the fatigue R-curve

CONCLUSIONS & FUTURE WORK

The numerical results indicate that:

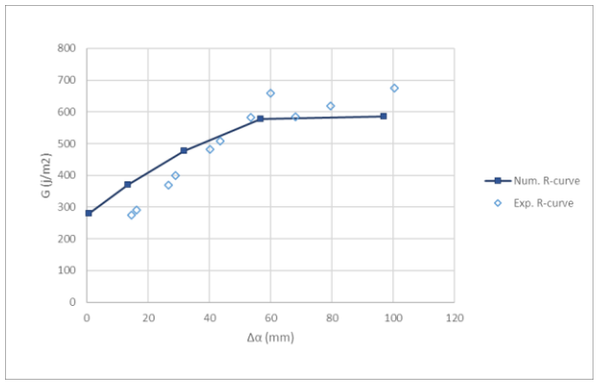
- The Quasi-Static (QS) and Fatigue R-curves can be modeled using a superposition of cohesive laws and the proposed CZM.
- The Paris Law for short cracks (exponent and pre-factor) can be accurately predicted.

Future work:
As errors are observed for longer crack extensions, it is proposed to:

- Verify the effect of Quasi-static (QS) characterization of the R-curve on the errors
- Evaluate the effect of the Fatigue mode's parameters on the errors

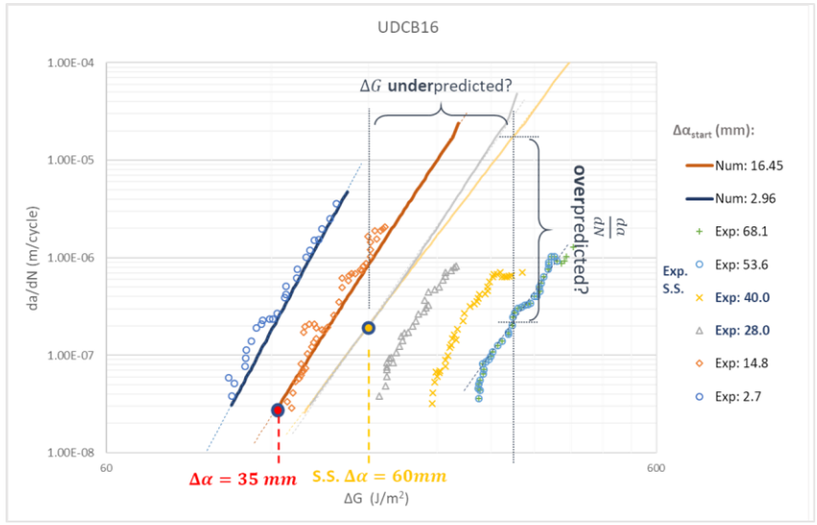
Fatigue results:

Fatigue R-curve:



Overprediction of G_c for short crack extensions VS
Underprediction of G_c for longer crack extensions

Typical propagation rate results:



[1] Yao, L., Alderliesten, R., Zhao, M., and Benedictus, R., "Bridging Effect on Mode I Fatigue Delamination Behavior in Composite Laminates," Composites Part A: Applied Science and Manufacturing, Vol. 63, 2014, pp. 103-109.
[2] Dávila, C. G., Rose, C. A., Murri, G. B., Jackson, W. C., and Johnston, W. M., "Evaluation of Fatigue Damage Accumulation Functions for Delamination Initiation and Propagation," Technical Publication NASA/TP–2020-220584, Hampton, VA, April 2020.

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