Finite Elements Solution of the Fiber-Matrix Interface Crack: Effects of Mesh Refinement and Domain Size

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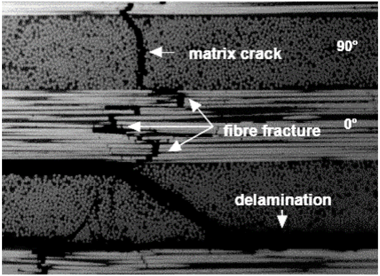
Outline

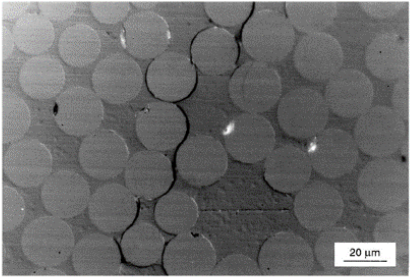
- Characterization of Fracture in FRPC Laminates
- The Fiber-Matrix Interface Problem in Fiber Reinforced Polymer Laminates
- Effects of Mesh Refinement & Domain Size
- Conclusions & Outlook

Characterization of Fracture in FRPC

Damage Onset and Propagation in FRPC Laminates



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



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

A visual definition of intralaminar transverse cracking.

Characterization of the Fracture Process

➔ Energy Release Rate

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

➔ Stress Intensity Factor

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

➔ J-Integral

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

➔ Crack Opening & Shear Displacement

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

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

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

Evaluation of Fracture Parameters

➔ Analytical

- ✓ Closed form
- ✓ Every material scale can be studied
- ✗ Available only for particular configurations

➔ Experimental

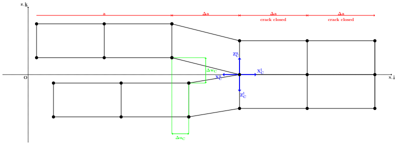
- ✓ Complex geometries can be studied
- ✗ Not every material scale is accessible

➔ Numerical

- ✓ Complex geometries can be studied
- ✓ Every material can be studied
- ✗ Discretization
- ✗ Finite domains

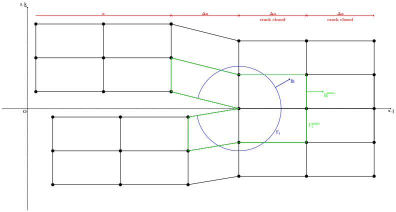
Numerical Estimation of Energy Release Rates

➔ Virtual Crack Closure Technique (VCCT)



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

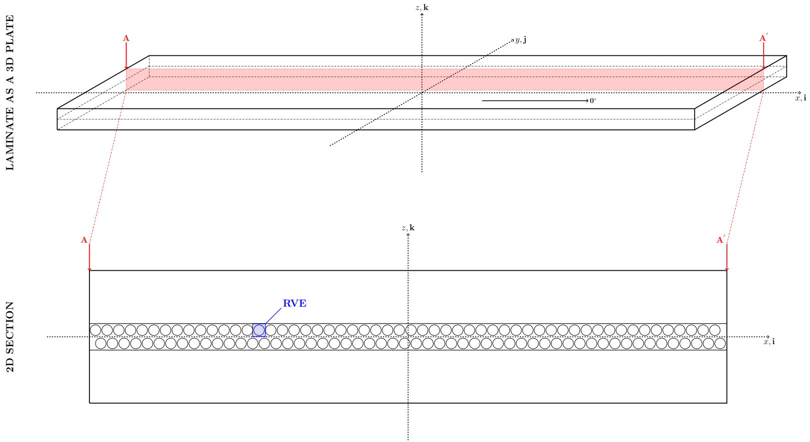
➔ J-Integral



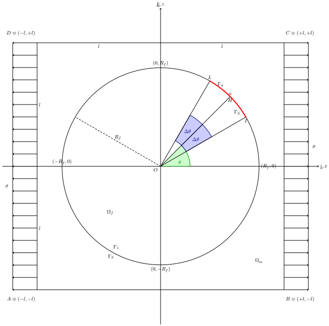
$$J_i = \lim_{\varepsilon \to 0} \int_{\Gamma_\varepsilon} \left(W(\Gamma)\, n_i - n_j \sigma_{jk} \frac{\partial u_k(\Gamma, x_i)}{\partial x_i} \right) d\Gamma$$

The Fiber-Matrix Interface Problem in FRPC

From macro to micro

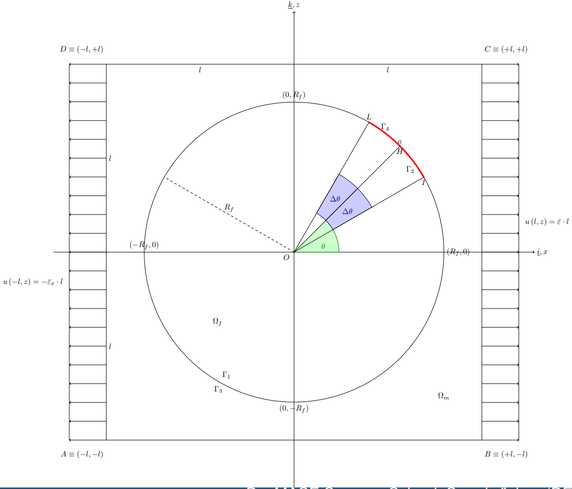


The Fiber-Matrix Interface Crack Problem



	Analytical	Numerical
Method	Analytical (complex) functions	FEM
Domain Type	Continuous	Discrete
Domain Size	Infinite	Finite
Natural variable	Stress (stress function)	Displacement field
Conjugate variable	Displacement	Stress
Dirichlet BC	Stress	Displacement
Loading process	Force-controlled	Displacement-controlled

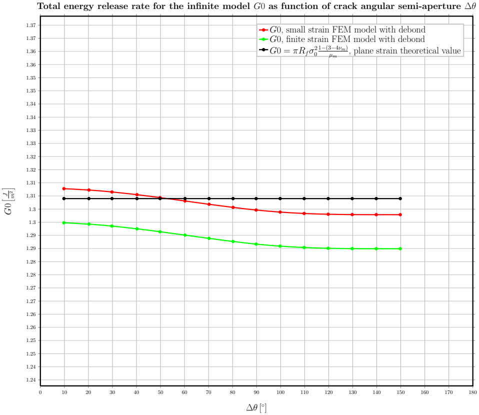
FEM Model of the Fiber-Matrix Interface Crack



- ➔ 2D space
- ➔ Linear elastic materials
- ➔ Displacement-controlled
- ➔ Dirichlet-type BC
- ➔ LEFM
- ➔ Contact interaction
- ➔ Bi-linear quadrilateral elements

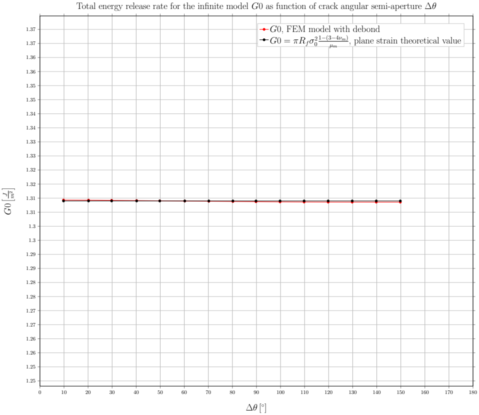
Mesh & Domain Size

G_0 for $Vf_f = 0.001$, $\frac{L}{R_f} \sim 28$, $\delta = 0.4°$



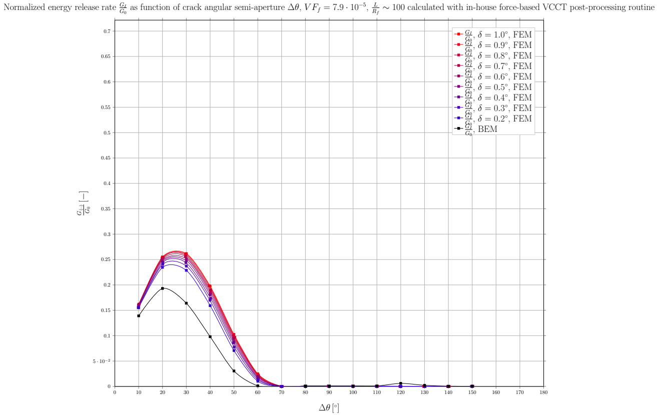
In red small strain FEM, in green finite strain FEM, in black G_0 calculated assuming $\sigma_0 = \frac{E}{1-\nu^2}\varepsilon$.

G_0 for $Vf_f = 0.000079$, $\frac{L}{R_f} \sim 100$, $\delta = 0.4°$



In red small strain FEM, in green finite strain FEM, in black G_0 calculated assuming $\sigma_0 = \frac{E}{1-\nu^2}\varepsilon$.

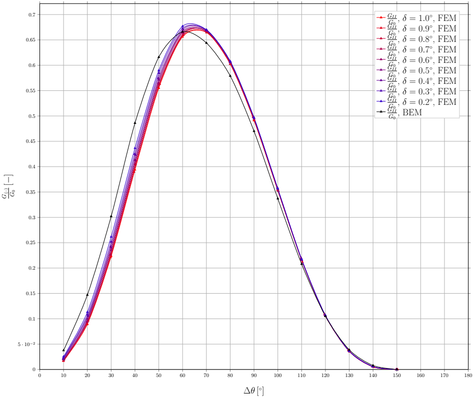
G_I, VCCT, $Vf_f = 0.000079$, $\frac{L}{R_f} \sim 100$



Fading from red to blue for decreasing size of elements at the interface, VCCT from FEM results; in black BEM results.

G_{II}, VCCT, $Vf_f = 0.000079$, $\frac{L}{R_f} \sim 100$

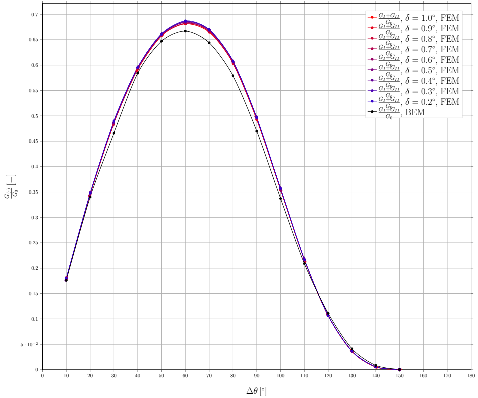
Normalized energy release rate $\frac{G_{II}}{G_0}$ as function of crack angular semi-aperture $\Delta\theta$, $VF_f = 7.9 \cdot 10^{-5}$, $\frac{L}{R_f} \sim 100$ calculated with in-house force-based VCCT post-processing routine



Fading from red to blue for decreasing size of elements at the interface, VCCT from FEM results; in black BEM results.

G_{TOT}, VCCT, $Vf_f = 0.000079$, $\frac{L}{R_f} \sim 100$

Normalized energy release rate $\frac{G_I+G_{II}}{G_0}$ as function of crack angular semi-aperture $\Delta\theta$, $VF_f = 7.9 \cdot 10^{-5}$, $\frac{L}{R_f} \sim 100$ calculated with in-house force-based VCCT post-processing routine



Fading from red to blue for decreasing size of elements at the interface, VCCT from FEM results; in black BEM results.

CONCLUSIONS

Conclusions & Outlook

Conclusions

- ➔ Domain size is a fundamental parameter in determining the RVE behaviour between finite and efffectively infinite size
- ➔ Mesh refinement affects directly mode ratio, increasing mode I with respect to mode II

Outlook

- ➔ Analyze the dependence on δ for $\frac{L}{R_f} = 200, 300, \ldots$
- ➔ Analyze the dependence on $\frac{L}{R_f}$ for constant δ
- ➔ Study finite size effects

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