Simulation des composites de bout en bout, Fabrication et Comportement à partir d'exemples

NAFEMS
SIMULATION DES MATERIAUX
Concevoir - Caractériser – Optimiser – Valider - Gérer

Patrick de Luca – Sebastian Mueller – Alain Trameçon

19 Novembre 2015

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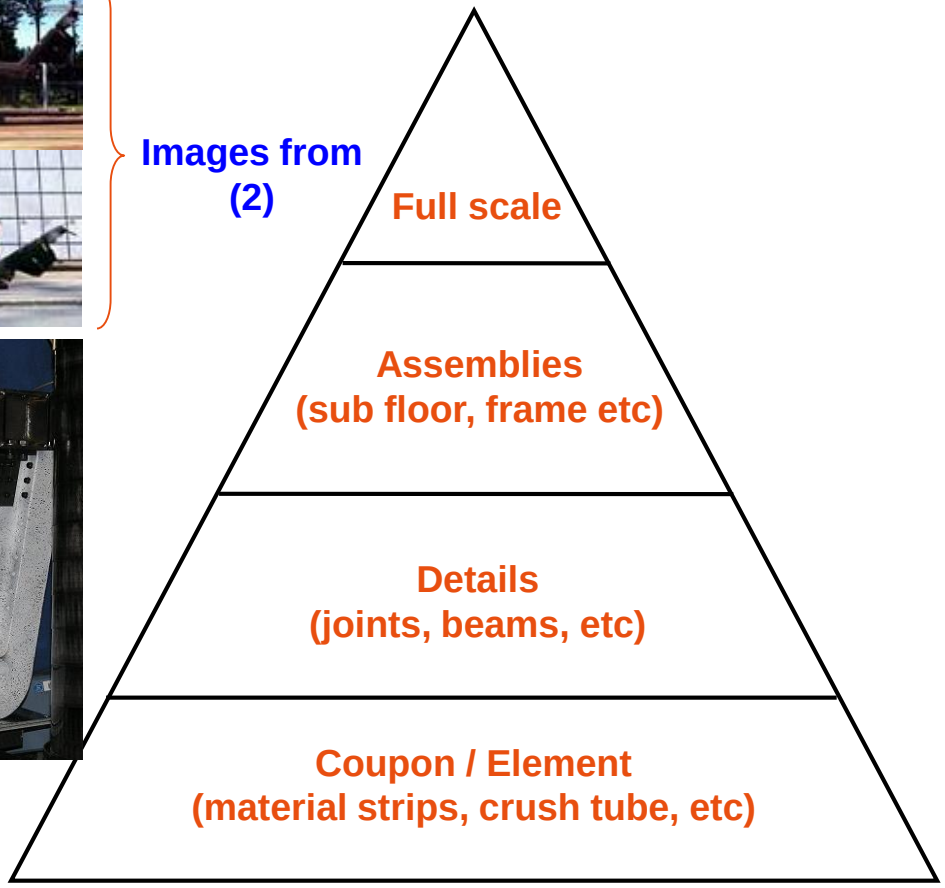
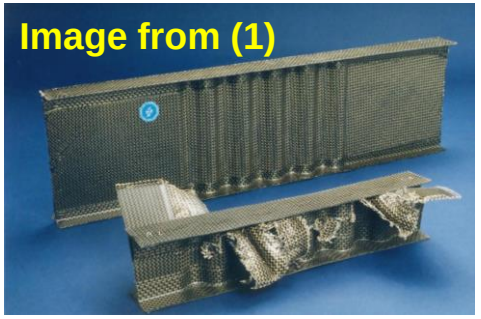
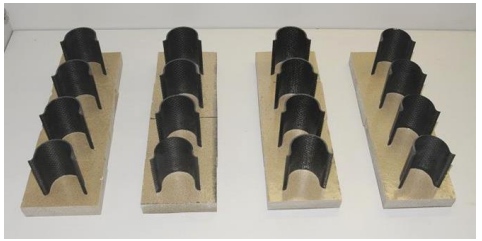
(1) Wiggenraad JFM, 'Crashworthiness research at NLR (1990-2003), NLR-TP-2003-317
(2) Jackson KE et al., 2002, 'A History of Full-Scale Aircraft and Rotorcraft Crash Testing and Simulation at NASA Langley Research Center'

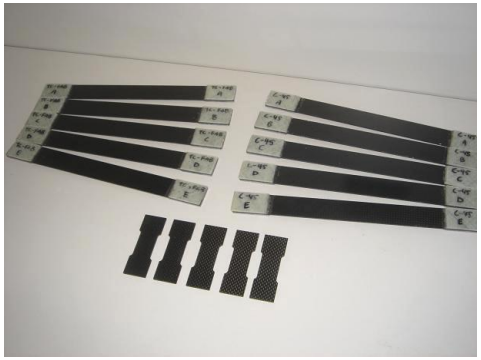
Crashworthy Design Approach

Images from (2)



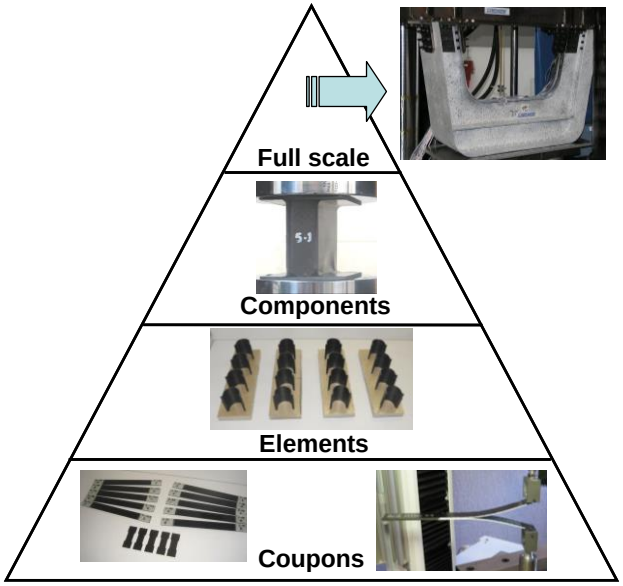




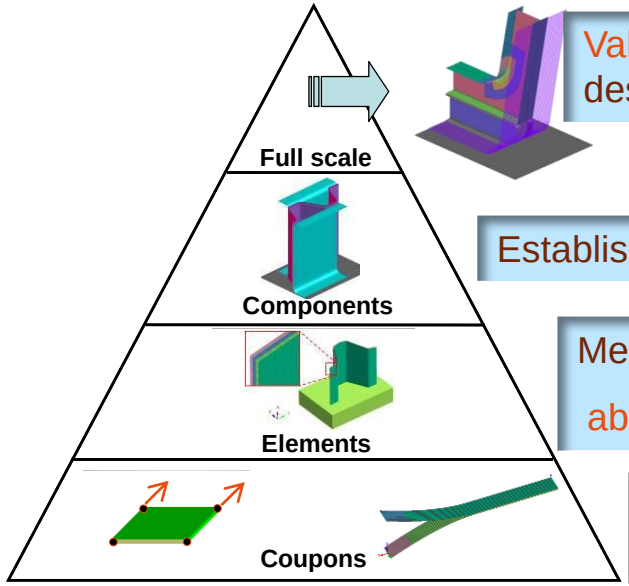


Development Approach
Experiment and Simulation

- Building Block Approaches – Test and Simulation Pyramids



Experimental Building Block



Simulation Building Block

Validate energy absorber design and crash design tools

Establish integration issues

Measure energy absorption characteristics

Determine material constants

Validation of Crashworthiness Simulation and Design Methods by Testing of a Scaled Composite Helicopter Frame Section

Christof Kindervater[*1], Rodney Thomson[2,3], Alastair Johnson[1], Matthew David[1], Mathew Joosten[4], Zoltan Mikulik[2,4,5], Lex Mulcahy[6], Sebastian Veldman[2], Andrew Gunnion[2], Adrian Jackson[4], Stuart Dutton[4]

- Details in this paper

Presented at the American Helicopter Society 67th Annual Forum, Virginia Beach, VA, May 3-5, 2011.

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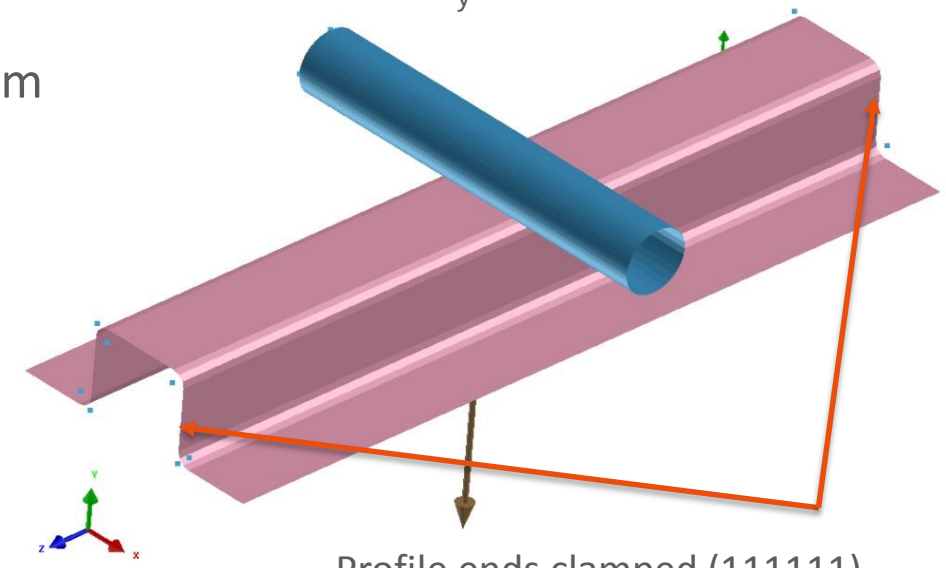
Model implemented and under current evaluation

Hat profile crash test

- Model dimension
  - Hat profile Dx = 190 mm, Dy = 70 mm, Dz = 600 mm
  - Tube Radius 25mm, Length 300 mm
- homogeneous mesh, element length h = 10mm, 5 mm and 2.5 mm
- 8 layers, UD and BD layup
- z-direction = 0° fiber direction
- linear elastic, transversal isotropic continuum properties
- linear cohesive degradation
- comparison with equivalent Ladeveze model

Impact tube:

- rigid body m = 20 (UD) / 40 (BD) kg
- init. vel. v_y = -10 mm/ms



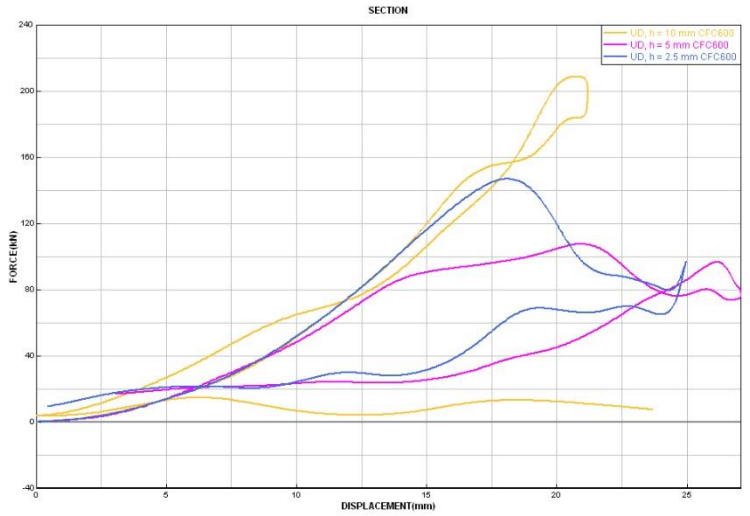
Profile ends clamped (111111)

Model evaluation

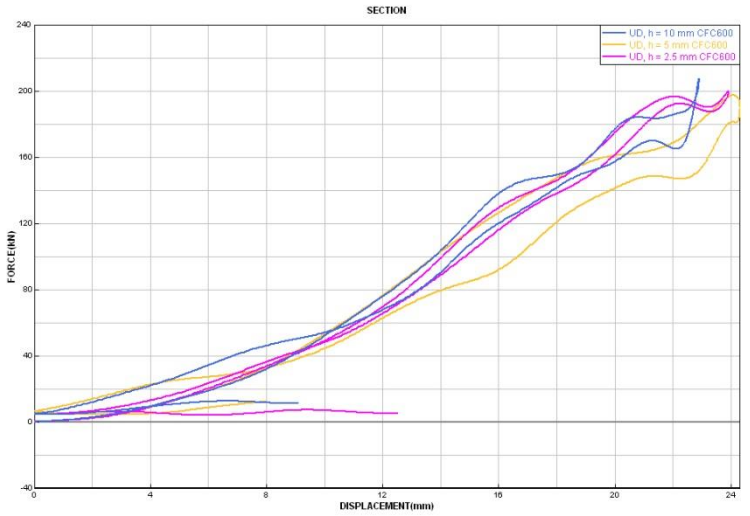
Hat profile crash test – UD layup – FORCE/DISPLACEMENT analysis

- Several mesh sizes: 2.5mm / 5.0 mm / 10.0 mm

Ladeveze model



New hybrid ply model



- Strong mesh dependence for continuum based Ladeveze model
- Mesh insensitive results for new hybrid ply model

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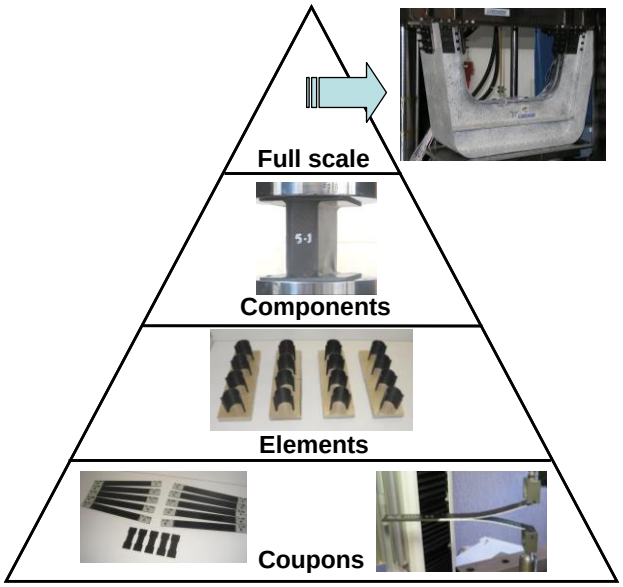
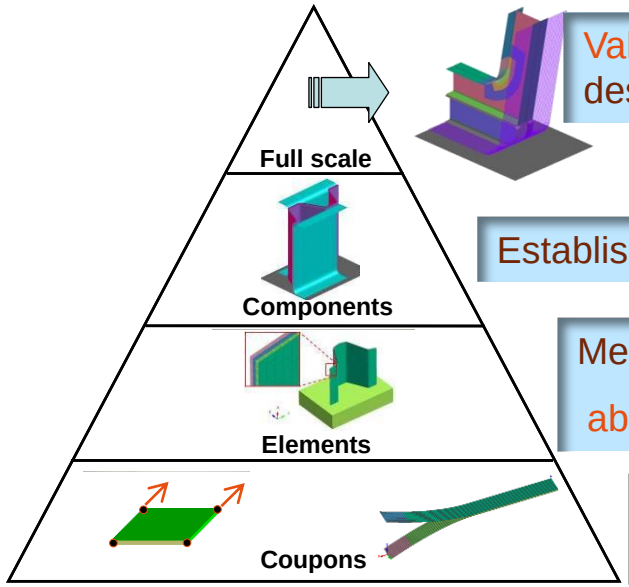


Experimental Building Block



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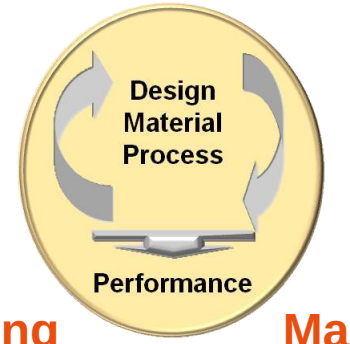
6

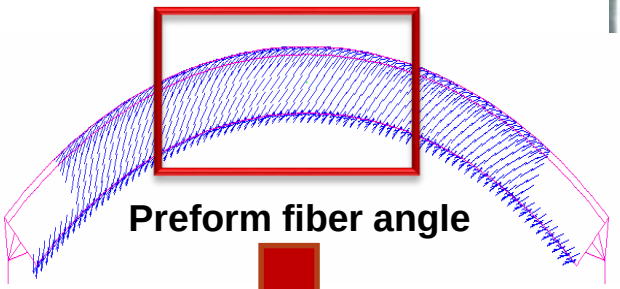
Composites: Performance - Manufacturing Cause - Effects



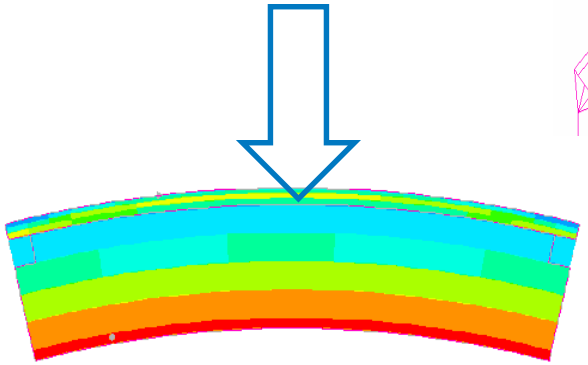
Without Manufacturing effects

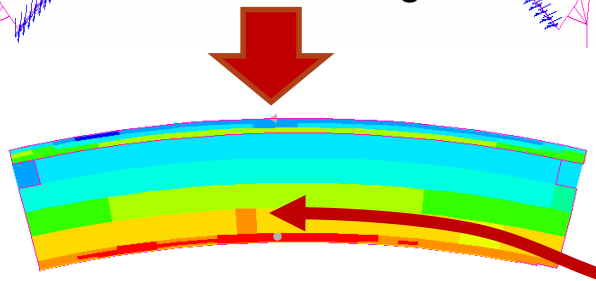
With Manufacturing effects

CAD
(Uniform stiffness)



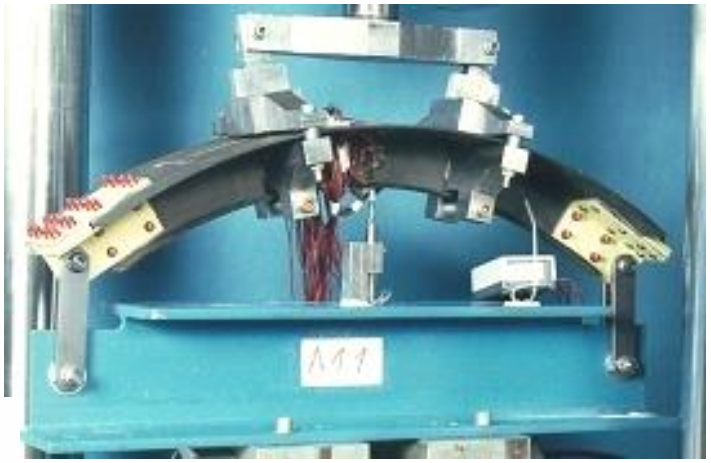
Preform fiber angle



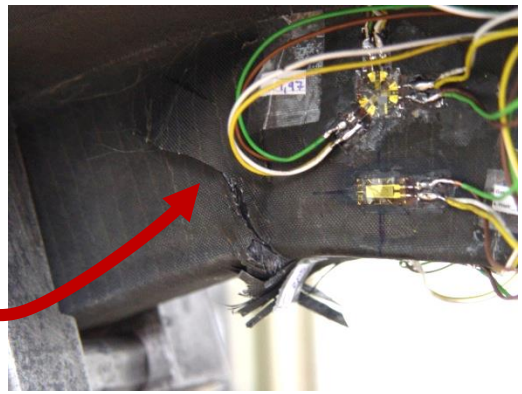


Unable to predict failure

Accurate failure prediction



Air Frame rupture test



Failure experimentally observed

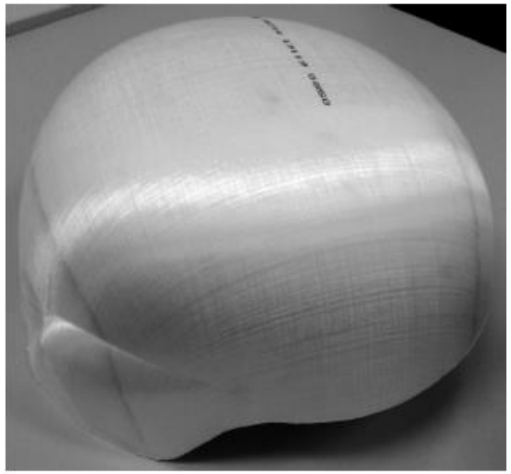
Courtesy: EADS-M

HELMET DESIGN: an E2E example

Successfull design of a combat helmet

- PU-based resin + SPECTRA Fibers
  - A bright white polyethylene fiber with high resistance to chemicals, water and ultraviolet light
  - Stronger than steel and 40 percent stronger than aramid fiber
  - Capable of withstanding high-load strain-rate velocities
- Double Diaphragm thermoforming
- Compression tests for certification

(a)

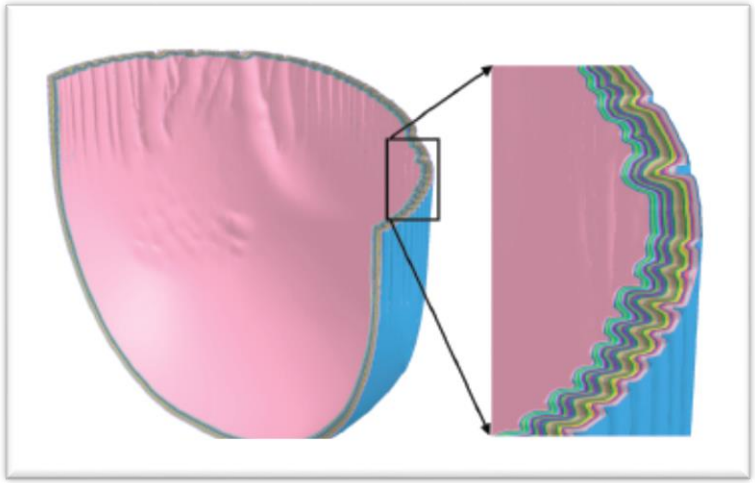


Thermoforming and Structural Analysis of Combat Helmets
Bruce K. Cartwright, N. Lex Mulcahy, Allen O. Chhor, Stuart G. F. Thomas, Madhusudan Suryanarayana, James D. Sandlin, Ian G. Crouch and Minoo Naebe
J. Manuf. Sci. Eng. 2015;137(5):051011-051011-9.
doi:10.1115/1.4031154.

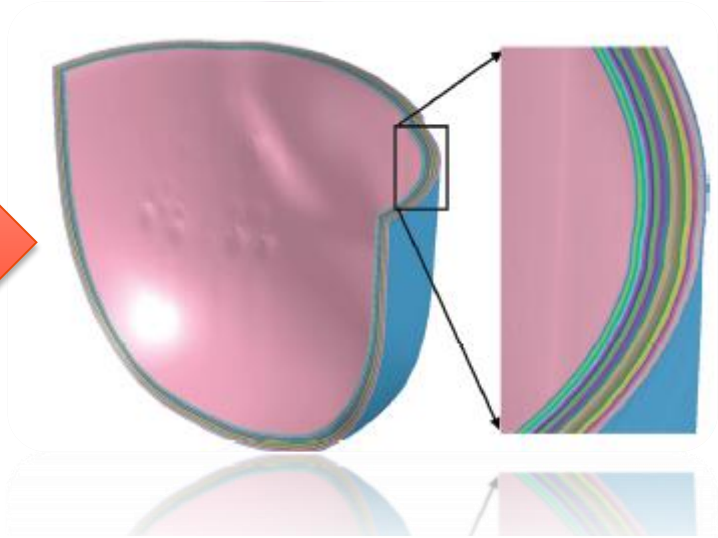
HELMET DESIGN: an E2E example

Successfull design of a combat helmet

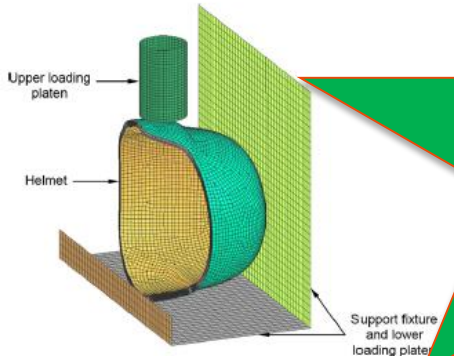
- Thermoforming simulations



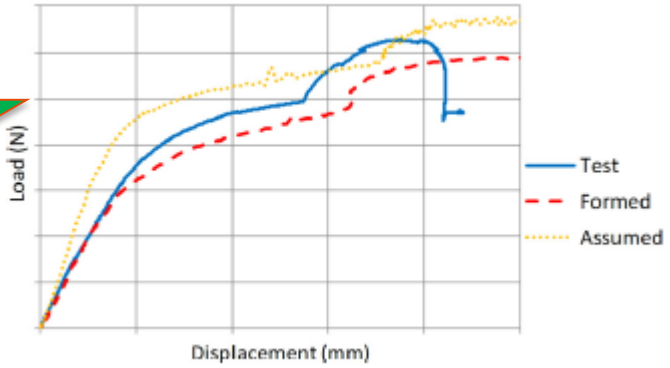
Process parameters optimisation



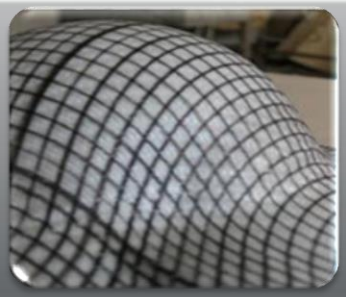
- Use of forming results in VPS



Mechanical Simulation

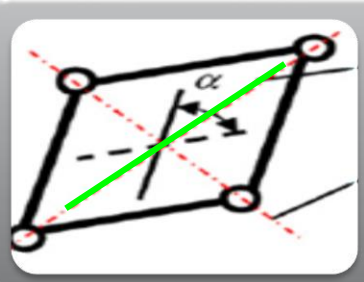


Draping effects in Performance Simulation



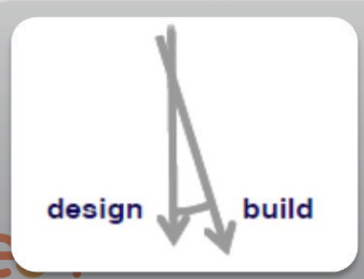
To form a part, the orientation of the fiber need to change

- This is to let the (flat) paralell fiber accomodate double curvatures
- The dominant deformation mode is shearing



Due to the change of fiber directions during the manufacturing process, stiffness/strength change

- Increase of strength in the ‘green’ direction
- Transverse to ‘green’ direction more vulnerable



Design needs to account for this manufacturing effect

Need to Link Draping results to Mechanical Simulation

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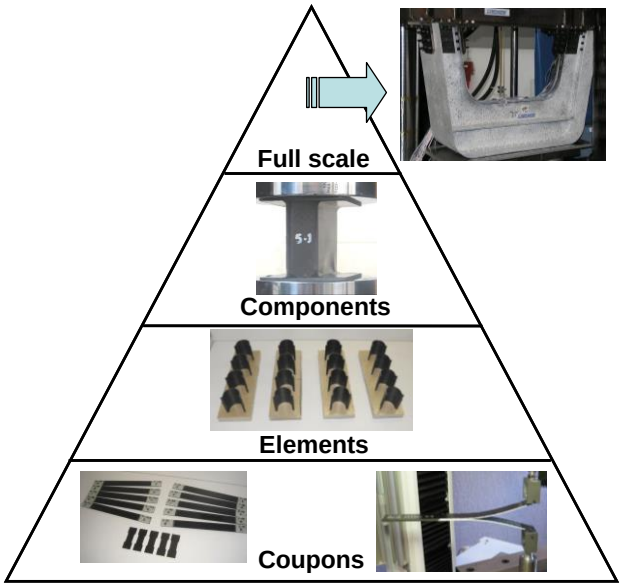
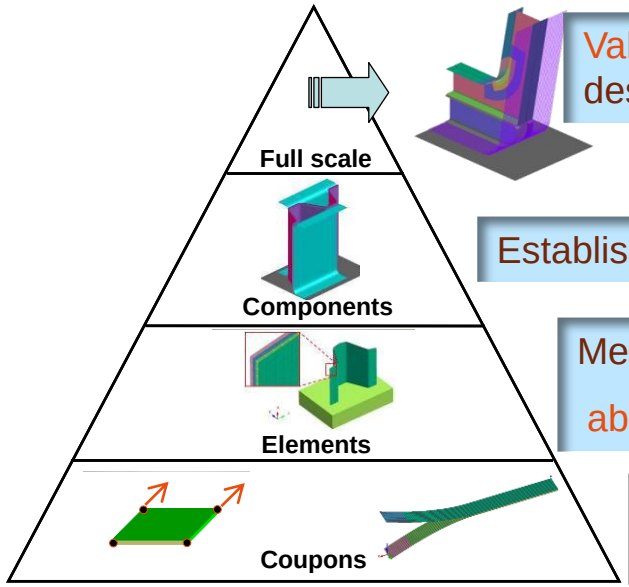


Experimental Building Block



Validate energy absorber design and crash design tools

Establish integration issues

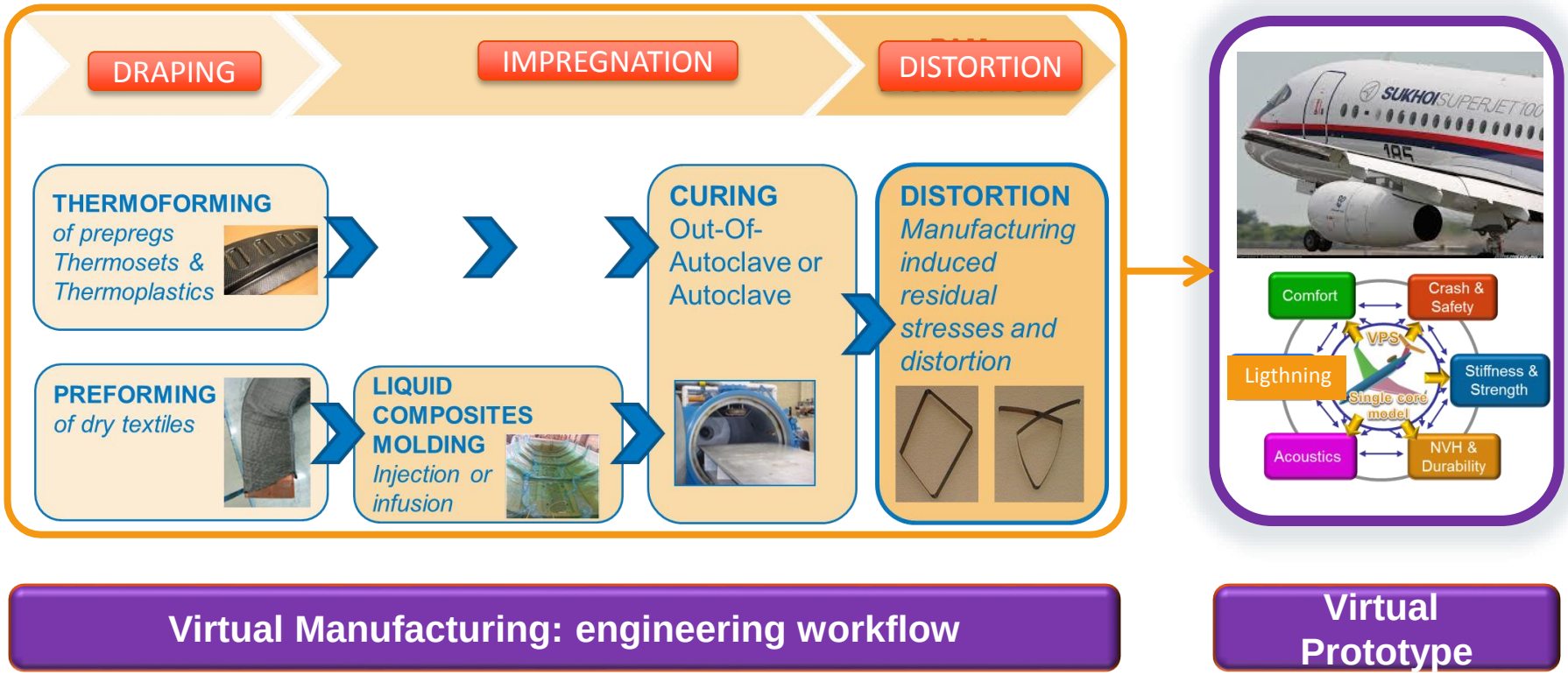
Measure energy absorption characteristics

Determine material constants

Manufacturing Simulation

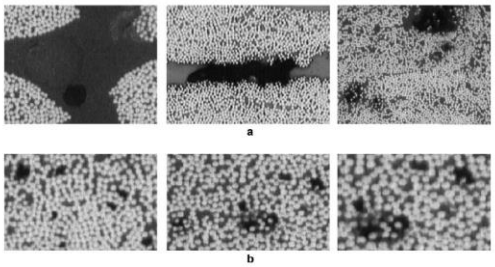
Simulation Building Block

Full process chain and optimized workflow



Virtual Manufacturing: engineering workflow

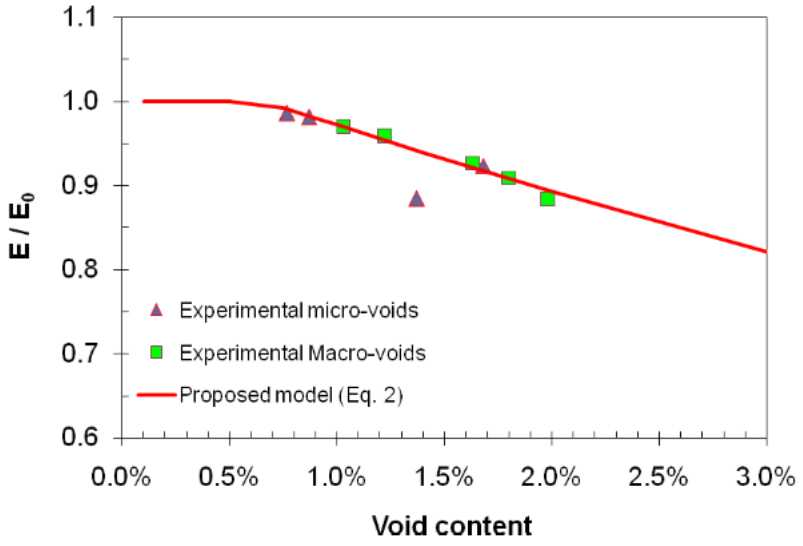
Virtual Prototype

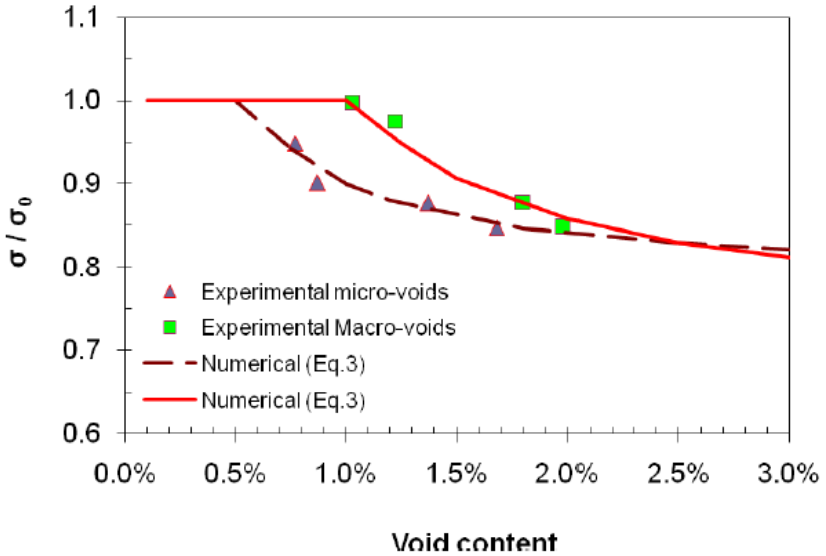


Effect of Micro-Voids on Mechanical Properties

- $E/E_0=A_E*\exp(B_E/x)$
- $\sigma/\sigma_0=A_T*\exp(B_T/x)$
- Where x = void content in %

Possible reuse of RTM simulation results in part performance assessment

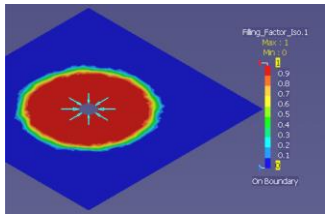




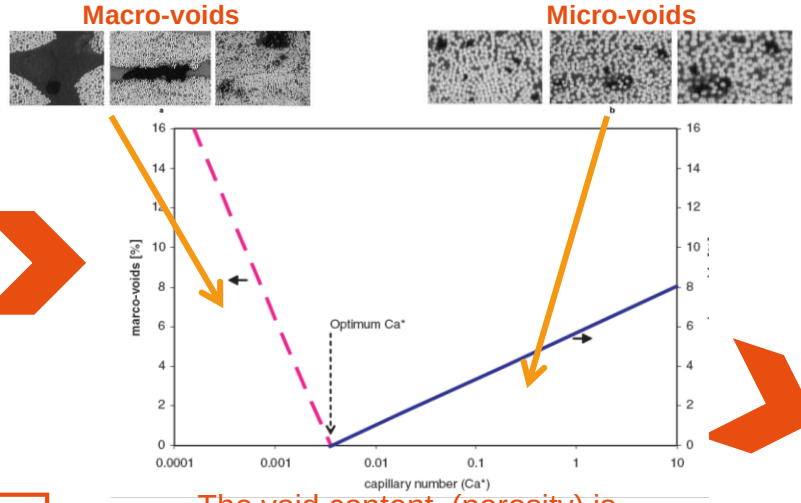
Leclerc Jean-Sebastien; Edu Ruiz, Porosity Reduction using Optimized Flow Velocity in Resin Transfer Molding, Elsevier Composites Part A

End-To-End Virtual Prototyping

Case Study: **Structural reinforcements in aircraft wings**

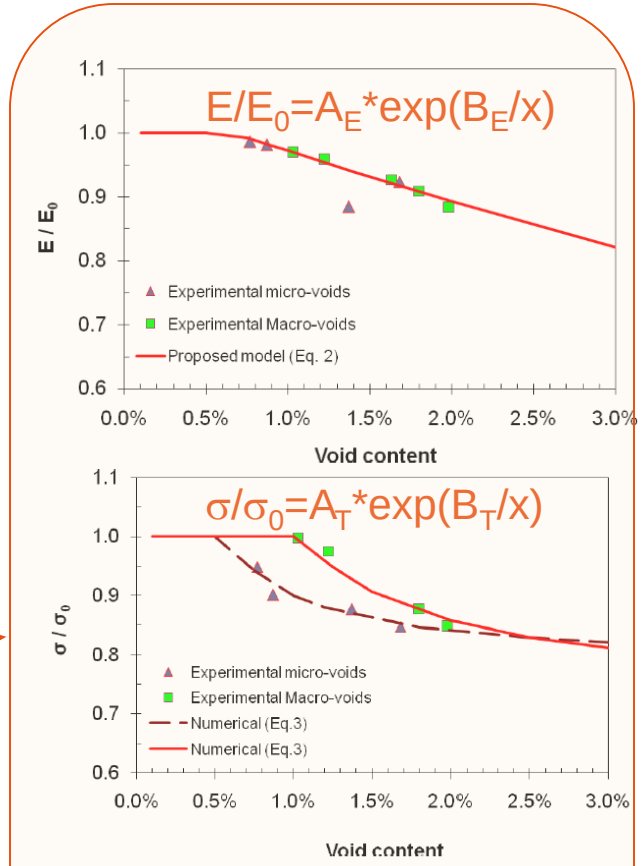


RTM simulation takes into account local permeabilities due to added tows



The void content (porosity) is determined from the RTM simulation (Void%=f(flow front velocity))

Physical checking of the design

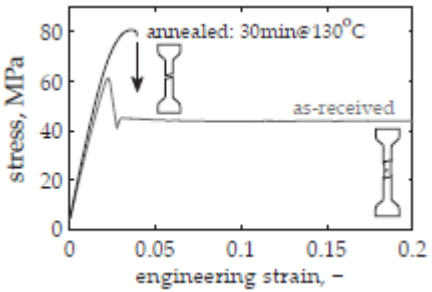


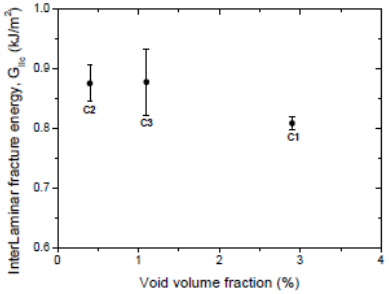
Porosity will affect Mechanical properties of the part

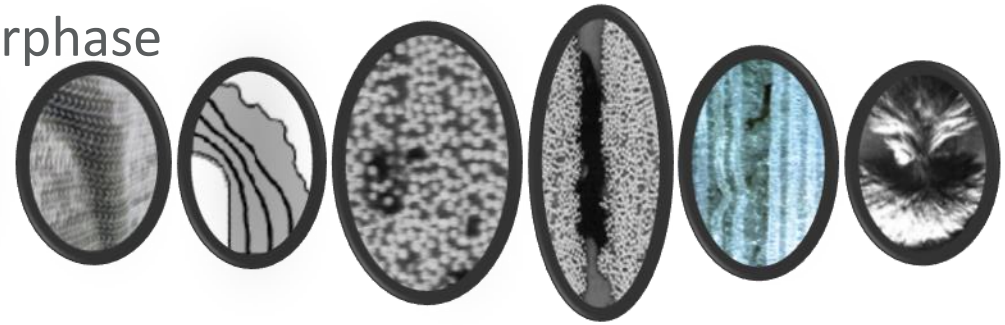
Damage analysis accounting for mechanical properties resulting from manufacturing

More Effects of Manufacturing process on to mechanics

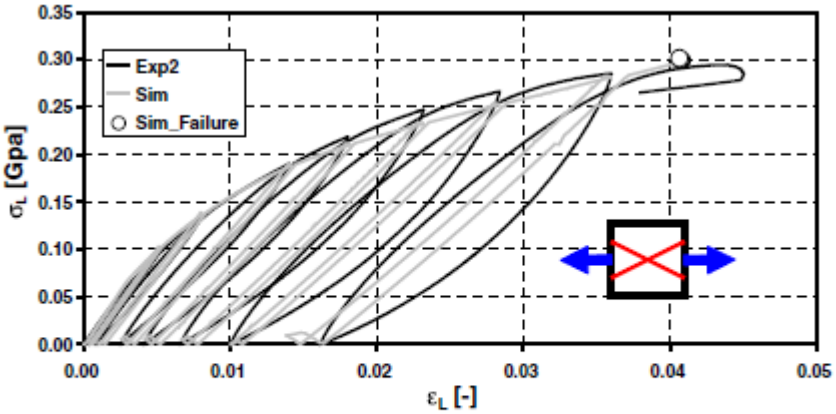
- Residual stresses
- Degree of cristallisation in thermoplastics (depends on thermal time history)
- Degree of consolidation between two layers of thermoplastics (depends on thermal and pressure time history)
- Resin rich zones
  - Over a radius
  - In drop-off zones (AFP, ATL)
- Fiber waviness
- Fiber/Resin interphase
- +++



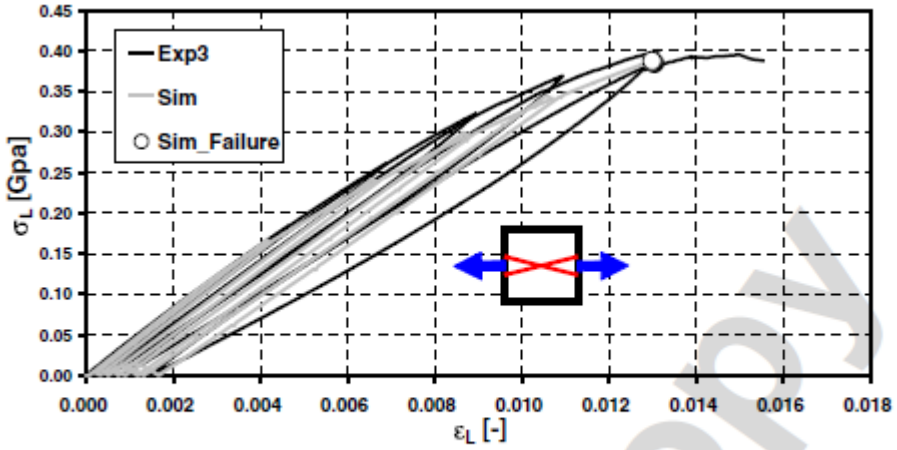




Draping influence on Non-Crimp Fabric Composites Damage



$[\pm 35]_{2s}$ cyclic tension



$[\pm 28]_{2s}$ cyclic tension

The model successfully captured intra-ply failure modes in the principal fibre directions for tension and compression, intra-ply shear and also the interaction of these modes

Modelling damage and failure in carbon/epoxy non-crimp fabric composites including effects of fabric pre-shear

L. Greve [a], A.K. Pickett [b,*]

Available online at www.sciencedirect.com ScienceDirect

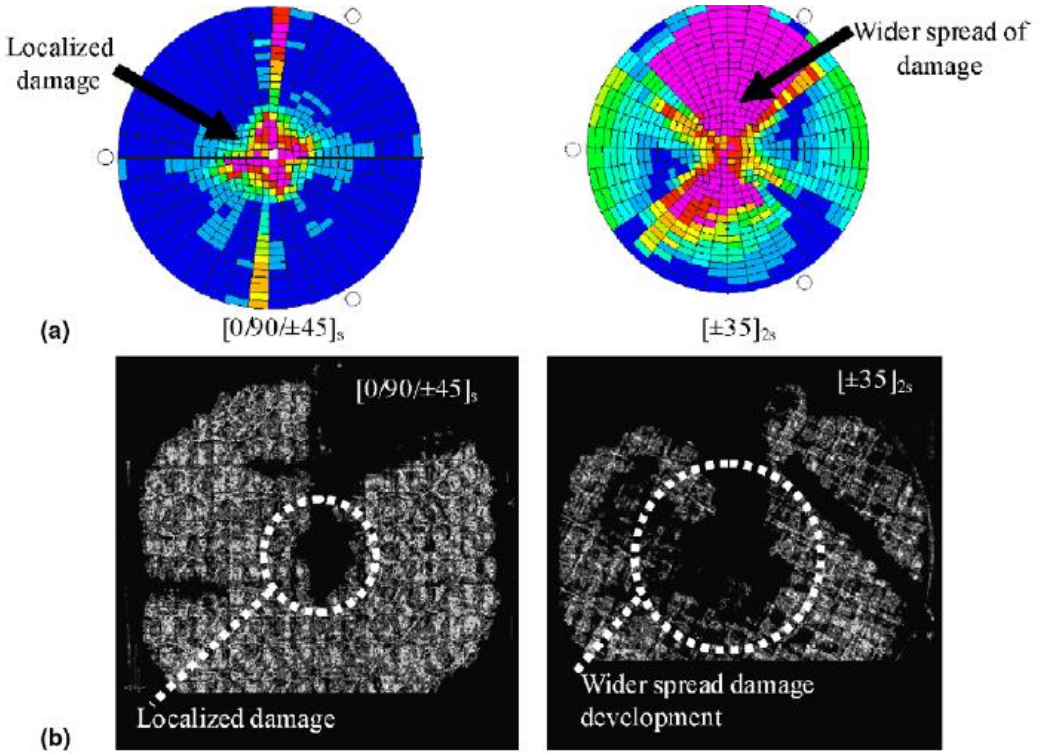
Composites: Part A 37 (2006) 1983–2001

composites Part A: applied science and manufacturing

www.elsevier.com/locate/compositesa

Draping influence on Non-Crimp Fabric Composites Damage

- Validation on pre-sheared composites disks quasi-static punch tests
- Good qualitative comparison with ultrasonic CT scans



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Part A: applied science and manufacturing
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17

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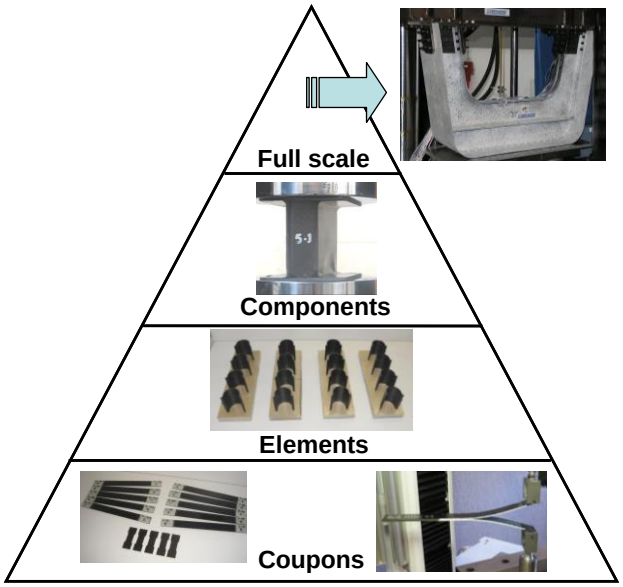
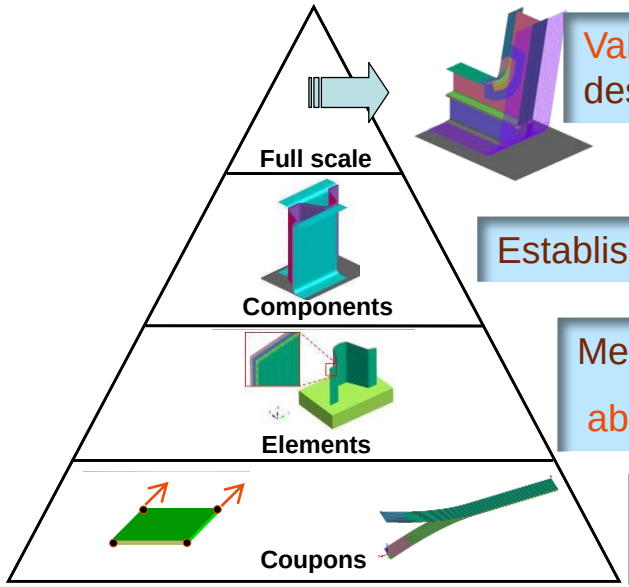


Experimental Building Block



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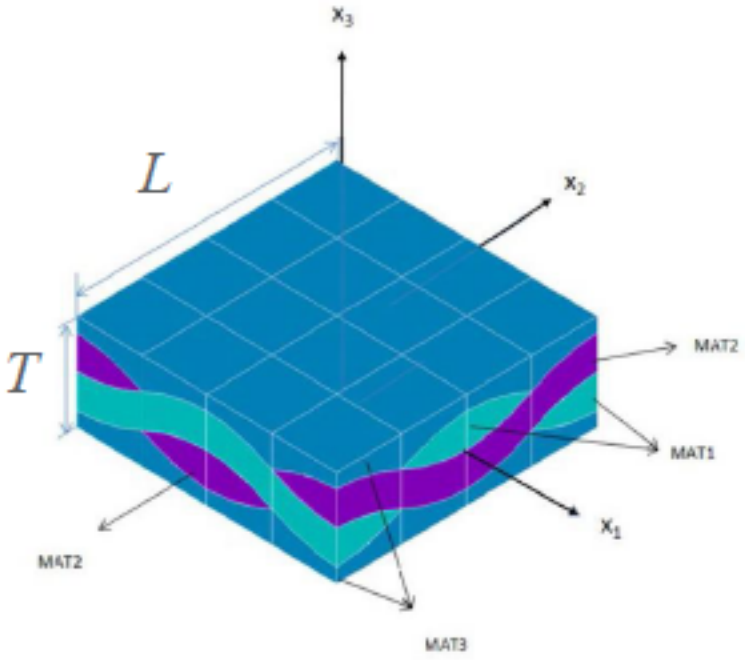
Simulation Building Block

18

WOVEN FIBER MICRO-STRUCTURE

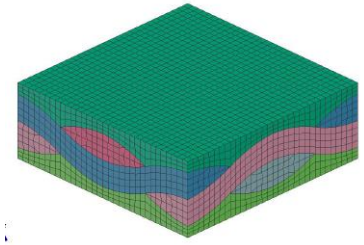
fiber volume fraction 60 %

	MAT 1	MAT 2	MAT 3
E (GPa)	450	300	45
v	0.17	0.22	0.18
α (10^6 / K)	-0.4	0.8	64.8



$$L = 8 \text{ mm}$$

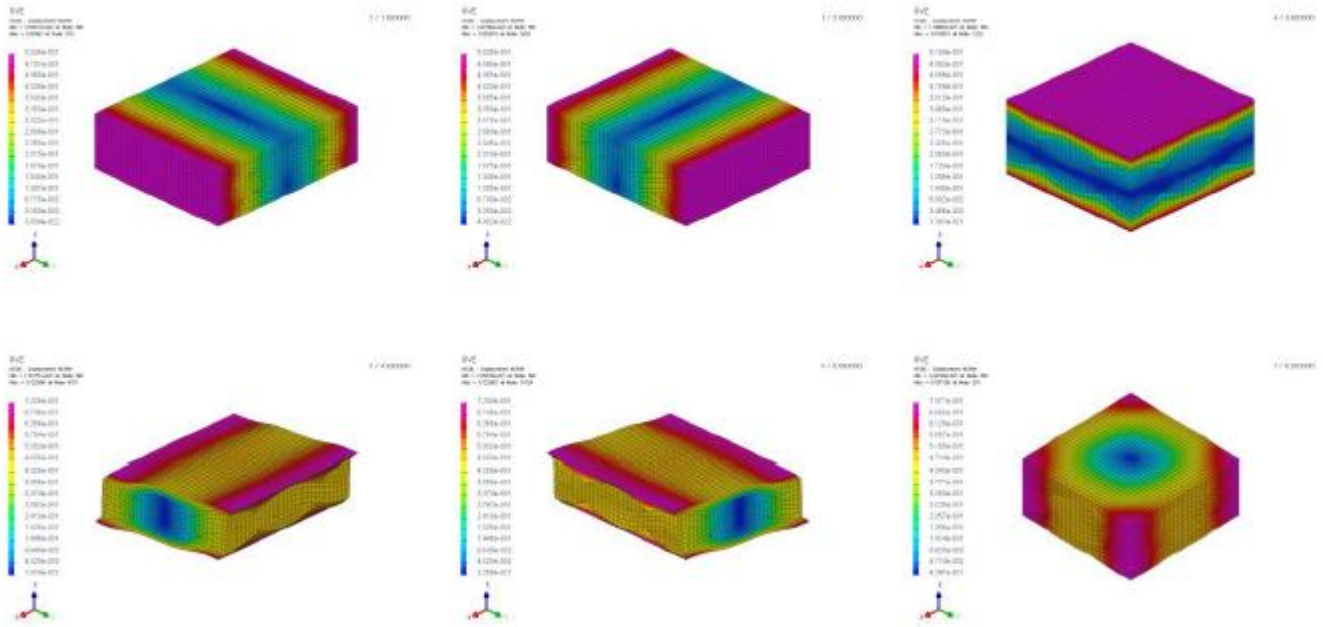
$$T = 2.84376 \text{ mm}$$



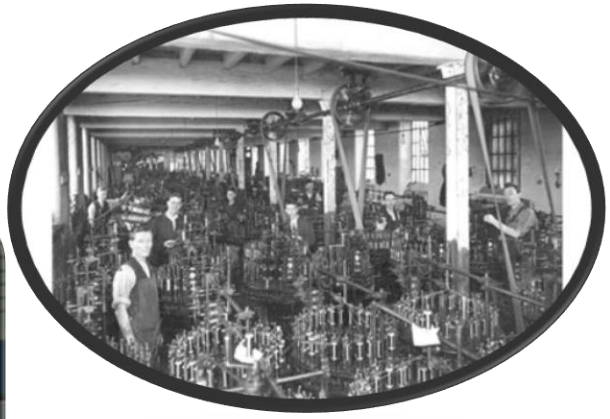
WOVEN FIBER MICRO-STRUCTURE

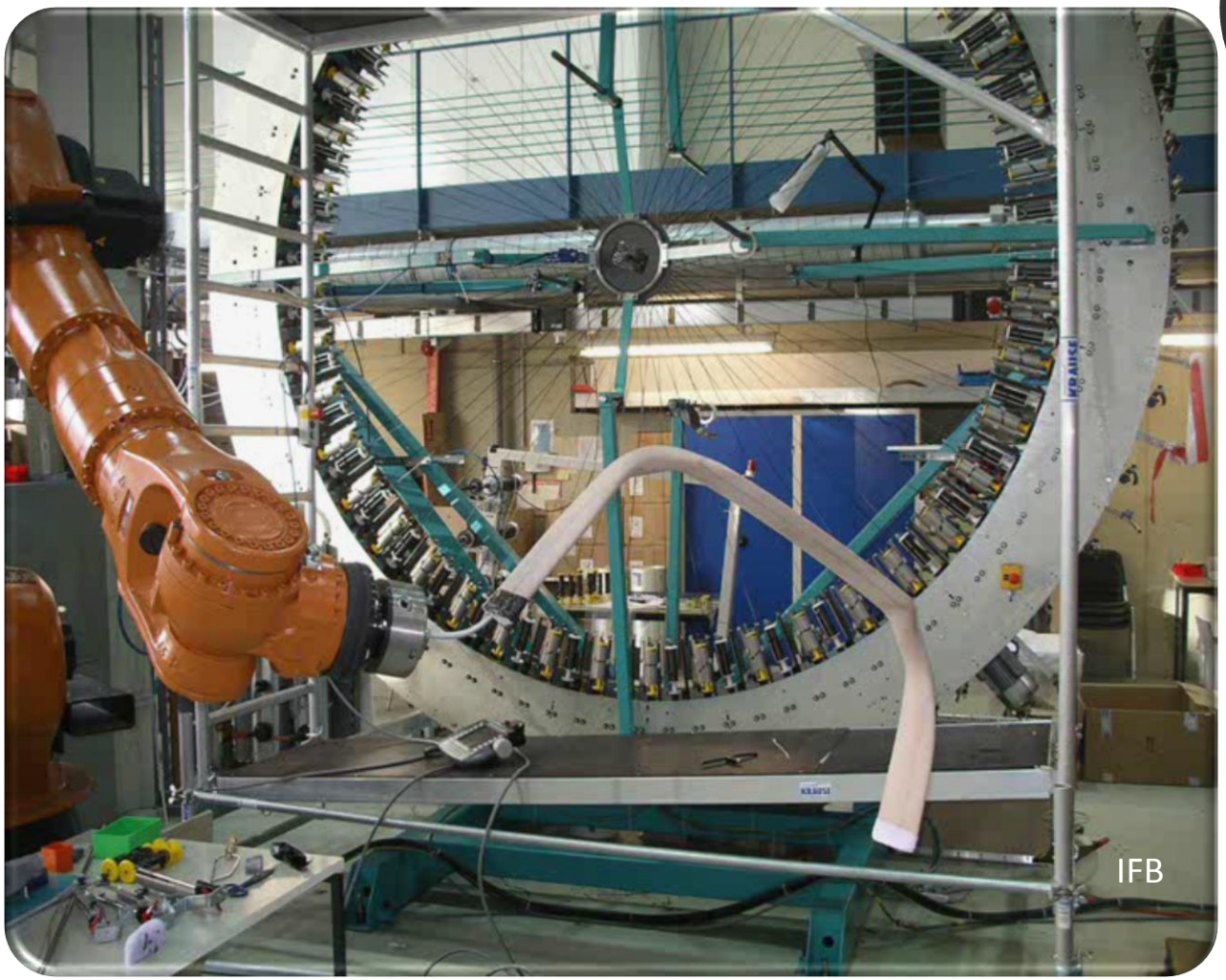
3 tensile tests + 3 shear tests

- Deformation modes

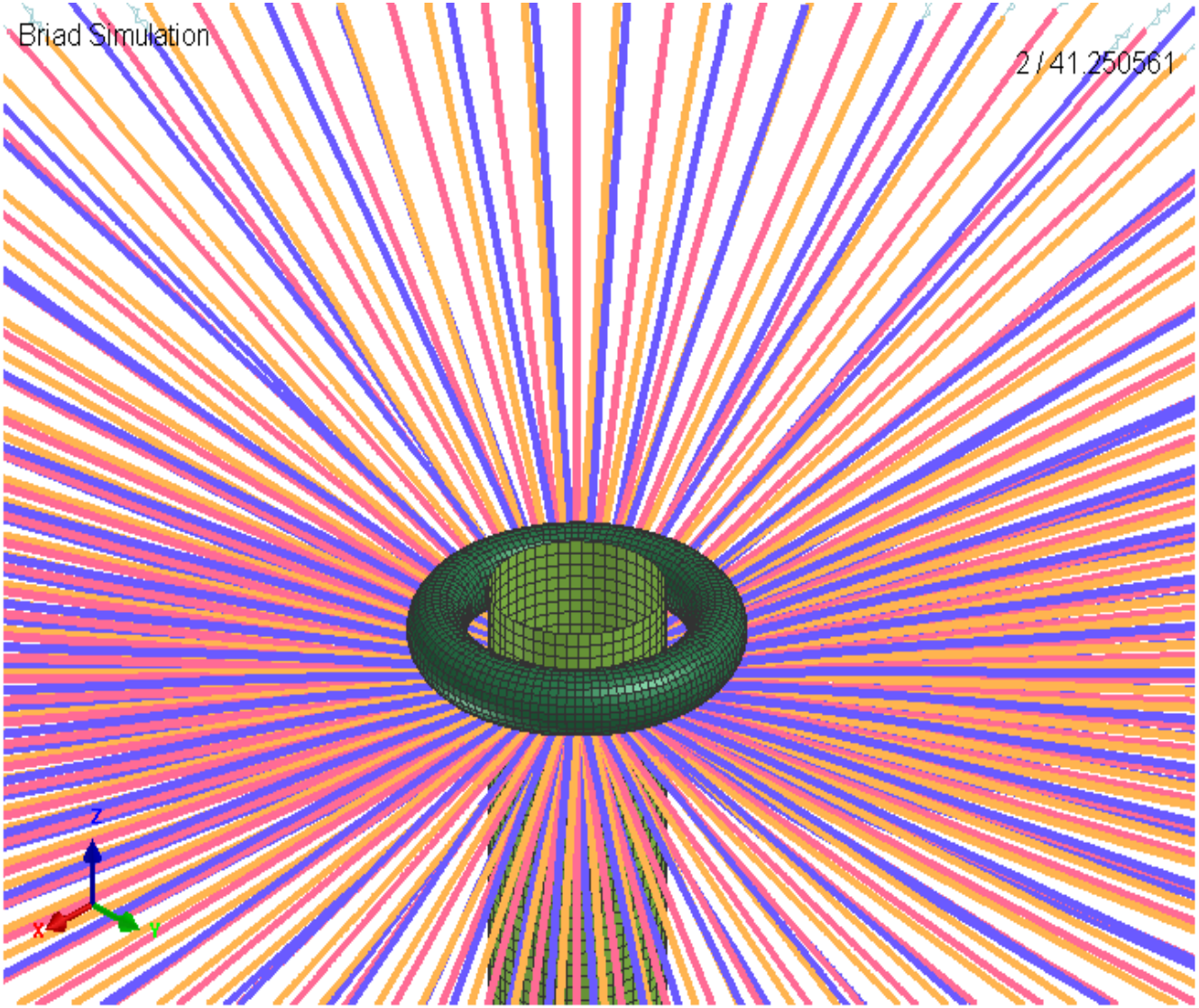


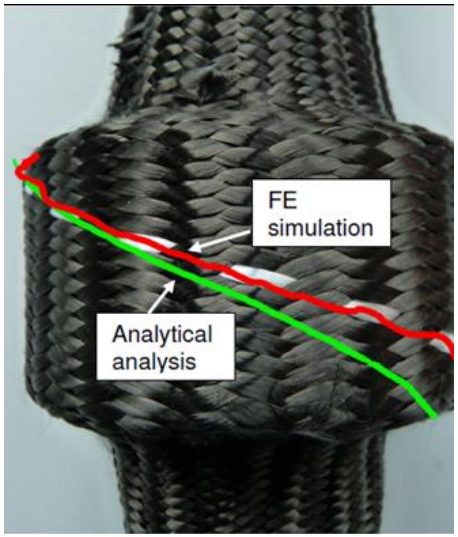
BRAIDING



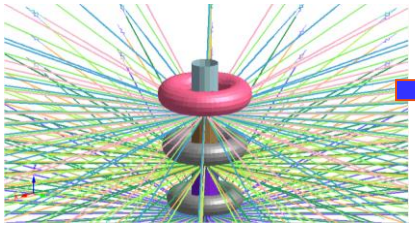


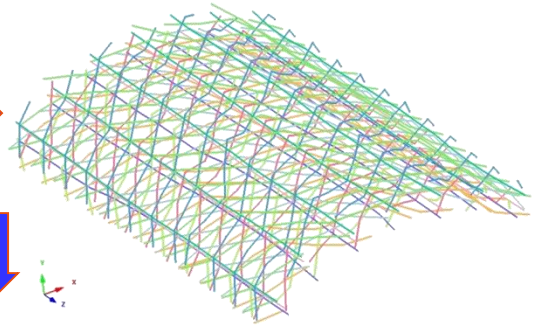
21



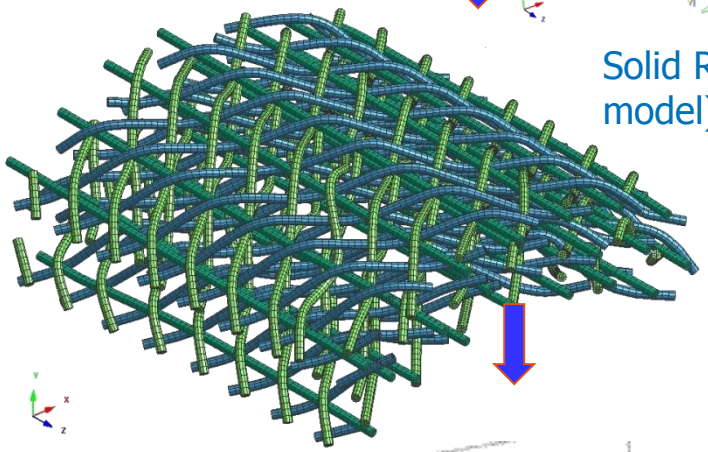


The ‚initial metric`pre-stress method to adjust yarn sections

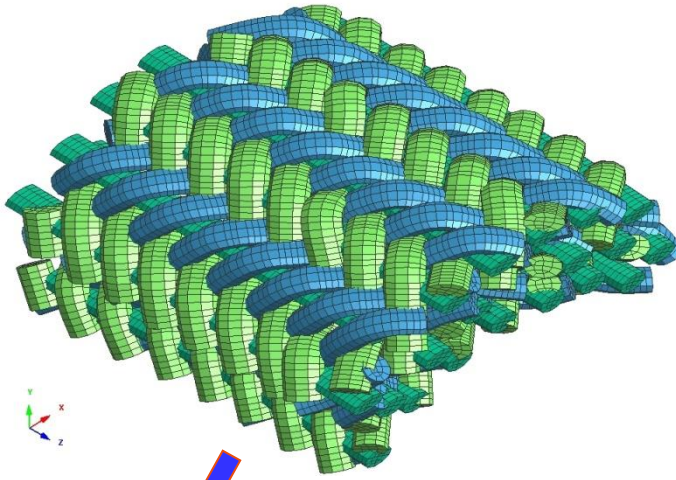


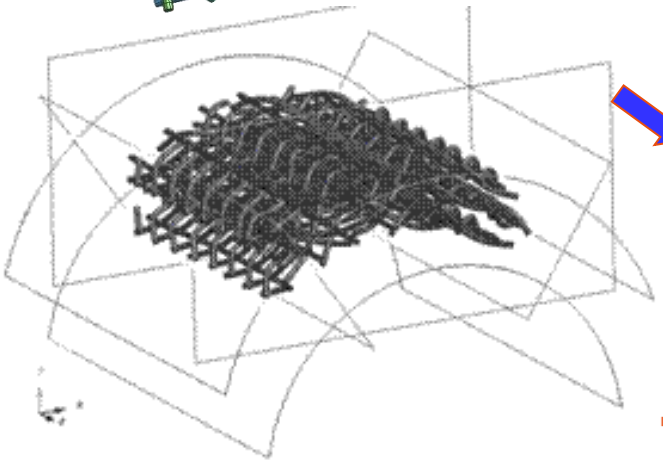


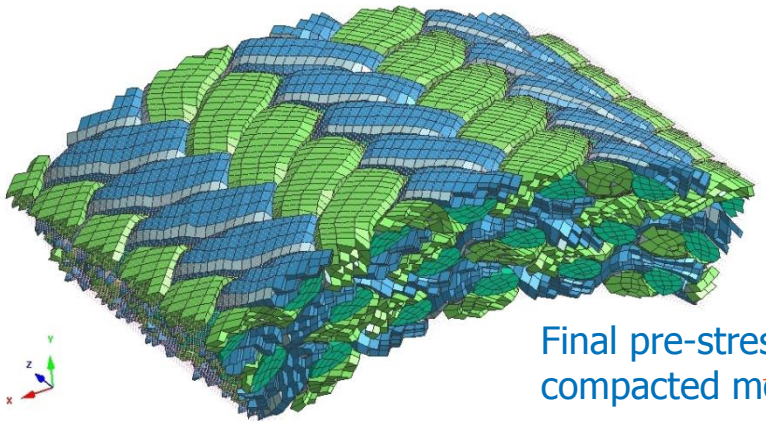
Solid RVE (Reference model)



Solid RVE model with scaled yarn sections (Initial metric model)

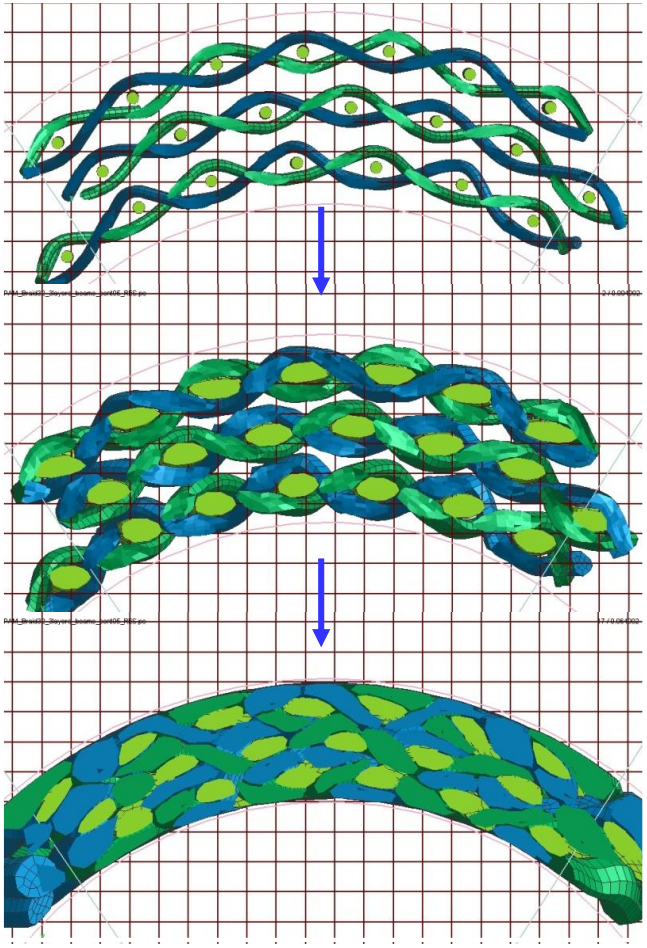




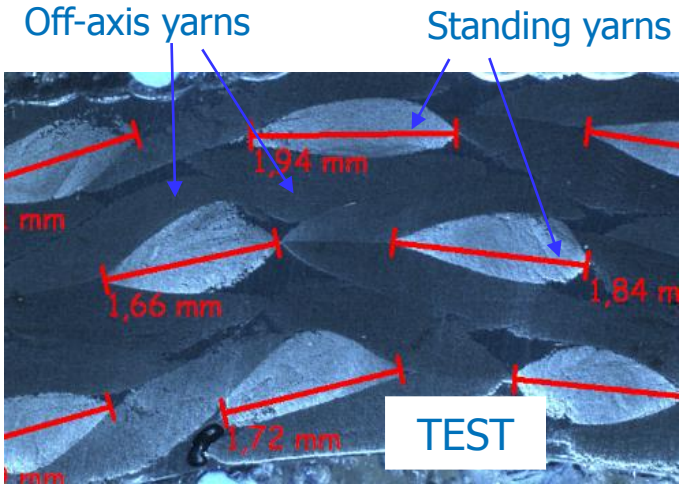


Final pre-stressed and compacted model

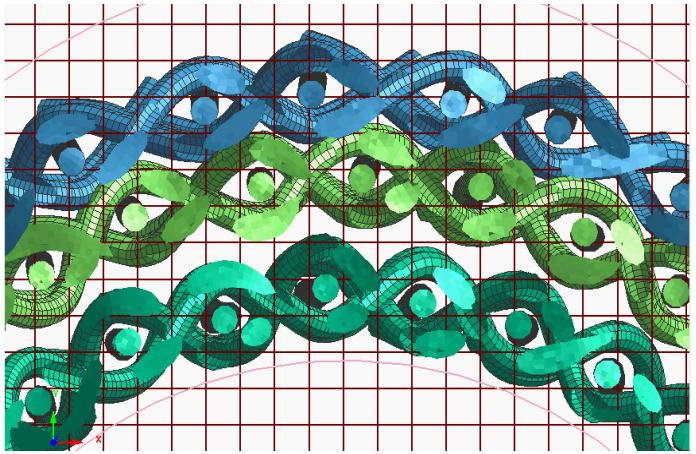
Extracting meso-models for analysis:RVE – Representative Volume Element



Simulation: Start, intermediate and final pre-stressing/compaction



Test showing standing and off axis yarns

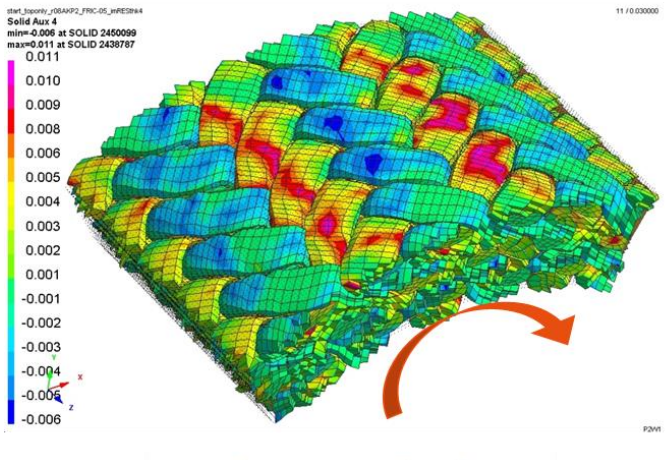


Animation of initial metric and compaction

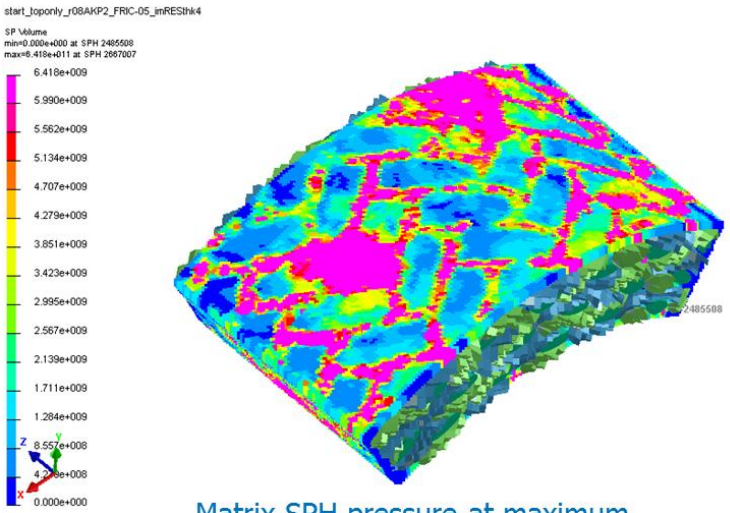
Tow section modification onto mech performance

Braided part example

- Stiffness modifications



Yarn shear stress distribution



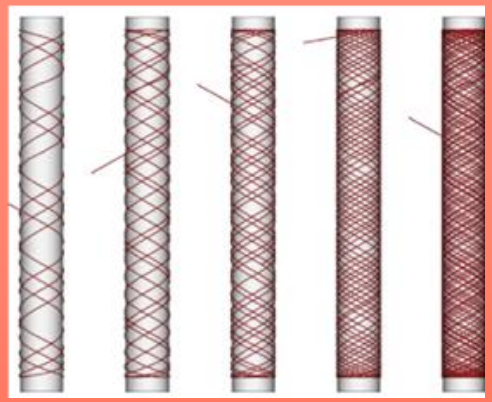
Matrix SPH pressure at maximum load indicating locations of first failure

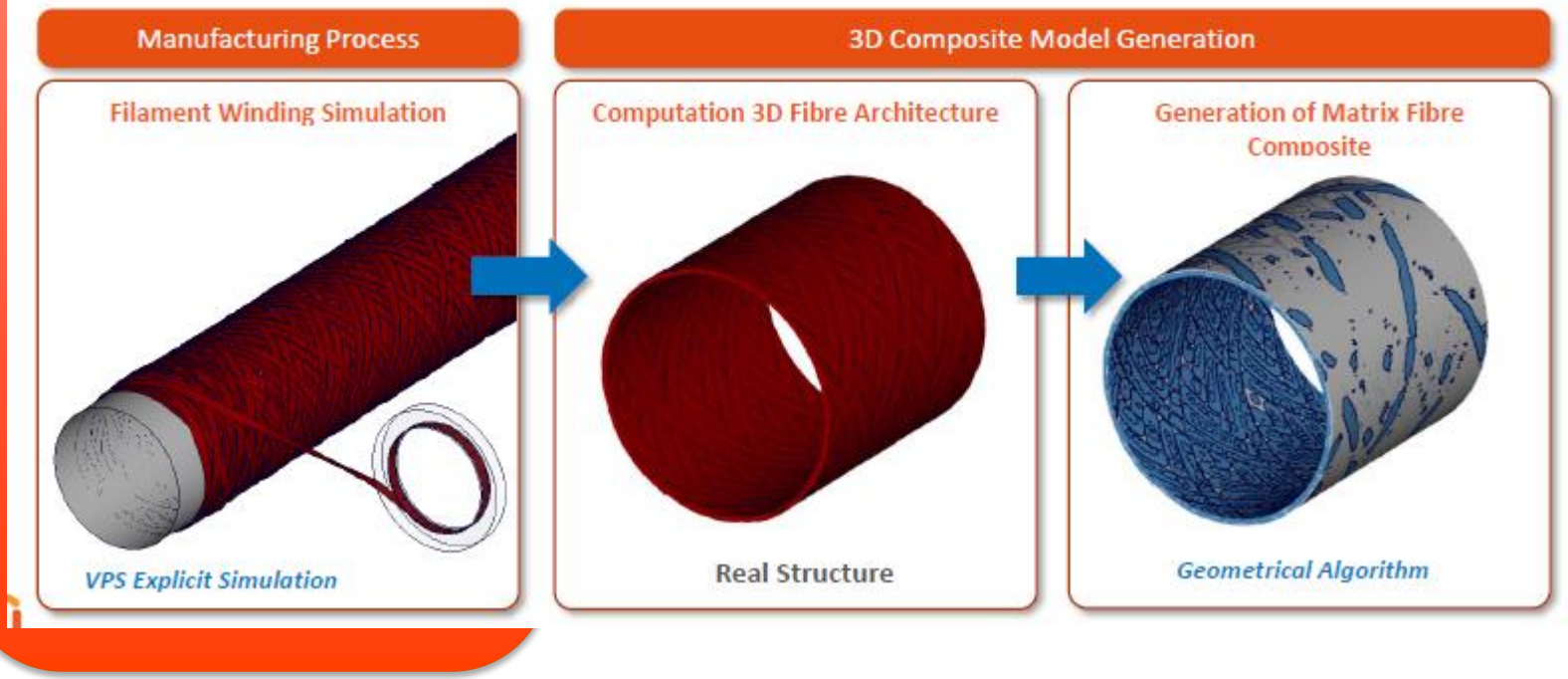
Shear stiffness results for loading in torsion

	G_{xy}, GPa	Difference from test result, %
Test	15.3	-
WiseTex	18.9	23.5
VPS	19.8	29.0
Stiffness averaging	22.0	44.0

Braiding works done by A.K. Pickett (IFB)

FILAMENT WINDING



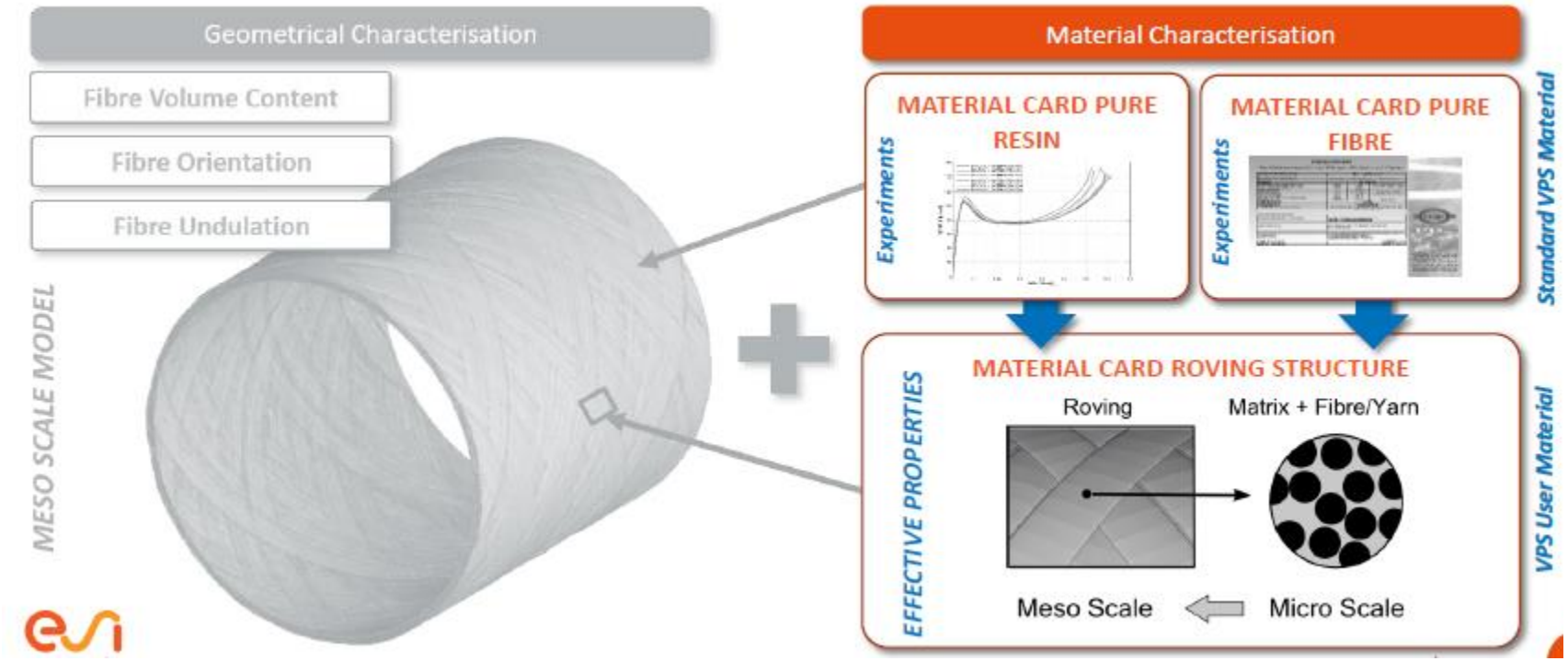


Works by A.Berger (ESI GmbH)

Crash simulation of wound composite tubes based on multi-level modelling

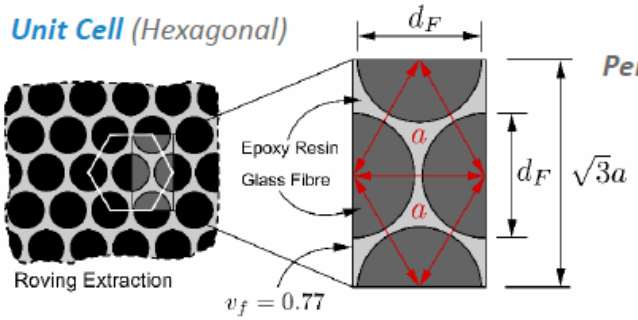
A. Berger[ab], T. Pyttel[c] & F. Duddeck[bd]

International Journal of Crashworthiness



Works by A.Berger (ESI GmbH)

Unit Cell *(Hexagonal)*



E-Glass Fibre

Base: Vendor Sheet

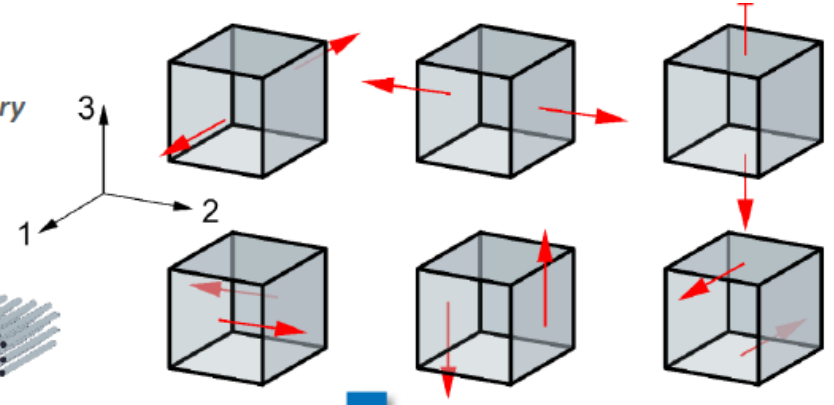
Material Model: Elastic

Epoxy Resin

Material Model: Elastic-Plastic

Base: Experiments

Periodic Boundary Conditions



6 Deformation Modes

Numerical Homogenisation

$E_{11}, E_{22}, E_{33}, G_{12}, G_{23}, G_{13}, \nu_{12}, \nu_{23}, \nu_{13}$

9 Deformation Modes

Max. Failure Stress

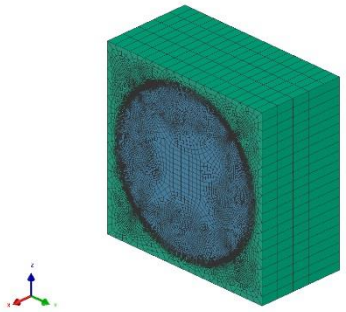
$R_{t11}, R_{c11}, R_{t22}, R_{c22}, R_{t33}, R_{c33}, R_{12}, R_{23}, R_{13}$

Works by A.Berger (ESI GmbH)

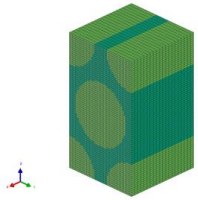
Virtual characterization for general composites

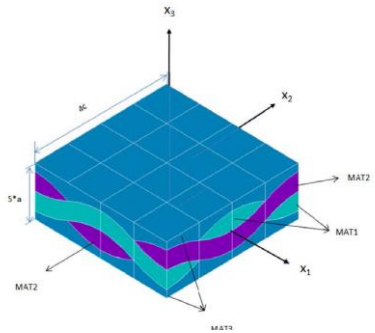
Validated for elasticity – damage behavior: on-going

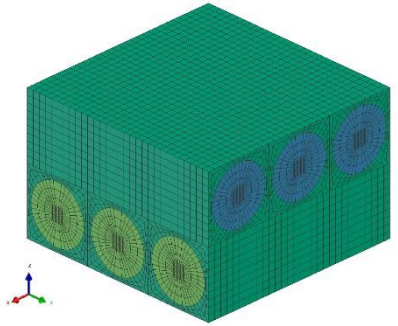
- Three-phase composite (interphase microstructure)



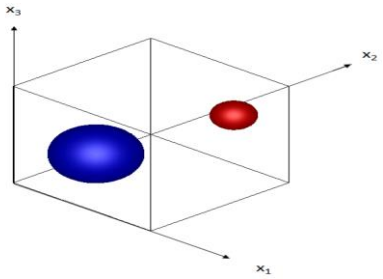
- UD & Woven textile & Laminate

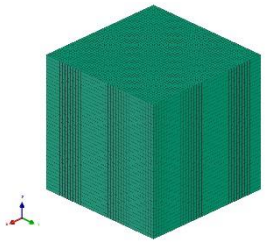


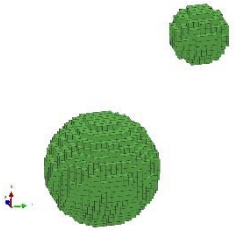




- Spherical Inclusion Microstructure

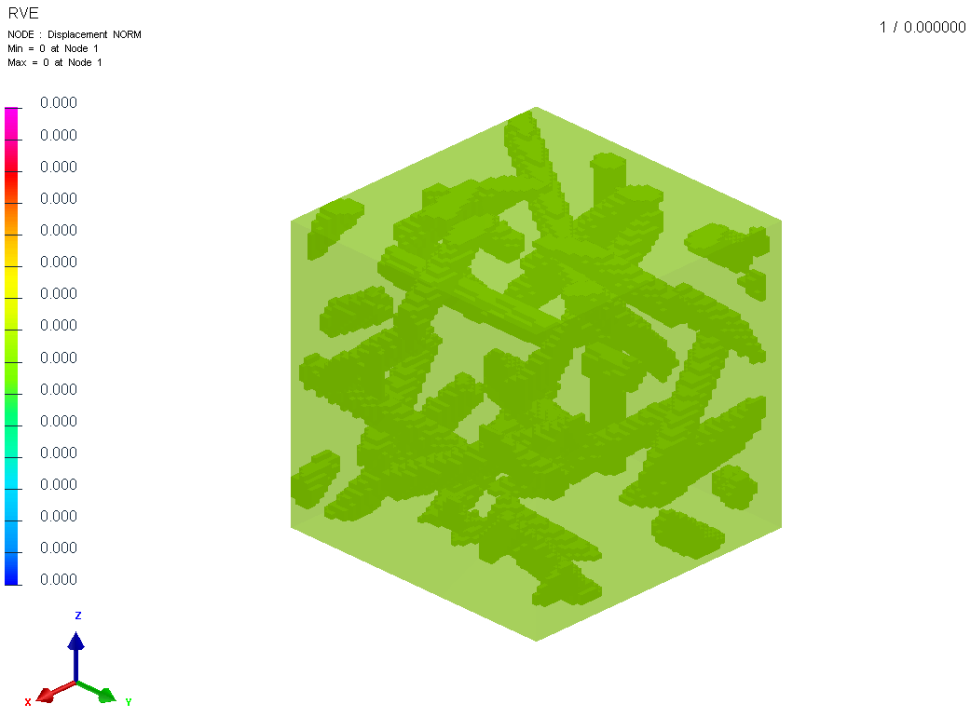






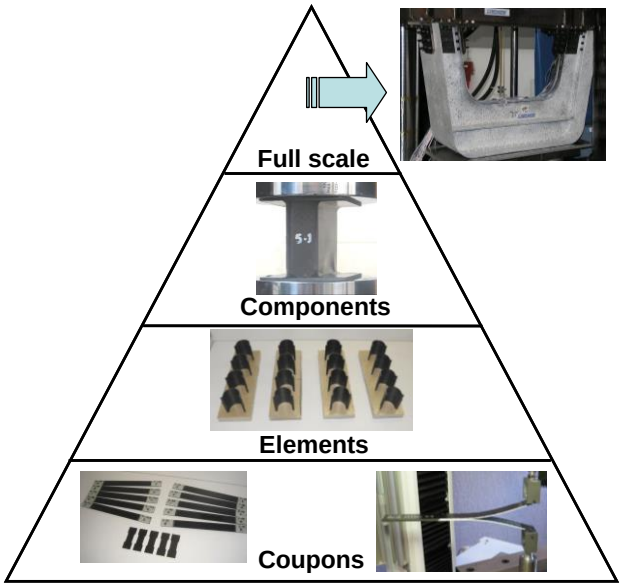
Example of a short fibers characterization

Sequence of 6 simulations

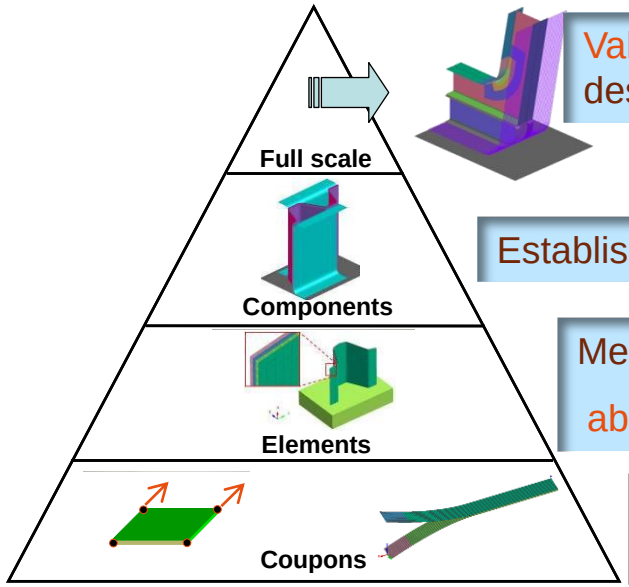


Development Approach
Experiment and Simulation

- Building Block Approaches – Test and Simulation Pyramids



Experimental Building Block



Validate energy absorber design and crash design tools

Establish integration issues

Measure energy absorption characteristics

Determine material constants

Manufacturing Simulation

Virtual Material characterization

Simulation Building Block

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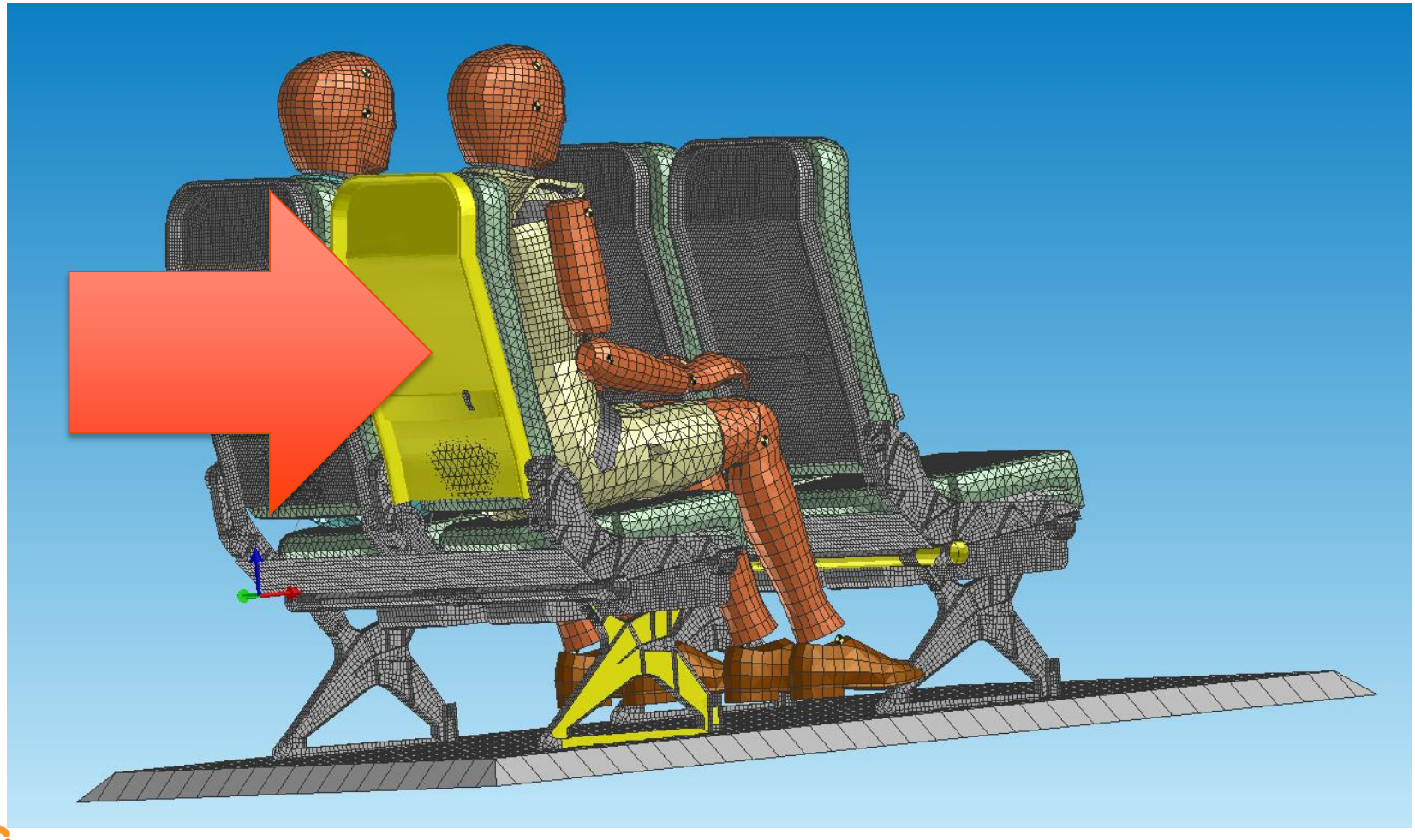
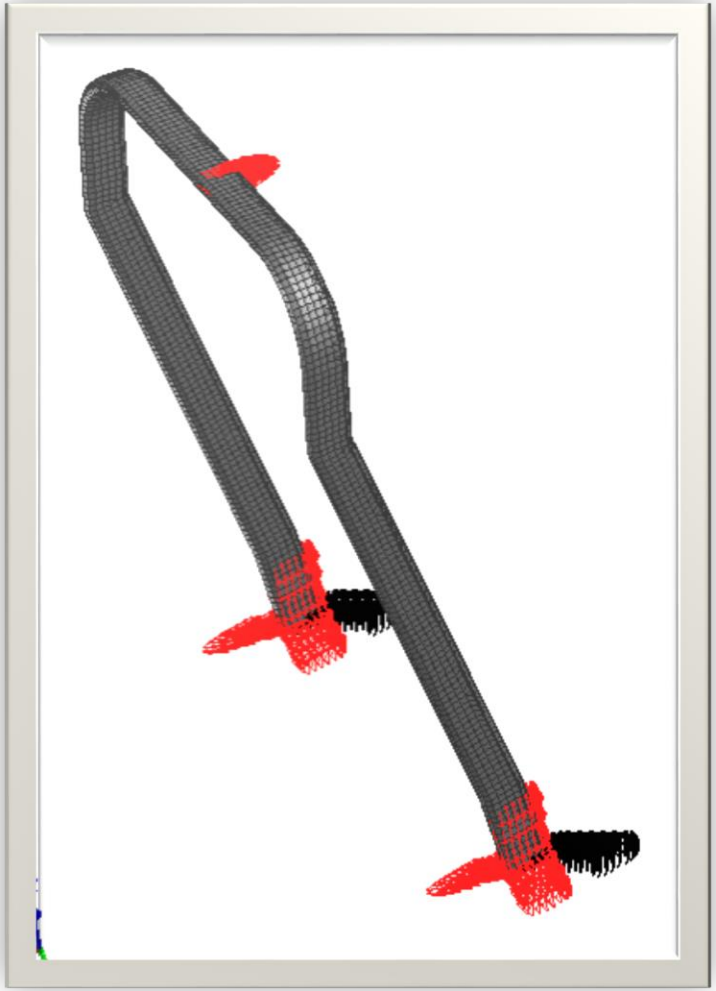
A significant weight saving opportunity

Example of (yellow) zones to switch to composites



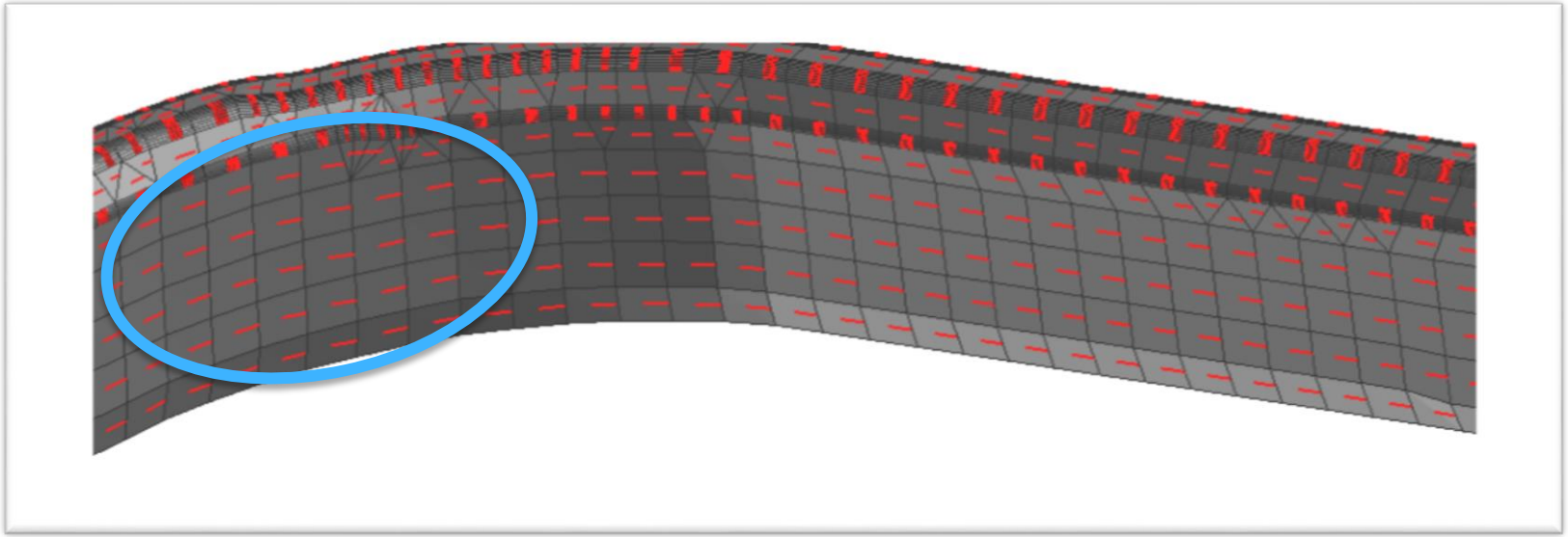
Accounting or not for draping ?

Ends of the frame fixed /// Applied load at the top

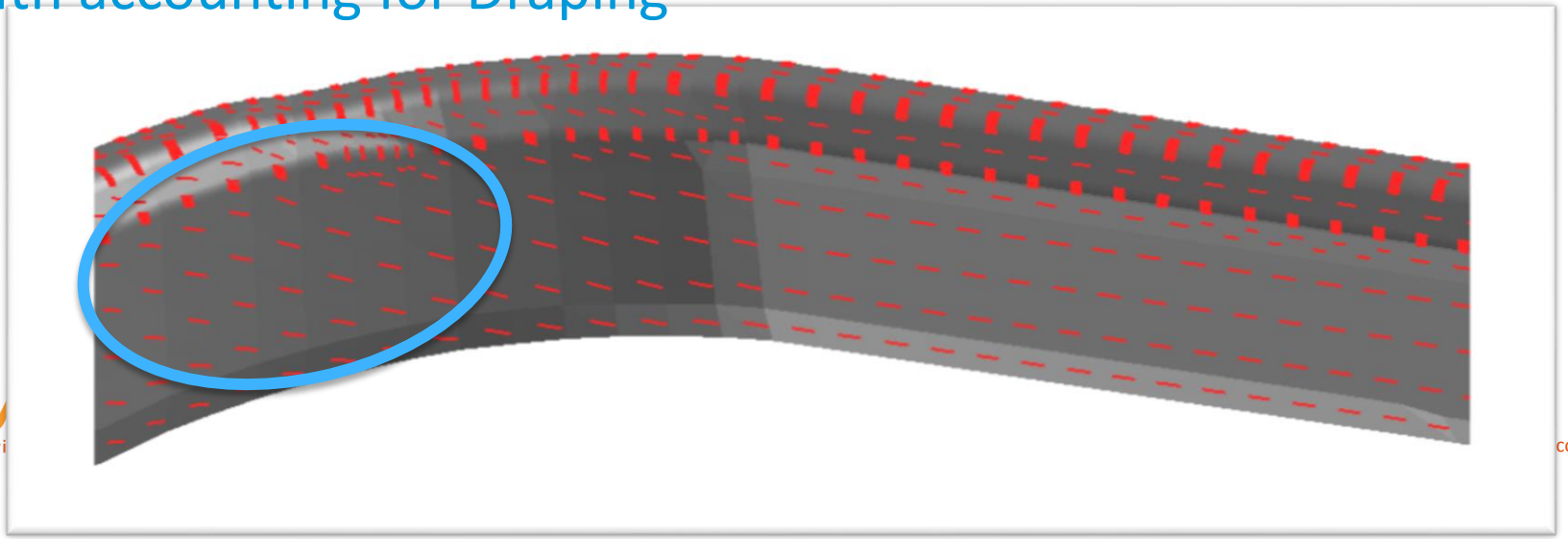


Fiber Orientation

Without Draping

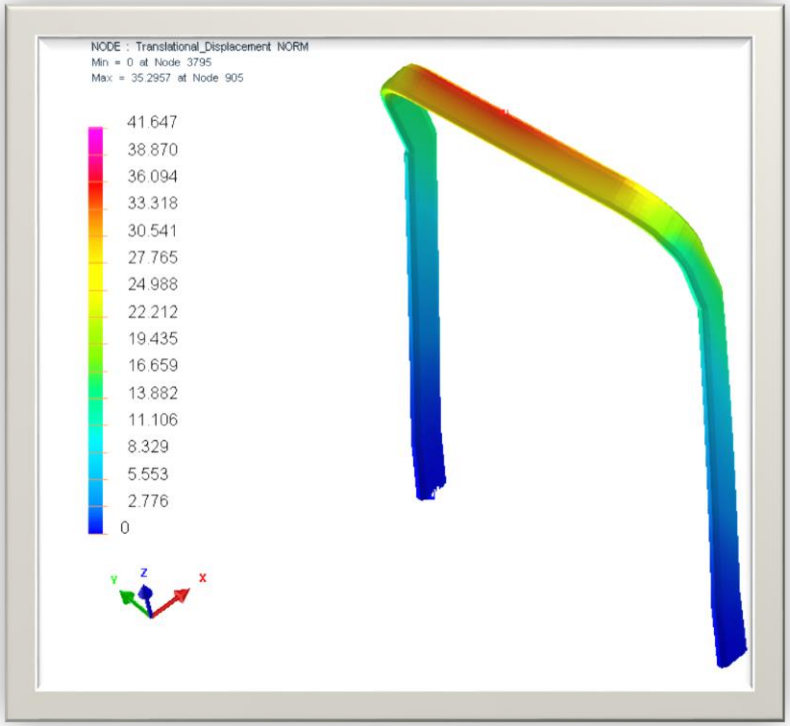


With accounting for Draping

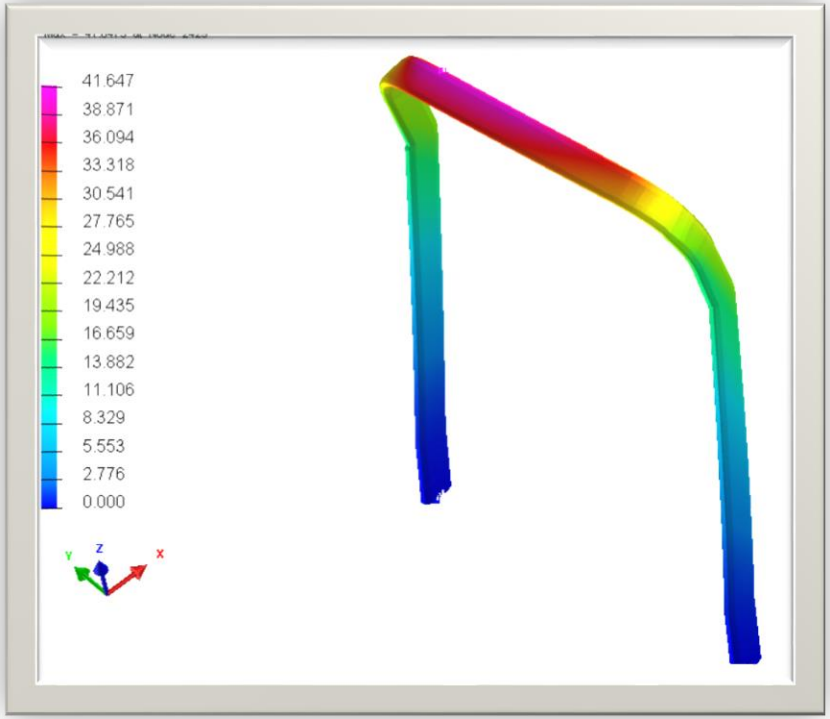


Displacement Contour

Without



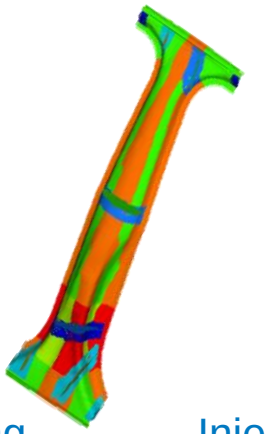
With acounting for Draping



- Around 20% difference over the top section

E2E Composites Simulation

B-PillarExample

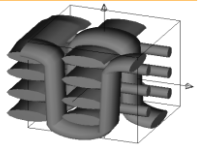


PROCESS

Draping

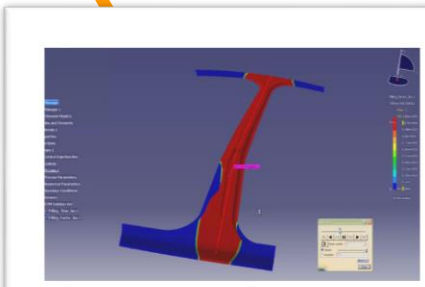
Injection

MATERIAL

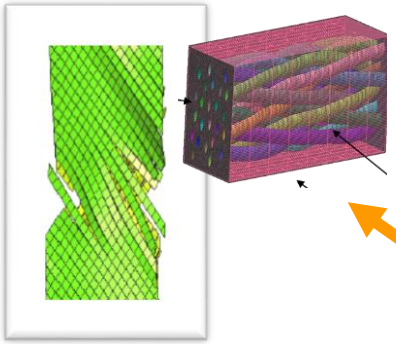


Weaving

VIRTUAL PROTOTYPING



Characterization



- Distortion
- Residual Stresses

- Sizing
- Strength
- Side crash
- Fatigue

PERFORMANCE

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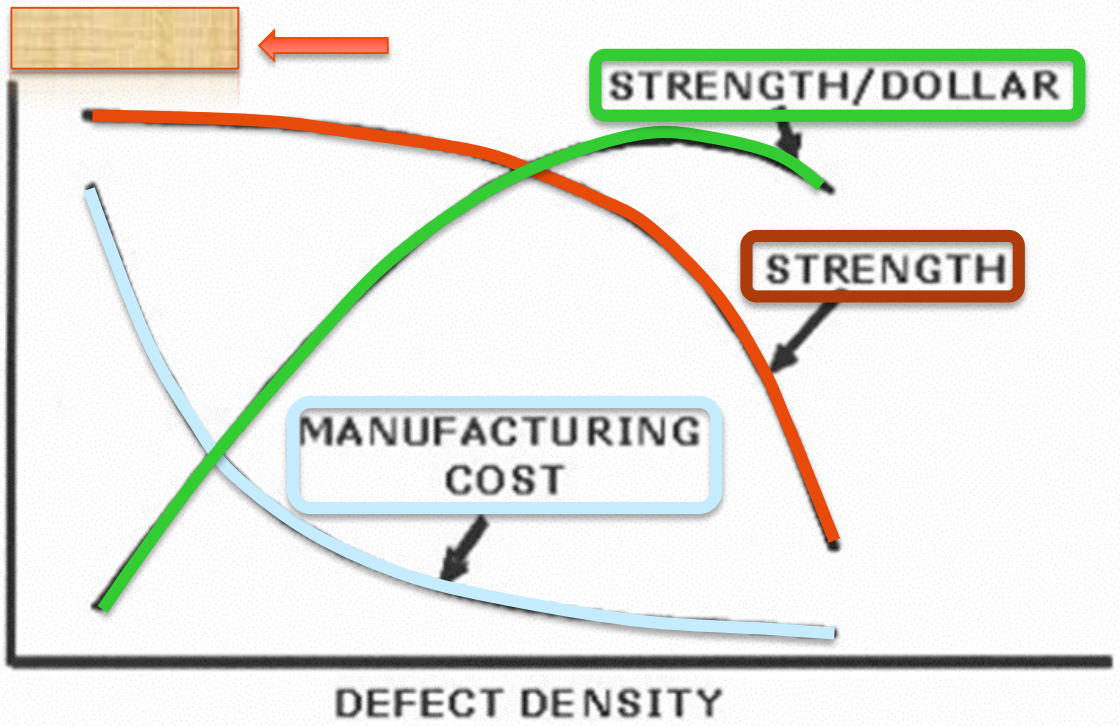
Performance Simulation

The role of defects in cost/performance tradeoff



Manufacturing Process simulation

Pr Talreja

THANK YOU

Patrick.de.Luca@esi-group.com