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Outline

- Symbols, Models, Equations & Reference Data
- Developments & Work Realised

Symbols, Models, Equations & Reference Data

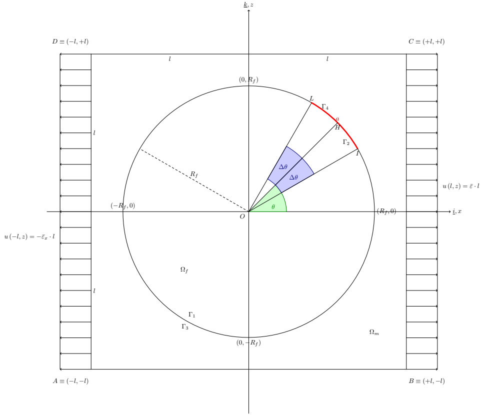
Symbols

Symbol	Unit	Description
θ	$[^\circ]$	Debond angular position with respect to the center of the arc defined by the debond itself
$\Delta\theta$	$[^\circ]$	Debond semi-angular aperture
δ	$[^\circ]$	Angle subtended by a single element at the fiber/matrix interface
VF_f	$[-]$	Fiber volume fraction
l	$[\mu m]$	Ply's half-length, equal to RVE's half-length (square element)
u	$[\mu m]$	Displacement along x
w	$[\mu m]$	Displacement along z

Symbols

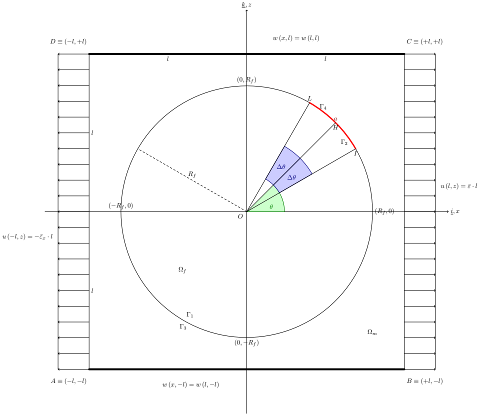
Symbol	Unit	Description
Γ_1	$[-]$	Bonded part of fiber surface
Γ_2	$[-]$	Free (debonded) part of fiber surface
Γ_3	$[-]$	Bonded part of matrix surface
Γ_4	$[-]$	Free (debonded) part of matrix surface

Reference Models



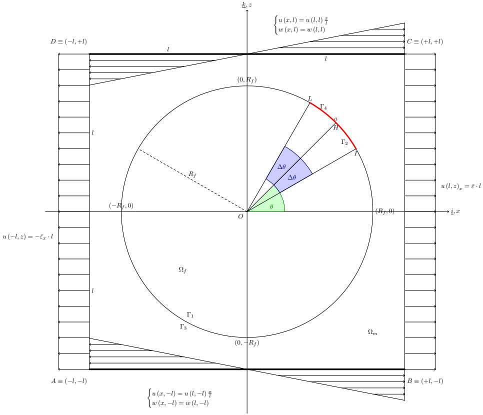
Simple RVE, BC: free.

Reference Models



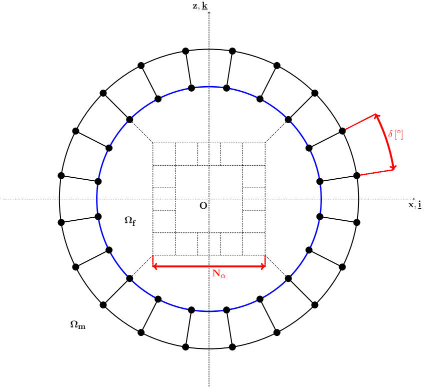
Simple RVE, BC: fixed vertical displacement.

Reference Models



Simple RVE, BC: fixed vertical and homogeneous horizontal displacement.

Angular discretization



Angular discretization at fiber/matrix interface: $\delta = \frac{360^\circ}{4N_\alpha}$.

Material properties

Material	$E\,[GPa]$	$G\,[GPa]$	$\nu\,[-]$
Glass fiber	70,0	29,2	0,2
Epoxy	3,5	1,25	0,4

Evaluation of G_0

$$G_0 = \pi R_f \sigma_0^2 \frac{1 + k_m}{8 G_m} \tag{1}$$

$$k_m = 3 - 4\nu_m \tag{2}$$

$$\sigma_0 = \frac{E_m}{1 - \nu_m^2} \varepsilon_{xx} \tag{3}$$

VCCT in Forces

$$\Delta u = \left(x^{fiber,def}_{1\text{ element before crack tip}} - x^{fiber,undef}_{1\text{ element before crack tip}}\right) - \left(x^{matrix,def}_{1\text{ element before crack tip}} - x^{matrix,undef}_{1\text{ element before crack tip}}\right) \tag{4}$$

$$\Delta w = \left(z^{fiber,def}_{1\text{ element before crack tip}} - z^{fiber,undef}_{1\text{ element before crack tip}}\right) - \left(z^{matrix,def}_{1\text{ element before crack tip}} - z^{matrix,undef}_{1\text{ element before crack tip}}\right) \tag{5}$$

$$\beta = \arctan\left(\frac{z^{matrix,def}_{\text{crack tip}}}{x^{matrix,def}_{\text{crack tip}}}\right) \tag{6}$$

$$\Delta_r = \cos(\beta)\Delta u + \sin(\beta)\Delta w \qquad \Delta_\theta = -\sin(\beta)\Delta u + \cos(\beta)\Delta w \tag{7}$$

$$F_r = \cos(\beta)F^{reaction}_x + \sin(\beta)F^{reaction}_z \qquad F_\theta = -\sin(\beta)F^{reaction}_x + \cos(\beta)F^{reaction}_z \tag{8}$$

$$G_I = \frac{1}{2}\frac{F_r\Delta_r}{R_f\delta} \qquad G_{II} = \frac{1}{2}\frac{F_\theta\Delta_\theta}{R_f\delta} \qquad b = 1.0 \leftrightarrow \Delta A = bR_f\delta \tag{9}$$

VCCT in Stresses

$$\Delta u = \left(x^{fiber,def}_{1\text{ element before crack tip}} - x^{fiber,undef}_{1\text{ element before crack tip}} \right) - \left(x^{matrix,def}_{1\text{ element before crack tip}} - x^{matrix,undef}_{1\text{ element before crack tip}} \right) \tag{10}$$

$$\Delta w = \left(z^{fiber,def}_{1\text{ element before crack tip}} - z^{fiber,undef}_{1\text{ element before crack tip}} \right) - \left(z^{matrix,def}_{1\text{ element before crack tip}} - z^{matrix,undef}_{1\text{ element before crack tip}} \right) \tag{11}$$

$$\Delta_r = \cos(\beta)\Delta u + \sin(\beta)\Delta w \quad \Delta_\theta = -\sin(\beta)\Delta u + \cos(\beta)\Delta w \qquad \text{with} \quad \beta = \arctan\left(\frac{z^{matrix,def}_{\text{crack tip}}}{x^{matrix,def}_{\text{crack tip}}} \right) \tag{12}$$

$$\sigma_{(\cdot\cdot)} = \frac{1}{2}\left(\sigma^{\text{element after crack tip}}_{\text{crack tip},(\cdot\cdot)} + \sigma^{\text{element before crack tip}}_{\text{crack tip},(\cdot\cdot)} \right) \tag{13}$$

$$\sigma_{rr} = \cos^2(\beta)\sigma_{xx} + 2\sin(\beta)\cos(\beta)\tau_{xz} + \sin^2(\beta)\sigma_{zz} \tag{14}$$

$$\tau_{r\theta} = (\sigma_{xx} + \sigma_{zz})\sin(\beta)\cos(\beta) + \tau_{xz}\left(\cos^2(\beta) - \sin^2(\beta) \right) \tag{15}$$

$$G_I = \frac{1}{2}\sigma_r\Delta_r \qquad G_{II} = \frac{1}{2}\tau_{r\theta}\Delta_\theta \qquad (b = 1.0) \tag{16}$$

Developments & Work Realised

Summary of previous results

- ✓ Correct global elastic response
- ✓ Symmetric results for symmetric model
- ✓ Correct order of magnitude of energy release rate
- ✓ Correct trends in mode ratio: $G_I \uparrow \Delta\theta \downarrow$, $G_{II} \uparrow \Delta\theta \uparrow$
- ✓ For $VF_f \rightarrow 0$ boundary conditions do not have effect on the result
- ✓ Interface formulation is effectively frictionless

✗ No agreement with BEM results

- ➔ Overestimated energy release rate
- ➔ Shifts of maxima of $\sim 10^{\circ}$

Summary of objectives

- ☐ Change interface formulation
- ☐ To test new formulations, create model of debond between two infinite half-planes of different isotropic materials

Notation

☐ Planned/proposed action

☑ Task completed

☑ Task in progress

Work realised & Follow-Up Actions

- ☐ Interface formulations (2/9)
  - ➔ (Old formulation) 2 surfaces: fibre surface $= \Gamma_1 + \Gamma_2$ et matrix surface $= \Gamma_3 + \Gamma_4$ with interaction **CONTACT* and **DEBOND*, SMALL-SLIDING with SURFACE TO SURFACE DEFINITION (with **DEBOND* in Abaqus/Standard crack surfaces are rigidly bonded when uncracked)
  - ☑ 4 surfaces: Γ_1 WITHOUT crack tip, Γ_2 WITH crack tip, Γ_3 WITHOUT crack tip and Γ_4 WITH crack tip, interaction $*$*TIE* between Γ_1 and Γ_3, interaction **CONTACT* and **DEBOND* between Γ_2 and Γ_4, SMALL-SLIDING with SURFACE TO SURFACE DEFINITION
    - ☑ Development of preprocessor
    - ☑ FEM model creation
    - ☑ Parametric simulation
    - ☑ Analysis of results

Work realised & Follow-Up Actions

- ☐ Interface formulations (3/9)
  - ☑ 2 surfaces: Γ_2 WITH crack tip and Γ_4 WITH crack tip, interaction **CONTACT* et **DEBOND* between Γ_2 and Γ_4, interaction **MPC TIE* between *nodes* of Γ_1 and Γ_3, SMALL-SLIDING with SURFACE TO SURFACE DEFINITION
    - ☑ Development of preprocessor
    - ☑ FEM model creation
    - ☑ Parametric simulation
    - ☑ Analysis of results

Work realised & Follow-Up Actions

- ☐ Interface formulations (4/9)
  - ☑ 4 surfaces: Γ_1 WITH crack tip, Γ_2 WITHOUT crack tip, Γ_3 WITH crack tip and Γ_4 WITHOUT crack tip, interaction $*$*TIE* between Γ_1 and Γ_3, interaction $*$*CONTACT* between Γ_2 and Γ_4
    - ☑ Development of preprocessor
    - ☑ FEM model creation
    - ☑ Parametric simulation
    - ☑ Implementation of VCCT (in stresses) procedure in the postprocessor
    - ☑ Analysis of results

Work realised & Follow-Up Actions

- ☐ Interface formulations (5/9)
  - ☑ 2 surfaces: Γ_2 WITHOUT crack tip and Γ_4 WITHOUT crack tip, interaction **CONTACT* between Γ_2 and Γ_4, interaction **MPC TIE* between *nodes* of Γ_1 and Γ_3
    - ☑ Development of preprocessor
    - ☑ FEM model creation
    - ☑ Parametric simulation
    - ☑ Implementation of VCCT (in stresses) procedure in the postprocessor
    - ☑ Analysis of results

Work realised & Follow-Up Actions

- ☐ Interface formulations (6/9)
  - ☑ 2 surfaces: Γ_2 WITHOUT crack tip and Γ_4 WITHOUT crack tip, interaction $*$*CONTACT* between Γ_2 and Γ_4, interaction $*$*EQUATION* between *nodes* of Γ_1 and Γ_3 with *dummy node* to measure reaction force
    - ☑ Development of preprocessor
    - ☑ FEM model creation
    - ☑ Parametric simulation
    - ☑ Implementation of VCCT (in forces) procedure in the postprocessor
    - ☑ Analysis of results

Work realised & Follow-Up Actions

- ☐ Interface formulations (7/9)
  - ☑ 2 surfaces: Γ_2WITHOUT crack tip and Γ_4 WITHOUT crack tip, interaction **CONTACT* between Γ_2 and Γ_4, interaction **CONN2D2 TIE* between *nodes* of Γ_1 and Γ_3
    - ☑ Development of preprocessor
    - ☑ FEM model creation
    - ☑ Parametric simulation
    - ☑ Implementation of VCCT (in forces) procedure in the postprocessor
    - ☑ Analysis of results

Work realised & Follow-Up Actions

- ☐ Interface formulations (8/9)
  - ☐ 2 surfaces: fibre surface $= \Gamma_1 + \Gamma_2$ et matrix surface $= \Gamma_3 + \Gamma_4$ with interaction $*$*CONTACT* and $*$*DEBOND*, FINITE SLIDING with NODE TO SURFACE DEFINITION (with $*$*DEBOND* in Abaqus/Standard crack surfaces are rigidly bonded when uncracked)
    - ☐ Development of preprocessor
    - ☐ FEM model creation
    - ☐ Parametric simulation
    - ☐ Analysis of results

Work realised & Follow-Up Actions

- Interface formulations (9/9)
  - 2 surfaces: fibre surface $= \Gamma_1 + \Gamma_2$ et matrix surface $= \Gamma_3 + \Gamma_4$ with interaction **CONTACT* and **DEBOND*, SMALL SLIDING with NODE TO SURFACE DEFINITION (with **DEBOND* in Abaqus/Standard crack surfaces are rigidly bonded when uncracked)
    - Development of preprocessor
    - FEM model creation
    - Parametric simulation
    - Analysis of results

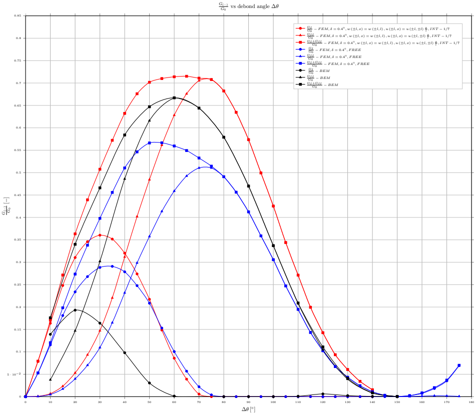
Work realised & Follow-Up Actions

- ☐ To test new formulations, create model of debond between two infinite half-planes of different isotropic materials
  - ☑ Full model
    - ☑ Development of preprocessor
    - ☑ FEM model creation and verification
    - ☑ Parametric simulation
    - ☑ Implementation of VCCT procedure in the postprocessor
    - ☐ Analysis of results

Work realised & Follow-Up Actions

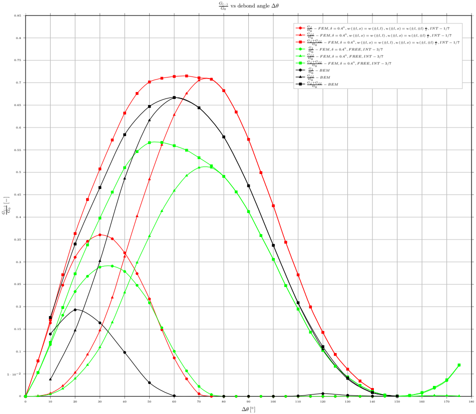
- ☐ To test new formulations, create model of debond between two infinite half-planes of different isotropic materials
  - ☑ Symmetric model
    - ☑ Development of preprocessor
    - ☑ FEM model creation and verification
    - ☐ Parametric simulation
    - ☐ Implementation of VCCT procedure in the postprocessor
    - ☐ Analysis of results

Results



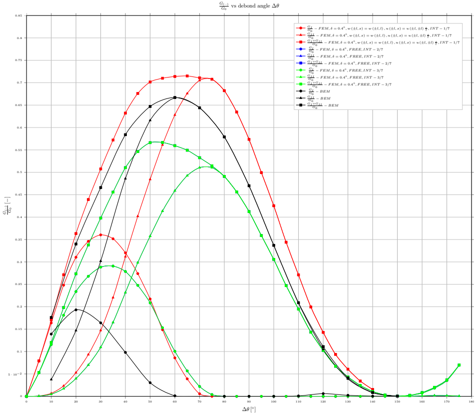
Interface formulation 2/9, in blue.

Results



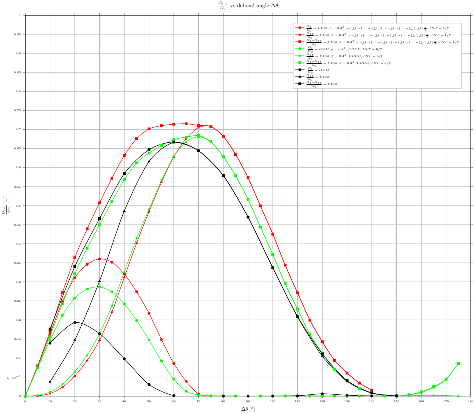
Interface formulation 3/9, in green.

Results



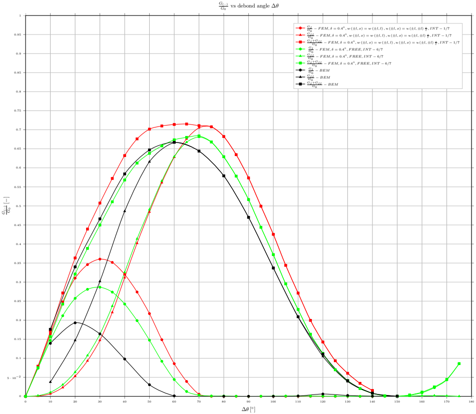
Interface formulations 2/9 and 3/9, respectively in green and blue.

Results



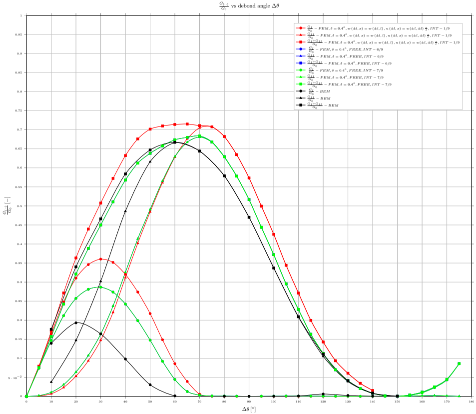
Interface formulation 6/9, in green.

Results



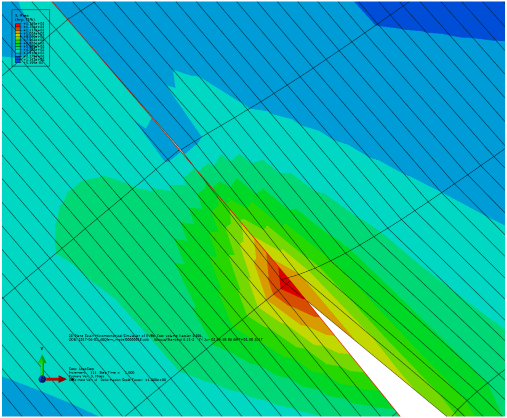
Interface formulation 7/9, in green.

Results



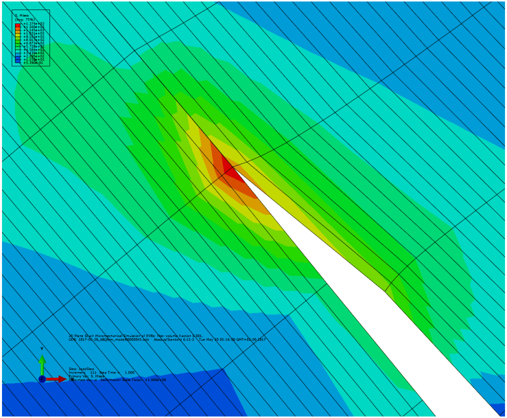
Interface formulations 6/9 and 7/9, respectively in blue and green.

Results



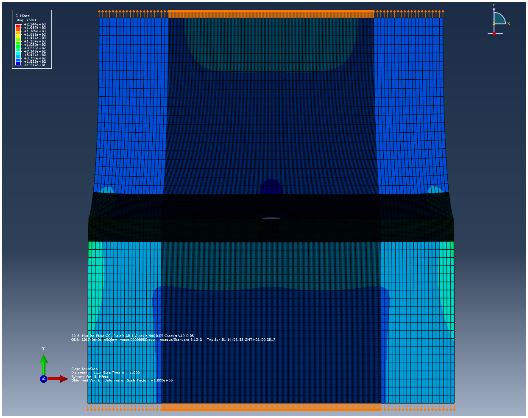
Crack tip in deformed configuration, surface contact pair with fracture interaction based on VCCT, $\Delta\theta = 40^{\circ}$.

Results



Crack tip in deformed configuration, local enforcement of continuity of displacements at the interface (connector elements in the present case), $\Delta\theta = 40^{\circ}$.

Results



FEM model of central debond between two infinite half-planes of different isotropic materials.

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