

# INVESTIGATION OF SCALING LAWS OF THE FIBER/MATRIX INTERFACE CRACK IN POLYMER COMPOSITES THROUGH FINITE ELEMENT-BASED MICROMECHANICAL MODELING

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Education and Culture

Erasmus Mundus

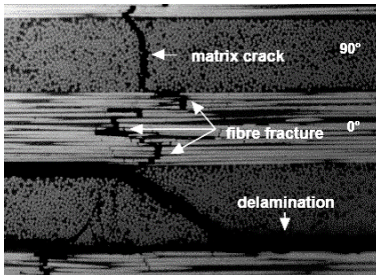


# Outline

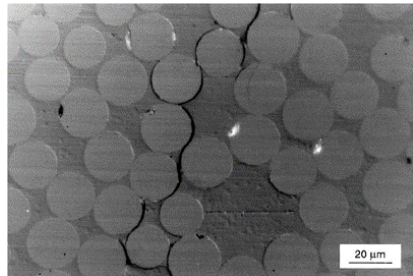
- Damage Mechanisms in Thin Ply Fiber Reinforced Polymer Laminates
- The Fiber-Matrix Interface Problem in Fiber Reinforced Polymer Laminates
- Analysis of the Infinite Reference Volume Element (RVE)
- Conclusions & Outlook

# ➤ DAMAGE IN THIN PLY FRPC

## Damage Onset and Propagation



(a) By Dr. R. Olsson, Swerea, SE.



(b) By Prof. Dr. E. K. Gamstedt, KTH, SE.

For a visual definition of intralaminar transverse cracking.

## Characterization of the Fracture Process

→ Energy Release Rate

$$G_m = G_m(p_1, \dots, p_i, \dots, p_n) \quad \text{where} \quad G = \frac{\partial W}{\partial A} - \left( \frac{\partial U}{\partial A} + \frac{\partial E_k}{\partial A} \right)$$

→ Stress Intensity Factor

$$K_m = K_m(p_1, \dots, p_i, \dots, p_n) \quad \text{where} \quad \sigma_m \sim K_m \frac{\alpha}{(x-a)^\beta} \quad \alpha, \beta > 0$$

→ J-Integral

$$J = J(p_1, \dots, p_i, \dots, p_n) \quad \text{where} \quad J = \lim_{\varepsilon \rightarrow 0} \int_{\Gamma_\varepsilon} \left( W(\Gamma) n_i - n_j \sigma_{jk} \frac{\partial u_k(\Gamma, x_i)}{\partial x_i} \right) d\Gamma = G$$

→ Crack Opening & Shear Displacement

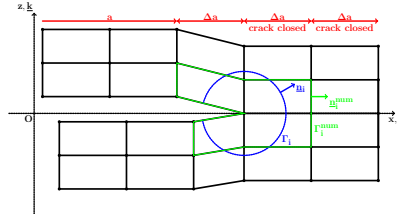
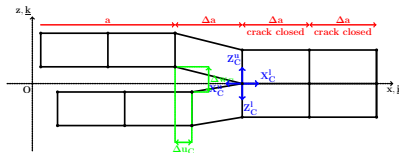
$$COD = COD(p_1, \dots, p_i, \dots, p_n) \quad \text{and} \quad CSD = CSD(p_1, \dots, p_i, \dots, p_n)$$

$$p_i \in \{\text{geometry, materials, boundary conditions, loading mode, scale}\}$$

$$m \in \{I, II, III, I/II, I/III, II/III\}$$

## Numerical Estimation of Energy Release Rates

→ Virtual Crack Closure Technique (VCCT) → J-Integral



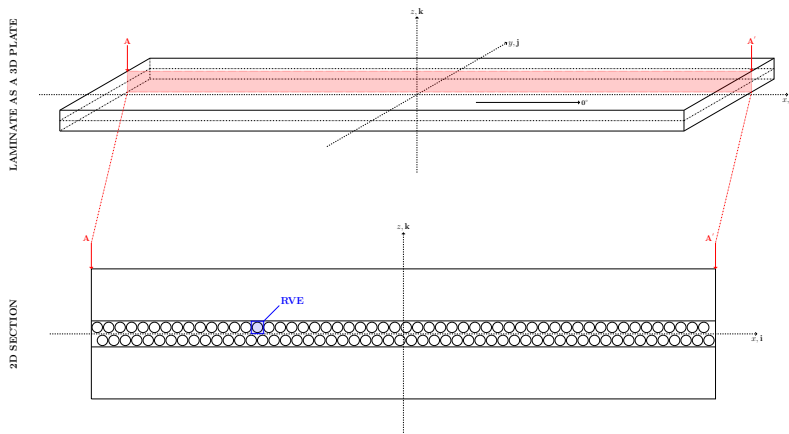
$$G_I = \frac{Z_C \Delta w_C}{2B \Delta a} \quad G_{II} = \frac{X_C \Delta u_C}{2B \Delta a}$$

Krueger, 2004

$$J_i = \lim_{\epsilon \rightarrow 0} \int_{\Gamma_\epsilon} \left( W(\Gamma) n_i - n_j \sigma_{jk} \frac{\partial u_k(\Gamma, x_i)}{\partial x_i} \right) d\Gamma$$

# THE FIBER-MATRIX INTERFACE PROBLEM IN FRPC

## Multi-scale Decomposition of Fiber Reinforced Polymer Laminates







## The Fiber-Matrix Interface Crack Problem: Solution

Method		Domain	Natural Variable	Conjugate Variable	Dirichlet BC
Analytical functions	(complex)	2D, continuous, infinite	Airy stress potential & stress	Displacement & strain	In stress
M. Toya (1975), A Crack Along the Interface of a Circular Inclusion Embedded in an Infinite Solid [10].					
Boundary Method (BEM)	Element	1D, discrete, finite	Stress, by using Green's potentials or Betti's influence functions	Displacement & strain	In stress
F. París et al. (1996), The fiber-matrix interface crack - A numerical analysis using Boundary Elements [11].					
Finite Element Method (FEM)		2D, discrete, finite	Displacement	Stress	In displacement

# ➤ ANALYSIS OF THE INFINITE RVE



## CONCLUSIONS

## Conclusions & Outlook

### Conclusions

- There is a limiting value of  $\frac{L}{R_f}$  after which models are effectively infinite
- For models larger than this value, domain size and mesh refinement at the interface has a similar effect on the energy release rate
- The discrepancy in modes with the use of linear elements might be linked to the deformed shape of crack faces

### Outlook

- Modeling extreme ply geometries, for example a ply with a single layer of fibers bounded by stiffer plies
- Investigate the effect of clusters of fibers in thin plies
- Analyzing the effect of complex stress and deformation states, thermal loads, different sets of boundary conditions

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