Mechanics of Extreme Thin Composite Layers for Aerospace Applications

Background, Rationale & Project's Start-Up

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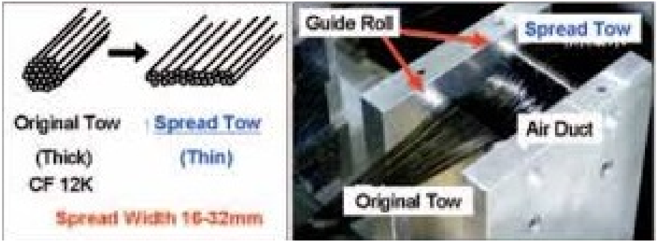
Outline

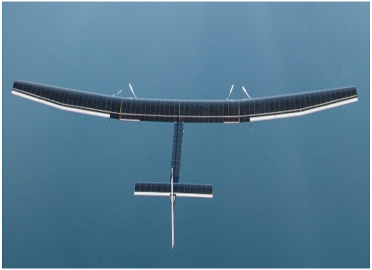
- The new frontier in fiber composites
- The kinks in thin ply mechanics
- The players in the field
- The model
- Project's on-line presence

The new frontier in fiber composites

Spread tow technology



Advanced transportation concepts



(a) By North Thin Ply Technology.

(b) By TeXtreme.

Sports

(c) By North Thin Ply Technology.

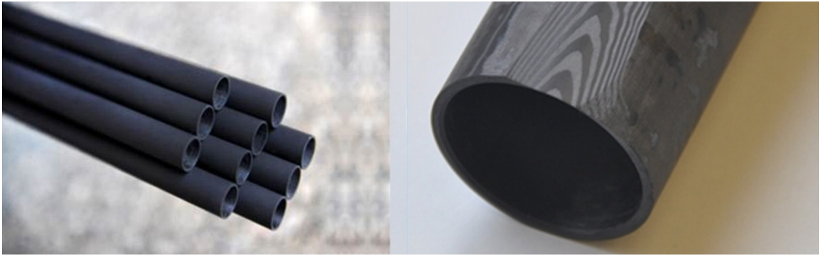
(d) By TeXtreme.

Sports

(e) By North Thin Ply Technology.

(f) By TeXtreme.

Structural elements



By North Thin Ply Technology.

Luxury goods

By North Thin Ply Technology.

THE KINKS IN THIN PLY MECHANICS

Work-flow of composite structural design

FIBER PROPERTIES
isotropic or transversely isotropic

$E_{(x),f}$ $(E_{z,f})$, $\nu_{(xy),f}$ $(\nu_{xz,f})$, $G_{(yz),f}$
$\alpha_{(x),f}$ $(\alpha_{z,f})$, $\kappa_{(x),f}$ $(\kappa_{z,f})$, $C_{V,f}$
$\bar{\sigma}^f_T$, $\bar{\sigma}^f_C$, $\bar{\tau}^f_{xy}$ $(\bar{\tau}^f_{xz})$

MATRIX PROPERTIES
isotropic

E_m, ν_m, G_m, α_f, κ_f, $C_{V,f}$
$\bar{\sigma}^f_T$, $\bar{\sigma}^f_C$, $\bar{\tau}^f_{xy}$ $(\bar{\tau}^f_{xz})$

Failure load analysis

Load
F

Progressive load analysis

Applied strain on laminate

$\{\varepsilon\}^{applied}_{laminate}$

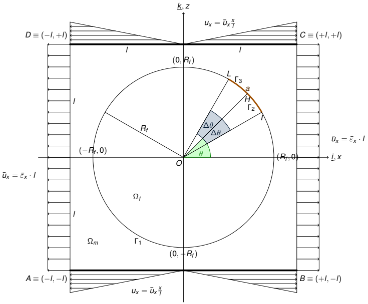
THE PLAYERS IN THE FIELD

A map of the players in the field

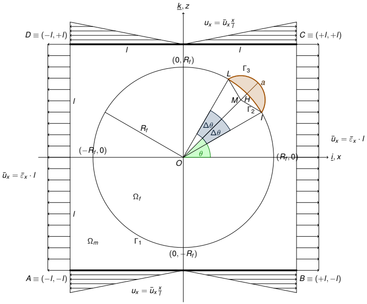
▸ Map

THE MODEL

Single RVE model

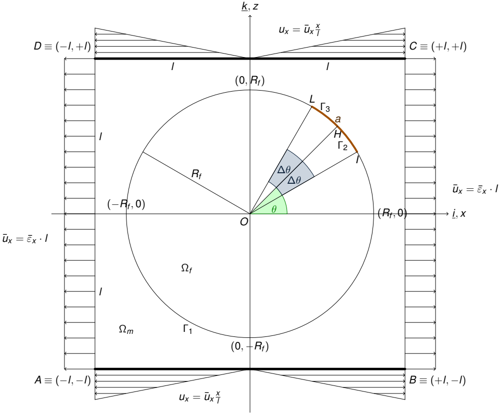


(a) Crack closed in the radial direction.



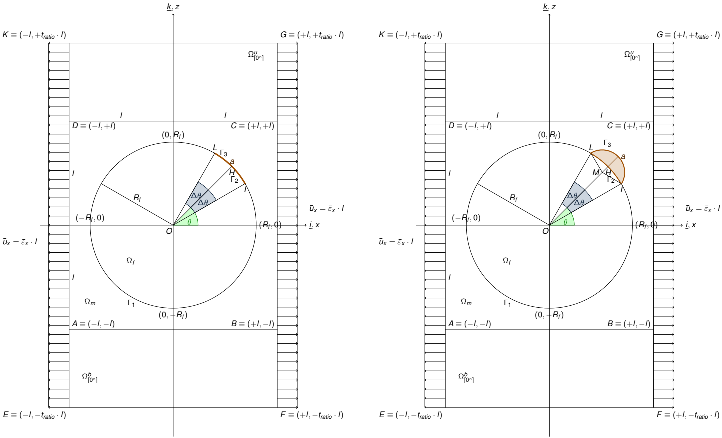
(b) Crack open in the radial direction.

Single RVE model



Initial state of single RVE model: crack closed in the radial direction.

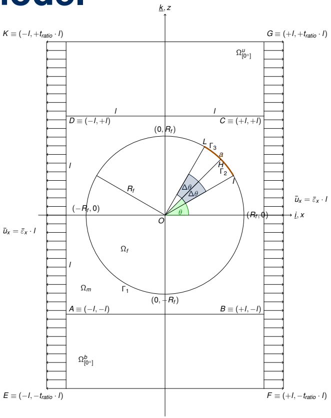
Bounded RVE model



(a) Crack closed in the radial direction.

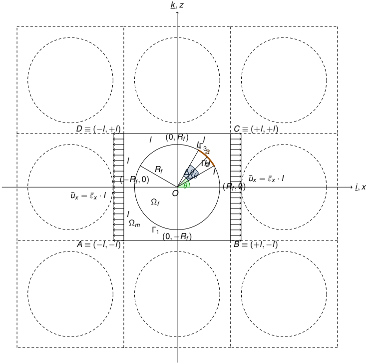
(b) Crack open in the radial direction.

Bounded RVE model

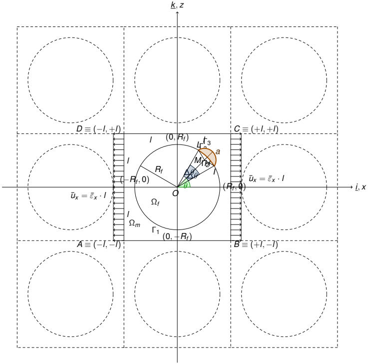


Initial state of bounded RVE model: crack closed in the radial direction.

Periodic RVE model

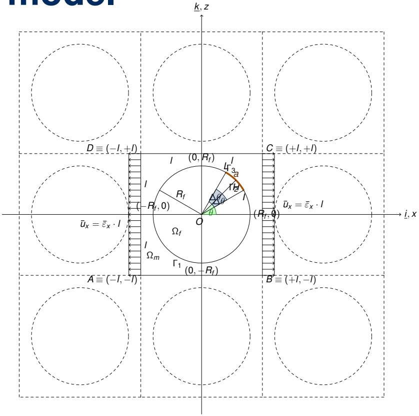


(a) Crack closed in the radial direction.



(b) Crack open in the radial direction.

Periodic RVE model



Initial state of periodic RVE model: crack closed in the radial direction.

Summary of designed geometries

Name	**Number of phases**
single-RVE	2

Description
Circular fiber inside a square matrix domain.

Geometry of each phase
Fiber: circular; matrix: square with circular inclusion at its center.

Boundary conditions
Constant strain at $z = \pm l$; in order to have constant strain, the displacement has a linear functional form, i.e. $u_x|_{z=\pm l} = \bar{u}_x \frac{x}{l}$.

Imposed conditions
Constant displacement $u_x|_{z=\pm l} = \bar{u}_x = \bar{\varepsilon}_x \cdot l$ at $x = \pm l$.

Summary of designed geometries

Name	Number of phases
bounded-RVE	3

Description

Circular fiber inside a square matrix domain, bounded by two UD rectangular domains on the upper and lower side.

Geometry of each phase

Fiber: circular; matrix: square with circular inclusion at its center; UD: rectangular.

Boundary conditions

Free surface at $z = \pm l$.

Imposed conditions

Constant displacement $u_x|_{z=\pm l} = \bar{u}_x = \bar{\varepsilon}_x \cdot l$ at $x = \pm l$.

Summary of designed geometries

Name	Number of phases
periodic-RVE	2

Description

Periodically repeated unit cell, constituted by a circular fiber inside a square matrix domain.

Geometry of each phase

Fiber: circular; matrix: square with circular inclusion at its center.

Boundary conditions

Periodic boundary conditions on all sides.

Imposed conditions

Constant displacement $u_x|_{z=\pm l} = \bar{u}_x = \bar{\varepsilon}_x \cdot l$ at $x = \pm l$.

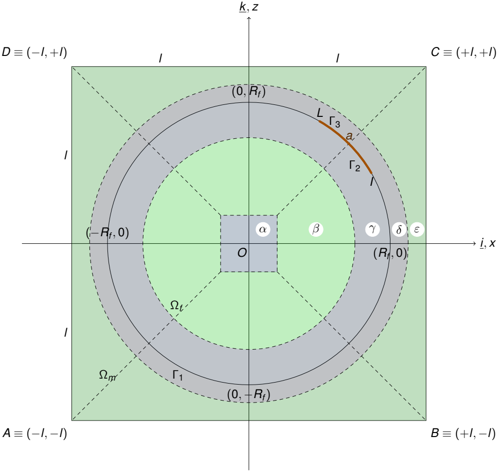
Summary of single phase properties

Material	E_1 $[GPa]$	E_2 $[GPa]$	G_{12} $[GPa]$	ν_{12} $[-]$	ν_{23} $[-]$	a_1 $\left[10^{-6}\ \frac{m}{mK}\right]$	a_2 $\left[10^{-6}\ \frac{m}{mK}\right]$
CF	500,0	30,0	20,0	0,2	0,5	-1,0	7,8
GF	70,0	70,0	29,2	0,2	0,2	4,7	4,7
EP	3,5	3,5	1,3	0,4	0,4	60,0	60,0

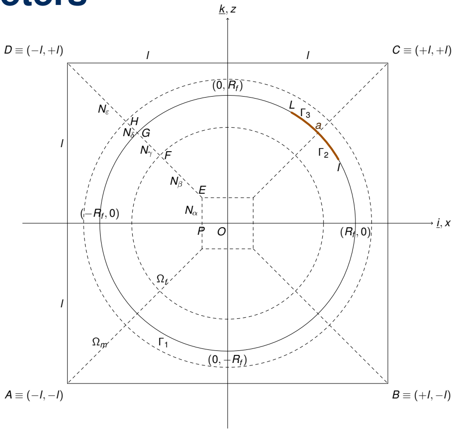
Summary of UD ply properties

Material	V_f $[-]$	E_1 $[GPa]$	E_2 $[GPa]$	G_{12} $[GPa]$	G_{23} $[GPa]$	ν_{12} $[-]$	ν_{23} $[-]$
CF/EP	0,6	301,4422	11,0389	4,0625	3,5767	0,2734	0,5432
CF/EP	0,4	202,1433	7,5694	2,6136	2,3803	0,3133	0,5899
GF/EP	0,6	43,4425	13,7145	4,3140	4,6808	0,2726	0,4650

Mesh regions

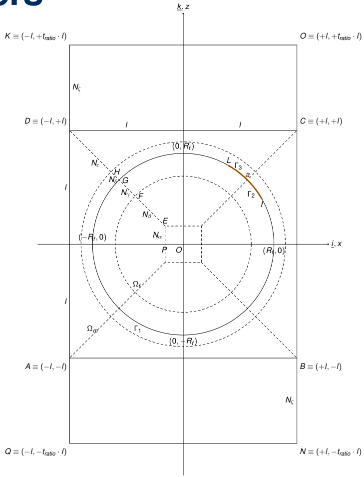


Mesh parameters

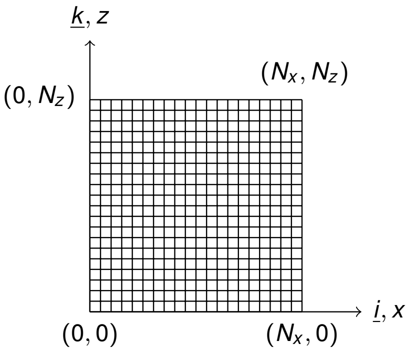


$E \equiv (-f_1 \cdot R_f, +f_1 \cdot R_f)$ $F \equiv f_2 R_f\,(-\cos 45°, \sin 45°)$

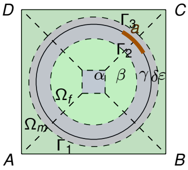
Mesh parameters



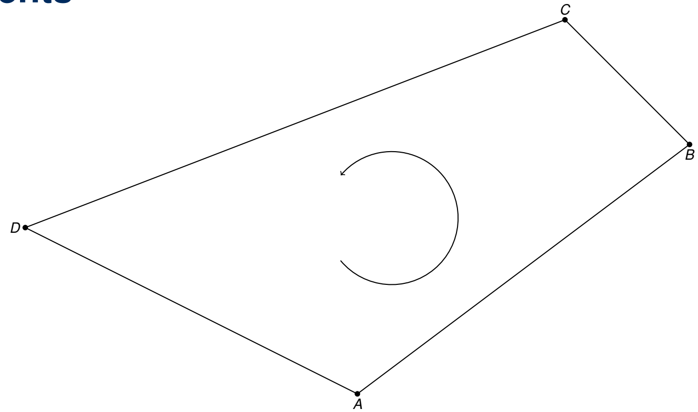
Helical numbering



Topological transformation

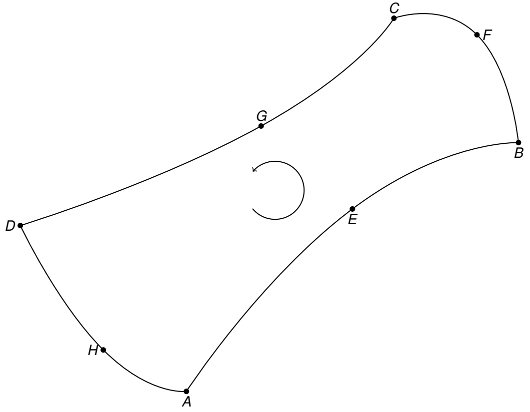


Elements



CPE4.

Elements



CPE8.

Features

Method	ABAQUS/STD static analysis + VCCT + J-integral.
Type	Static, i.e. no inertial effects. Relaxation until equilibrium.
Elements	CPE4/CPE8
Interface	Tied surface constraint & contact mechanics
Input variables	R_f, V_f, material properties, interface properties.
Control variables	θ, $\Delta\theta$, $\bar{\varepsilon}_x$.
Output variables	Stress field, crack tip stress, stress intensity factors, energy release rates, a.

Features

Method	ABAQUS/STD static analysis + CZM.
Type	Static, i.e. no inertial effects. Relaxation until equilibrium.
Elements	CPE4/CPE8 + COH2D4
Interface	Cohesive elements.
Input variables	R_f, V_f, material properties.
Control variables	Interface properties, maximum stresses at crack onset, energy release rates, applied strain.
Output variables	θ, $\Delta\theta$, a, stress field, peak crack boundary stresses.

Abaqus commands

Method	ABAQUS command
static analysis	*STATIC
VCCT	*FRACTURE CRITERION, TYPE=VCCT
J-integral method	*CONTOUR INTEGRAL
cohesive element method	*COHESIVE SECTION
tied surface constraint	*TIE
contact mechanics	*CONTACT
stress intensity factors	*CONTOUR INTEGRAL, TYPE=K FACTORS

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THANK YOU!

DocMASE

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Erasmus Mundus