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# Engineering with composites: a multi-physics and multi-scale challenge

*Delphine Carrella-Payan*
*Sr. Research Engineer - Siemens PLM Software*

# Simcenter Portfolio: Accurate Prediction & Testing – Collaboration and Linking – Materials Data Management – Decision Making

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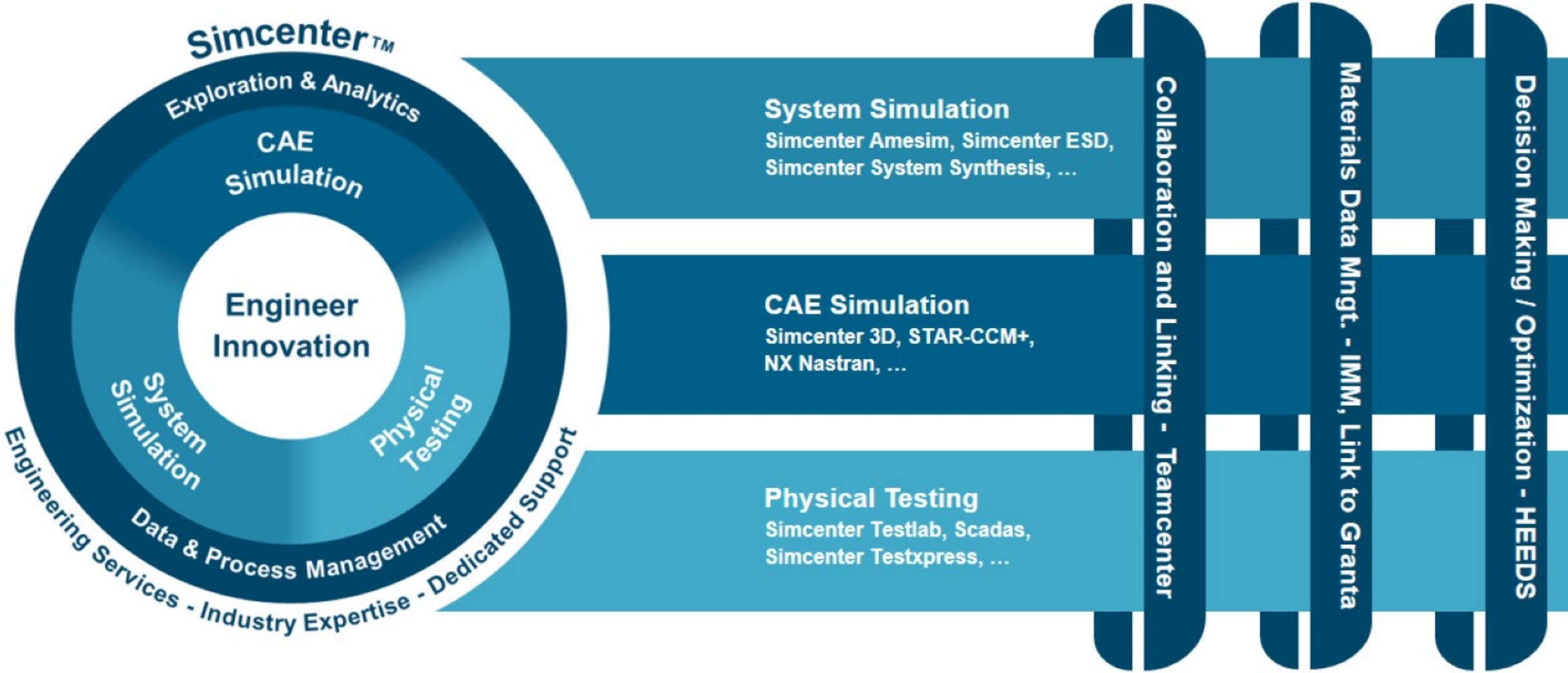


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# Introduction
# Simcenter 3D

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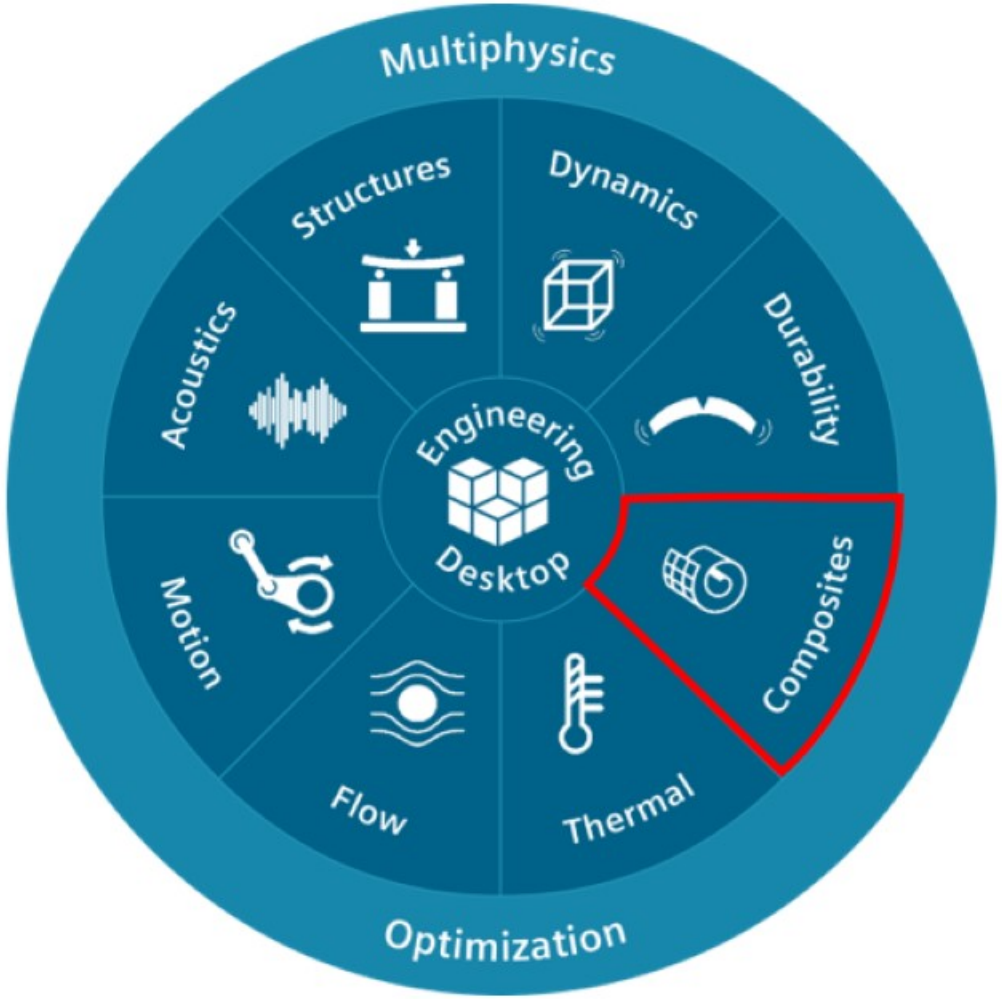
**Accurate multi-discipline simulation with connections to design,1D simulation, test, and data management**

**Best-in-class geometry editing and associative CAE modeling**

**Unified, scalable, open and extensible environment**

**Capture knowledge and automate processes to extend to team**

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# Our vision towards engineering with complex materials

## Supporting manufacturing and performance decisions

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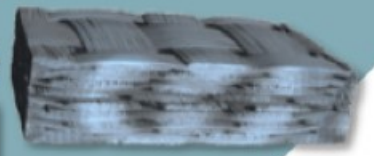
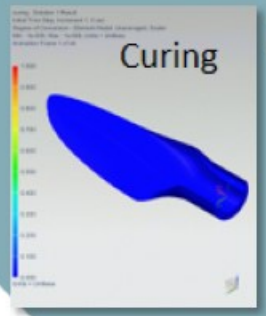
### Multi-Material

right material

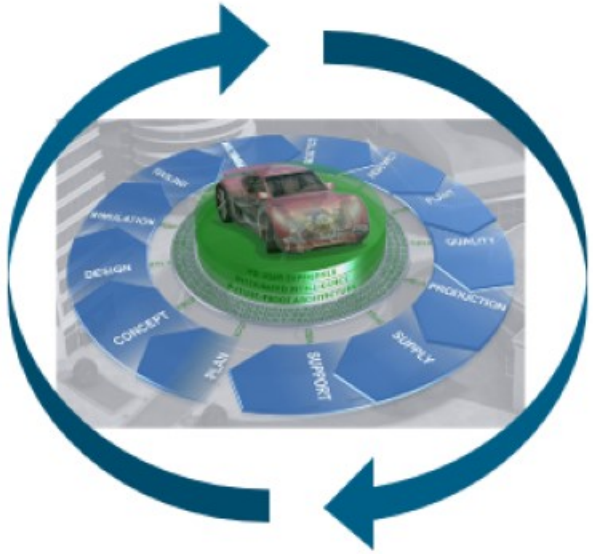
at right place



### Multi-Physics



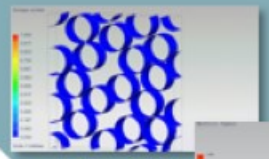

manufacturing



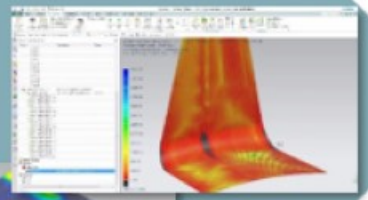

**PLM - process linking and data management**

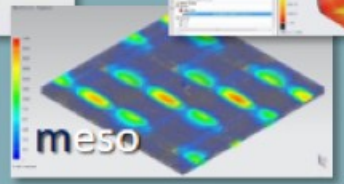
### Multi-Scale

µicro



Macro

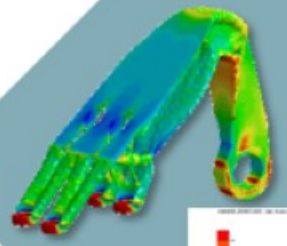


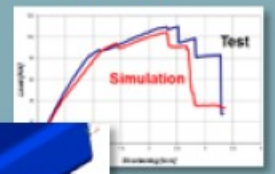


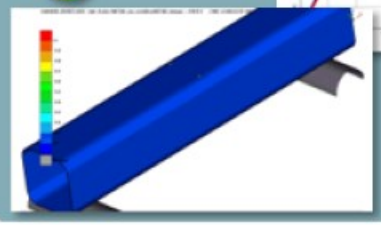
meso

### Multi-Attribute

applications





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# Our vision towards engineering with complex materials

## Supporting via SIM program

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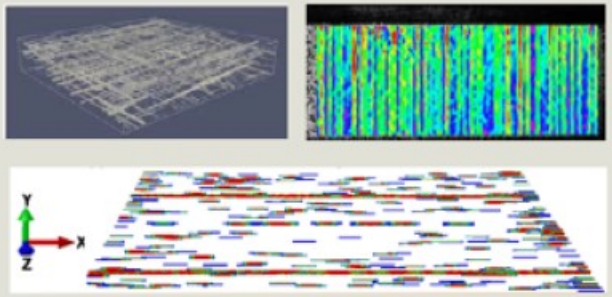
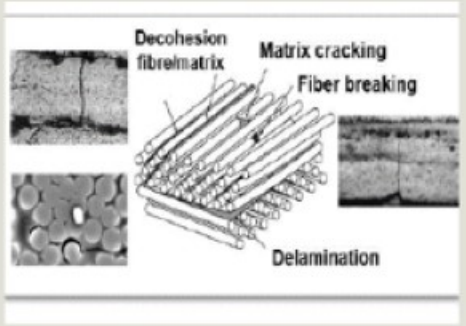
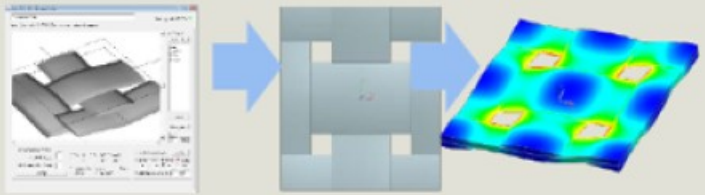
Clusters for Growth

### Effect of defects in composites






### Virtual material characterization



### Composite fatigue life prediction

KU LEUVEN

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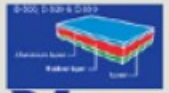
GHENT UNIVERSITY



Nitto

LAZER SPORT

engie Lab

LCV Laser Cladding Venture

materialise innovators you can count on

Atlas Copco

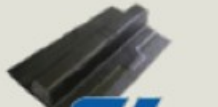
FLANDERS MAKE

3d weaving

TOYOTA

MITSUBISHI CHEMICAL

DEJOND



SABCA LIMBURG N.V.

HONDA

Honda R&D Co., Ltd.

EDDY MERCKX

OptoMET non-contact Optical Metrology

bmt aerospace

# Our vision towards engineering with complex materials

## Supporting manufacturing and performance decisions

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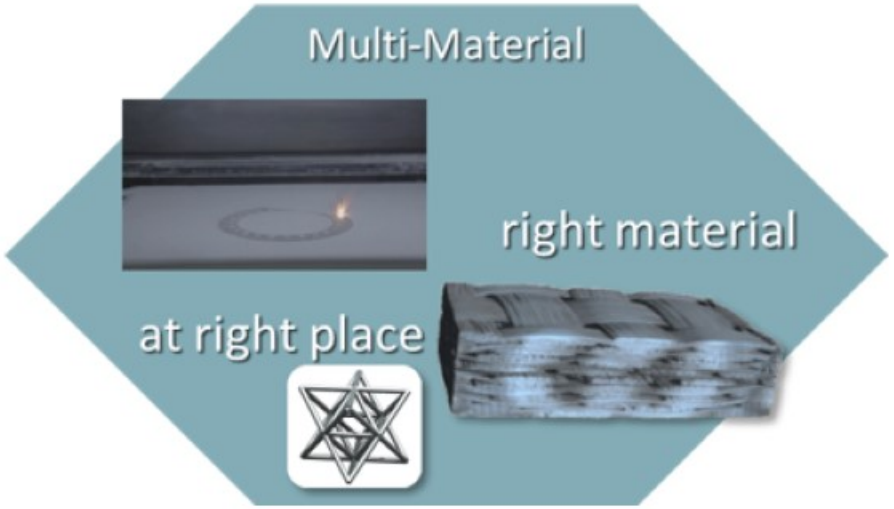


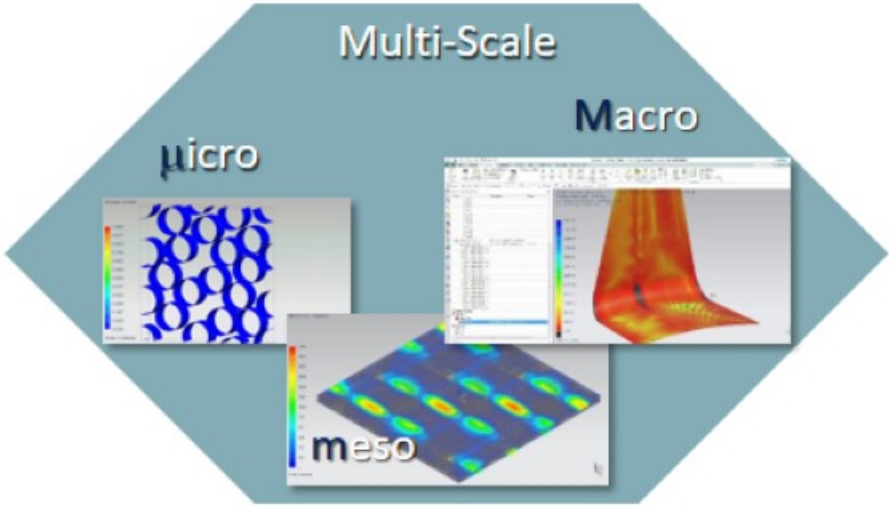


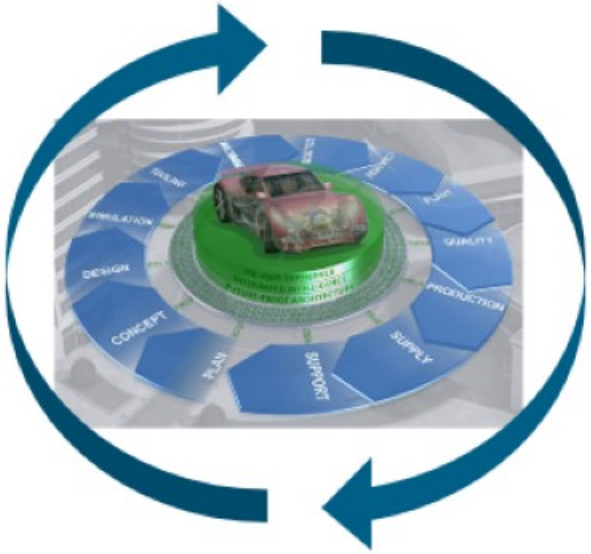

**PLM - process linking and data management**

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# Virtual Material Characterization (VMC)

*to accelerate composite material engineering*

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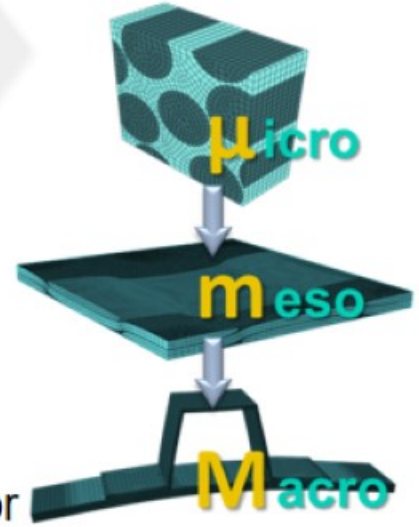
**Multiscale modeling for virtual material characterization**

## Motivation




**Large number of parameters** (fiber/matrix/interface properties, material architecture, stacking )

→ large and **expensive test campaign** (100's of coupon tests for multi-attribute characterization)

- ✓ **Reduced number of tests**
- ✓ Considering **performance** and **manufacturing-related aspects** (effect of defects)
- ✓ Enabling **multi-attribute virtual material optimization**

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# Virtual Material Characterization with the VMC ToolKit

## Composite properties & Workflow

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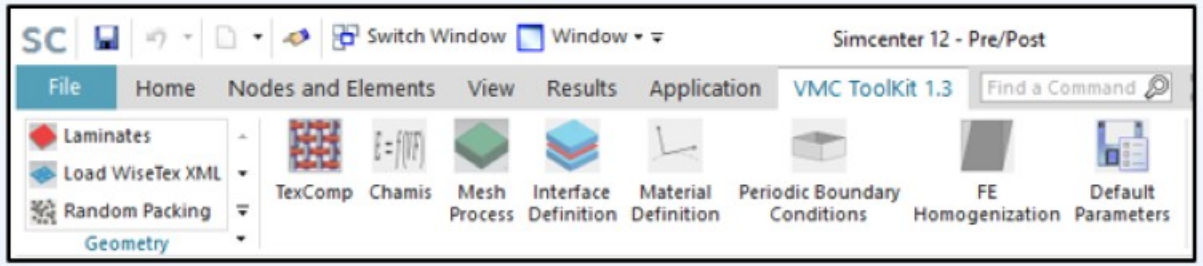
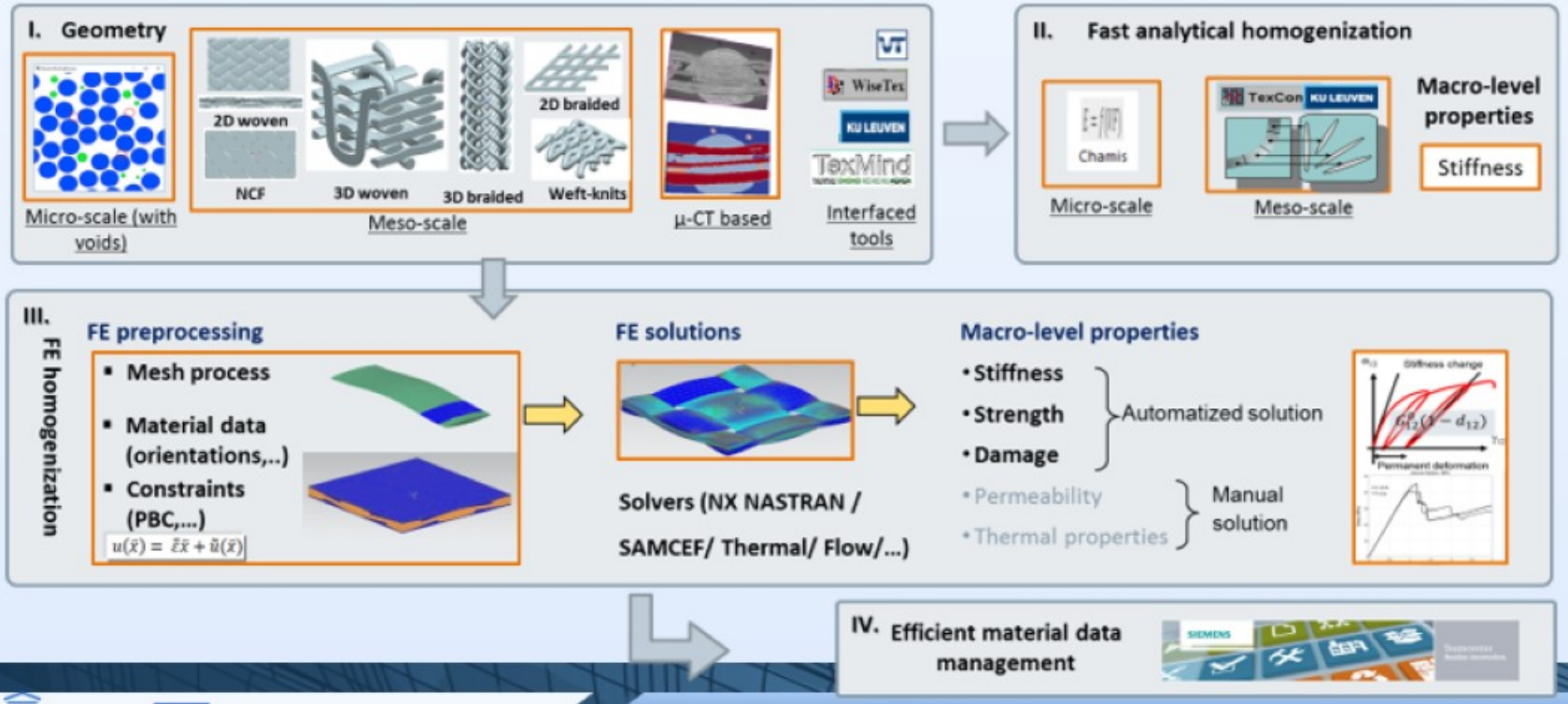
## VMC Toolkit for multi-physics

- **Mechanical properties**
  - *Stiffness*
  - *Strength*
  - *Damage*
  - *Dry-fabric mechanics (forming)*
- **Thermo-mechanical assessment**
  - *Residual stresses/ deformations (curing)*
  - *Thermal conductivity*
- **Flow properties**
  - *Permeability (for infusion)*
- **Multi-solver support**
  - *NX Nastran*
  - *Samcef*

## VMC Workflow



# Virtual Material Characterization with the VMC ToolKit

## Homogenization for Stiffness

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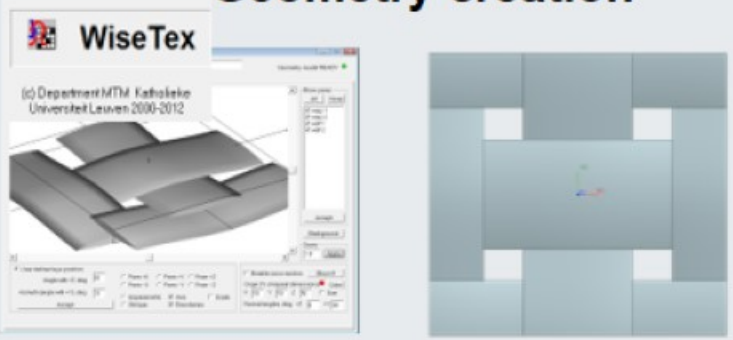
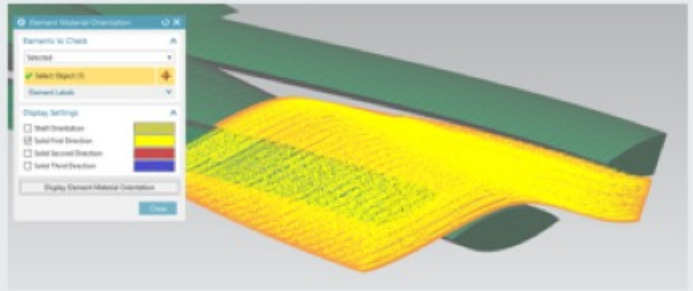
Clusters for Growth

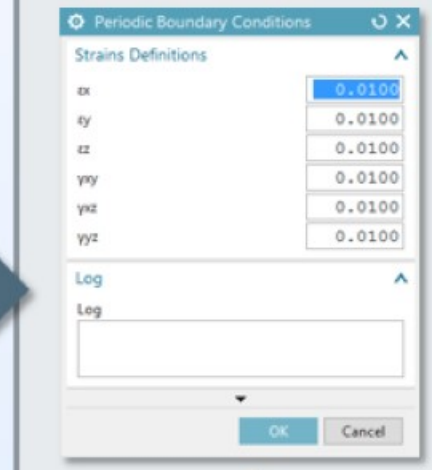
### Geometry creation

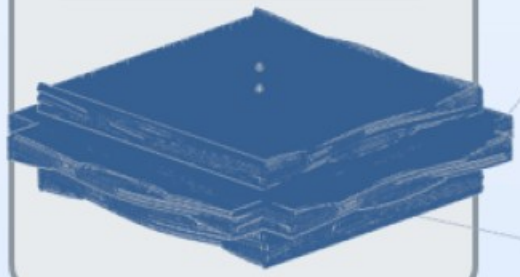



### Meshing & local material properties

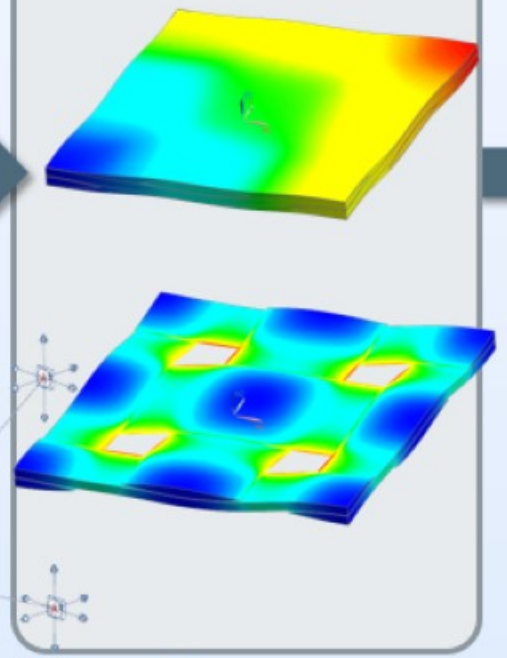


### Six load cases +PBC

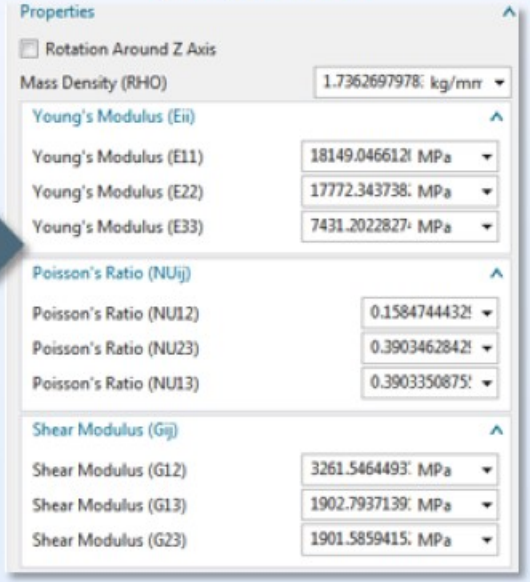


### FE solutions



### Resulting material properties




*supported for both NX-Nastran and Samcef

# Virtual Material Characterization with the VMC ToolKit

*Workflow: from µCT images to material properties*

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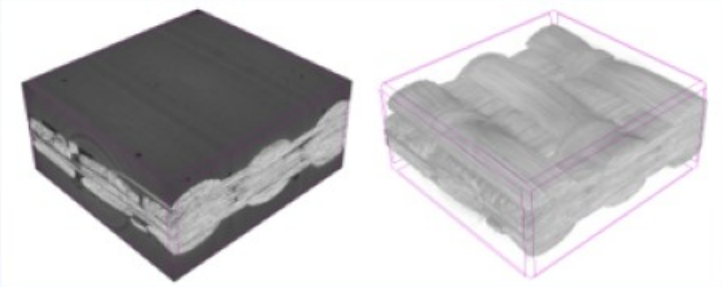
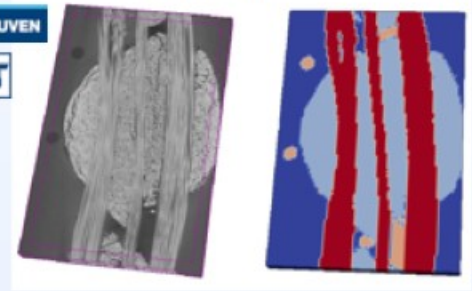
Clusters for Growth

## µCT volumetric image

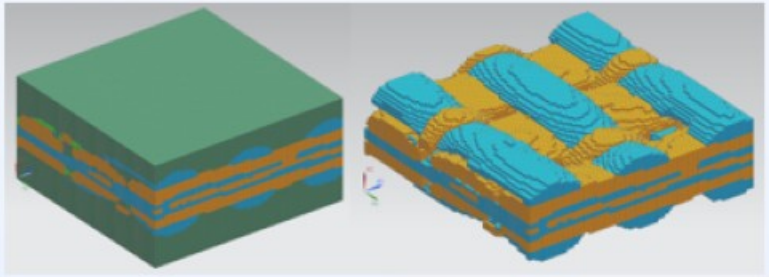


## Supervised segmentation

*VoxTex (MTM, KU Leuven)*

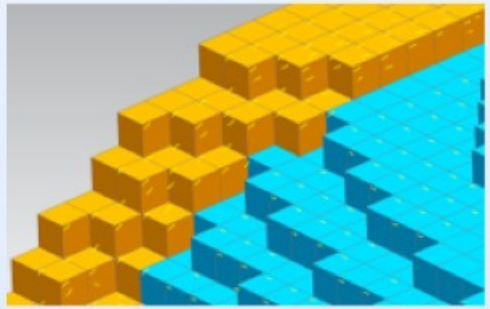



## Export to Simcenter 3D as a voxel model



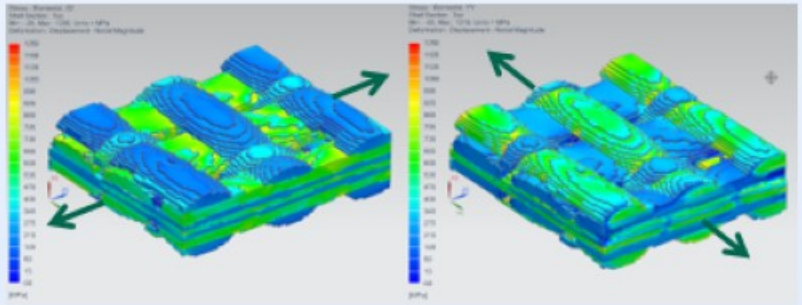
## Local material orientations

*are included*



## Virtual testing with VMC ToolKit

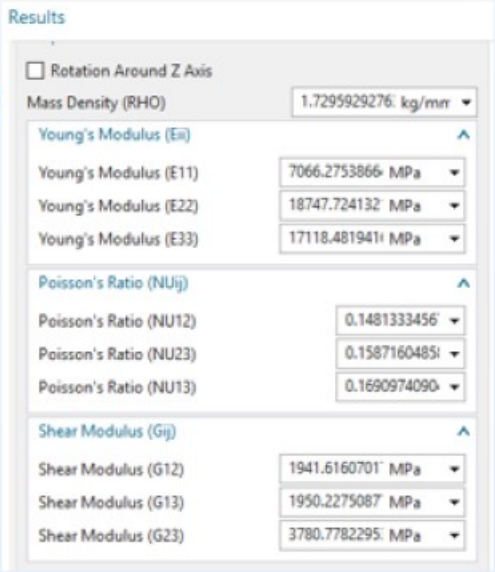
*stress shown in the direction of the load (2 cases)*



## FE homogenization

*full set of the elastic constants:*

- Young's moduli
- Shear moduli
- Poisson's ratios




18th EUROPEAN CONFERENCE ON COMPOSITE MATERIALS
ECCM18

**X-RAY COMPUTED TOMOGRAPHY-BASED FE-HOMOGENIZATION OF SHEARED ORGANO SHEETS**

O. Shishkina[1*], A. Matveeva[1*], S. Wiedemann[2], K. Hoehne[2], M. Wevers[3], S. V. Lomov[3], L. Farkas[1]

M3 Macro Model Mat

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# Virtual Material Characterization with the VMC ToolKit

## Homogenization for Damage

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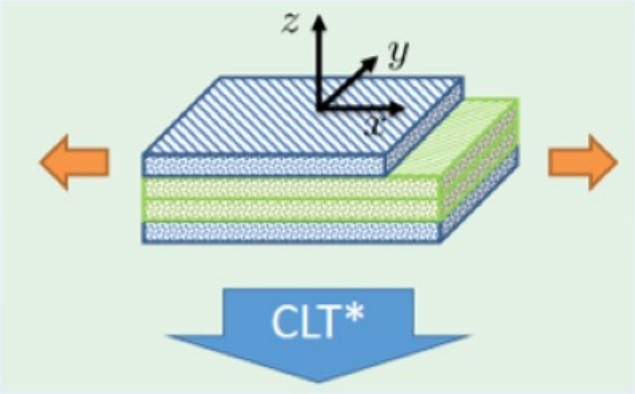
### MACRO SCALE (CLPT)

Macro strains are determined for each stacking sequence



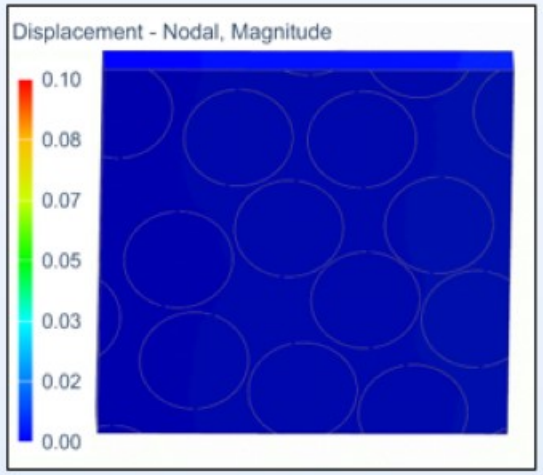

$$\varepsilon_{11} = \varepsilon_{22} = f(\varepsilon_{12}) \quad \text{(based on CLPT)}$$

$$\varepsilon_{13} = \varepsilon_{23} = 0 \quad \text{(assumption)}$$

$$\varepsilon_{33} = g(\varepsilon_{11}, \varepsilon_{22}) \quad \text{(from Poisson effect)}$$

### MICRO SCALE (FEM)

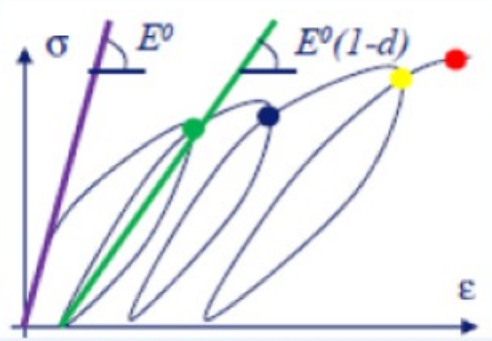
RVE geometries with random distribution of fibers (with/without voids)




- ✓ Matrix microcracking
- ✓ Fiber-matrix debonding

UNIVERSITEIT GENT

*Garoz, D et al, 2017, Composite Structures, 181, 391--404

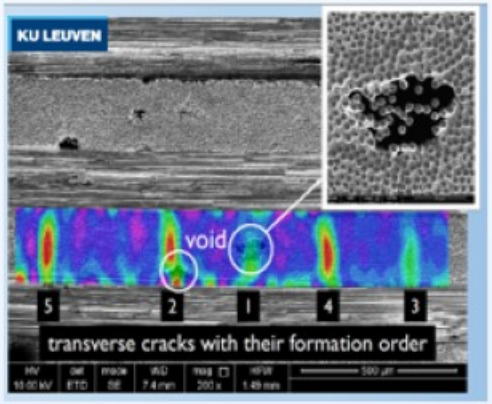



**Material parameters of the elementary ply damage mesomodel developed at LMT-Cachan**

| Elastic (9) | Damage ply(14) | |
|---|---|---|
| $E^0_{11}$ | $Y^{s\pm}_{11}$ | |
| $E^0_{22}$ | $\zeta^{\pm}$ | |
| $E^0_{33}$ | $Y^o_{12}$ | or $f\sqrt{(Y)}$ |
| $G^0_{12}$ | $Y^s_{12}$ | |
| $G^0_{13}$ | $Y^c_{12}$ | |
| $G^0_{23}$ | $Y^s_{22}$ | |
| $\nu_{12}$ | $b_2$, $b_3$ | |
| $\nu_{13}$ | $R_0$ | |
| $\nu_{23}$ | K | |
| | $\gamma$ | |
| | a | |

# Virtual Material Characterization with the VMC ToolKit

## Effect of defects - Porosity representation on the micro scale for RP



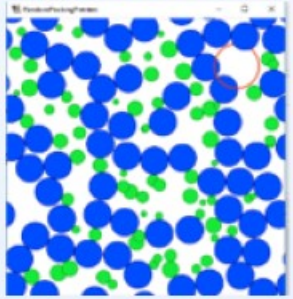

Mehdikhani, JEC 2018

**Porosity morphology at the micro scale (from microscopy, X-Ray..):**

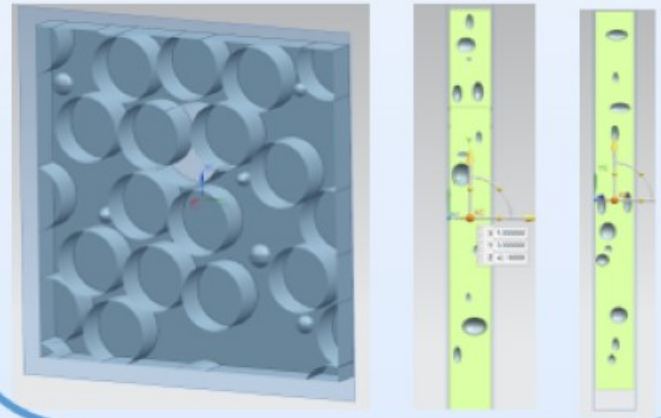
- ✓ Shape of voids
- ✓ Void volume fraction
- ✓ Void size

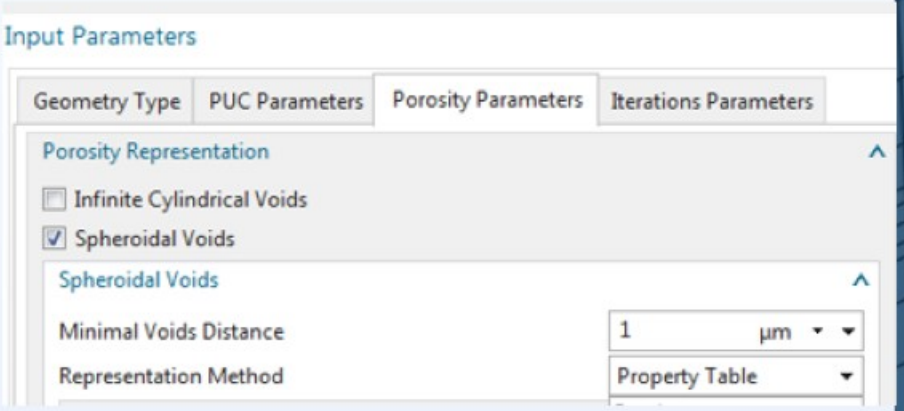
**WORKFLOW:**

- Profile sketch of fibers and voids



- Extrusion of fibers and cylindrical voids
- Revolving spheroidal voids






**User parameters to control voids:**

- ✓ Shape of voids (cylindrical and spheroidal)
- ✓ Void volume fraction
- ✓ Void size (min, max)
- ✓ Minimum distance between voids
- ✓ Spatial distribution (random or user input)

↓

**FE-Homogenization for stiffness and damage in the presence of voids**

# Our vision towards engineering with complex materials

## Supporting manufacturing and performance decisions

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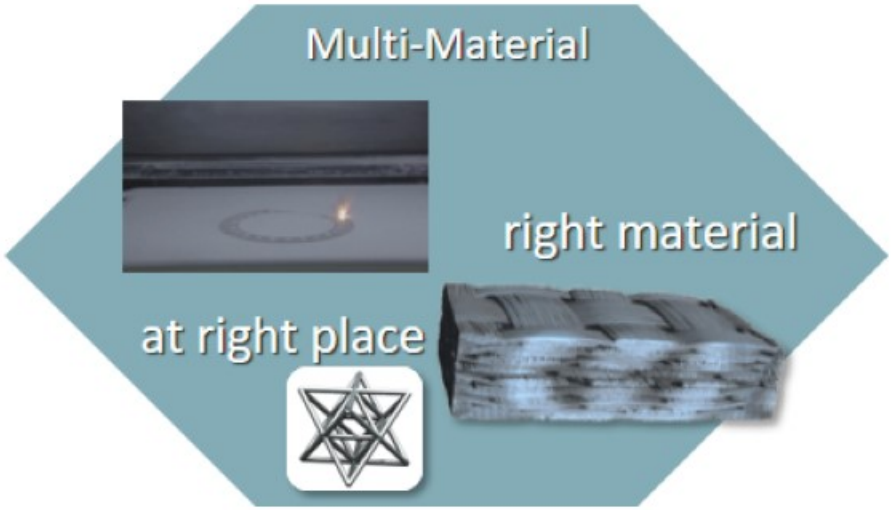
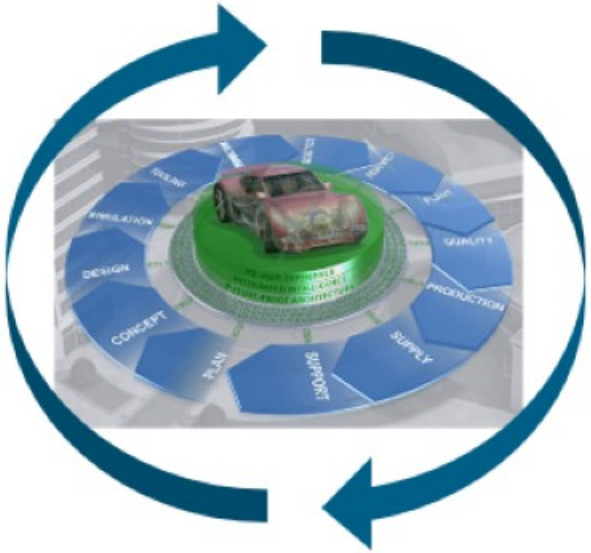
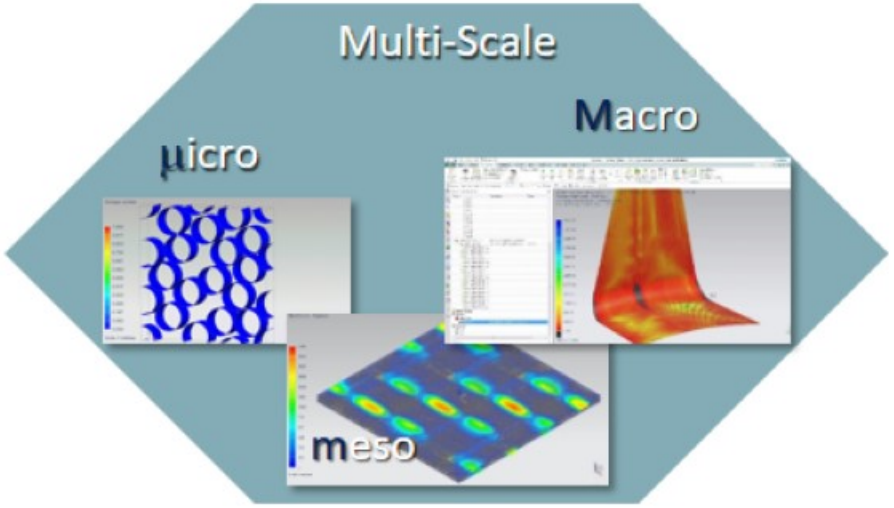
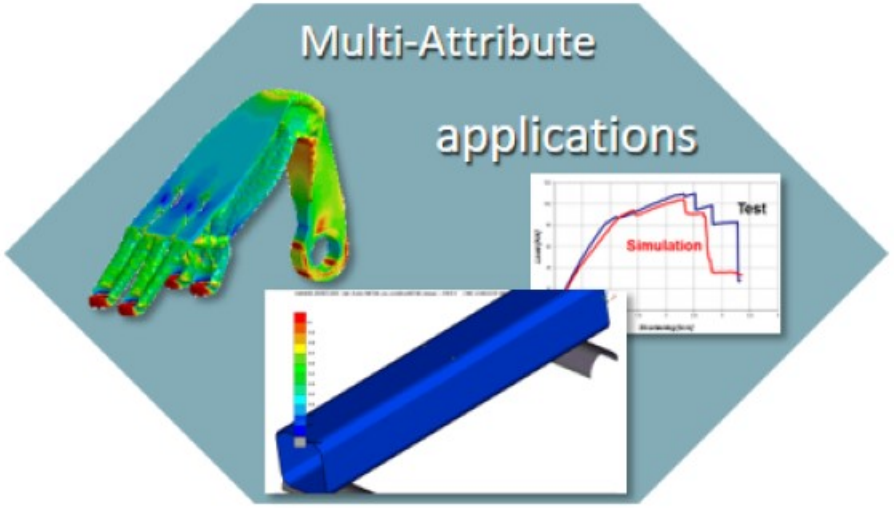


**PLM - process linking and data management**

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# Continuous fiber composites

*Application N-L damage behavior (Honda)*

**Released solution: Performance simulations for composites**

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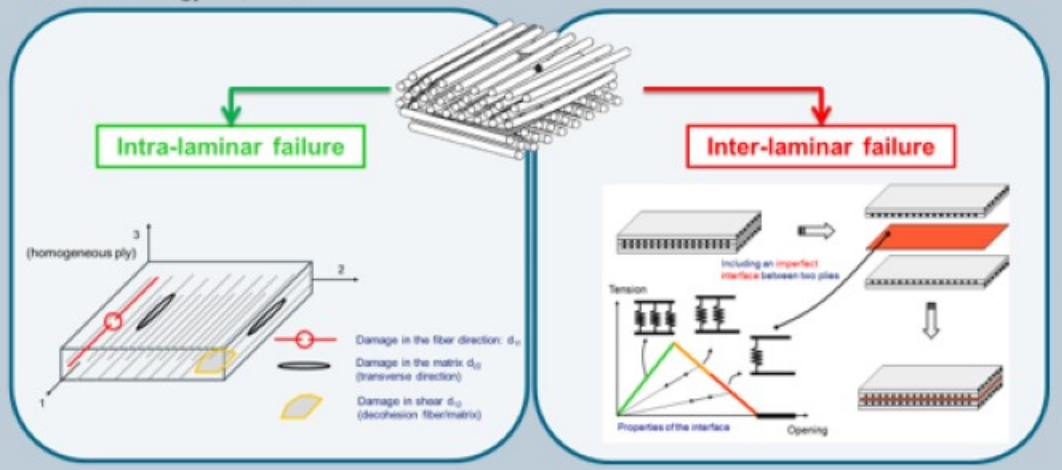
## Static numerical prediction based on Damage Continuum Mechanics

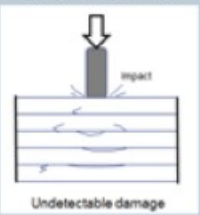
### Damage evolution law by Ladeveze and Allix

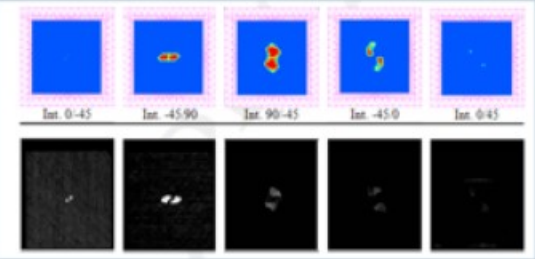
*"Damage modeling of the elementary ply for laminated composites, Composites Science and Technology 43, 1992"*



### Case Study: Low velocity impact on UD laminated plies

- Barely visible impact damage (BVID)
- FE model:
  - solid shell elements with element thickness = ply thickness
  - cohesive elements




- Delamination appears at the interfaces between the plies
- Very good agreement between tests and simulation

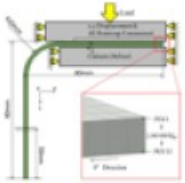
**Exploitation of the methodology**

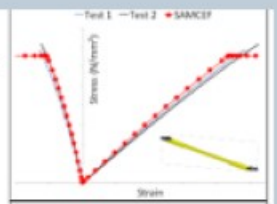
- **Validation of damage models at coupon level**

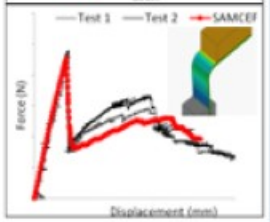
Starting from identified material parameters, the damage model is used to predict the mechanical behavior at the coupon level for evaluation of the behaviour for other stacking sequences and hence replacing physical tests.

- **Application of damage models for predictive delamination behavior at component level**

The damage models are supporting the prediction of the progressive damage and delamination inside the plies and at their interface at component level






Source : "Strength Calculation of Composite Material considering multiple progress of failure by Ladeveze model", Y.Urushiyama, T. Naito, JSAE Spring Conference, 2014 52 05

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# Continuous fiber composites

## Intra/Interlaminar fatigue prediction

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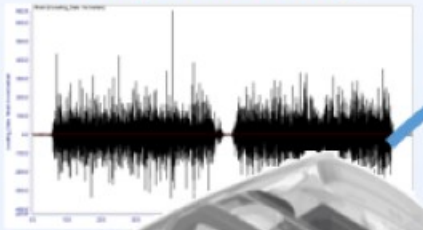
### Problem statement

Complex loading



application performance
(safe fatigue-life)

Stresses (redistribution)

Stiffness degradation

Stress redistribution

Mean Stress

Lay-up

Different damage mechanism

Manufacturing influence

Cross influence of different loads

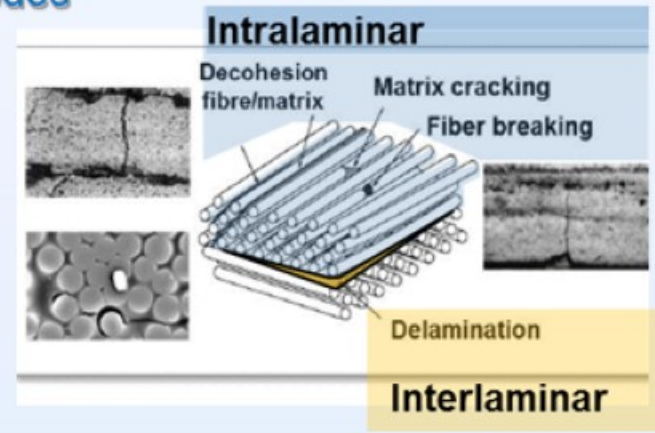
Anisotropic Behavior

Fatigue Damage

Test data – frequency, environmental dependent

Stiffness (degradation)

Complex material: several failure modes




Interaction in material property degradation

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# Continuous fiber composites
## Intra/Interlaminar fatigue prediction

HONDA Honda R&D Co., Ltd. | SIEMENS Ingenuity for life | FLANDERS INNOVATION & ENTREPRENEURSHIP SIM Clusters for Growth

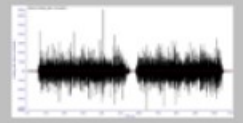
## Added values

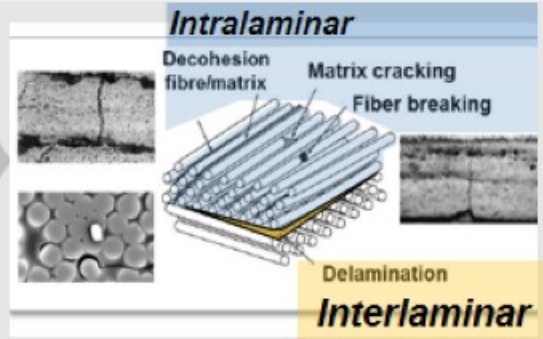
- Prediction of continuous fiber composite behavior for **high cycle fatigue**
- **Intra/inter**-laminar coupling fatigue
- **Multiaxial** and **variable amplitude** loadings.

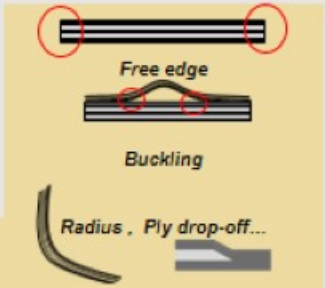
## Key points

- **Intralaminar** fatigue prediction via **stiffness degradation**
- Combined with **interlaminar** fatigue onset/ re-onset prediction via **energy release rate degradation**
- **Non-Linear** calculation to predict accurate stress and strain fields

**Road condition =**
**Variable Amplitude loading**
**Multi-axial loading**





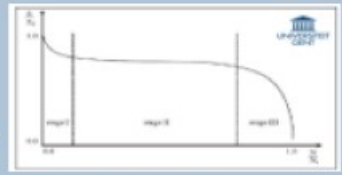

### *Intralaminar*

Stiffness degradation

Permanent strain

Mean stress effects

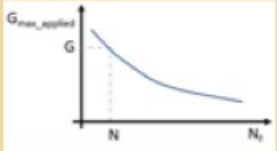
Initial damage due to first loading



### *Interlaminar*

Energy release rate degradation

Linear damage accumulation




- Considering stress/strain redistribution after damage accumulation for both intralaminar and interlaminar elements
- Non-Linear FE calculation for delamination onset/re-onset prediction

# Short fiber composites
## SN-Curve prediction

**Released solution: Performance simulations for composites**

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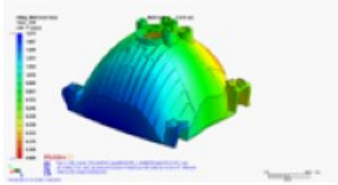
Ingenuity for life

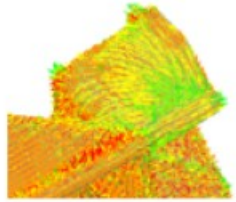
**Challenge**
- Structural performance behavior determined by local short fiber orientation and material behaviour

**Solution**
- Accurate fatigue analysis using local material behavior
- Interface to manufacturing simulation

**Benefits**
- Less testing
- Fully exploit weight reduction potential

Manufacturing Simulation

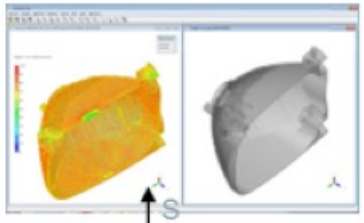


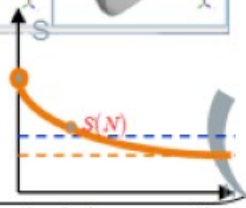


Injection Mold Modeling
Fibre orientation

Material Behavior

**Local Anisotropic effects**
- Fiber Orientation Tensors



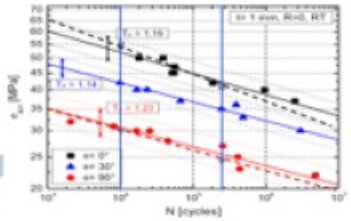



Mapping of material properties
Rheological – Structure Mesh

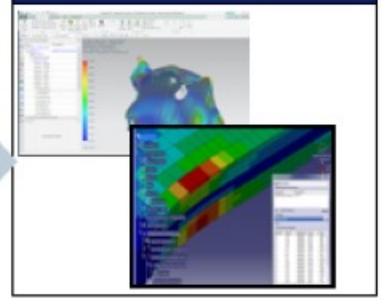
Durability Prediction

**Enabling an efficient SN-based durability assessment based on minimal set of coupon testing**

Only 1 measured SN-curve needed



Durability



KU LEUVEN

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# Our vision towards engineering with complex materials

## Supporting manufacturing and performance decisions

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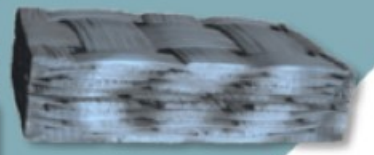
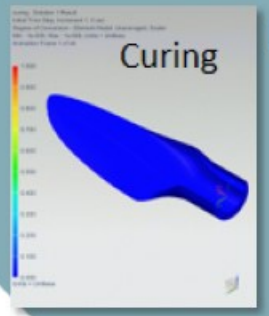
### Multi-Material

right material

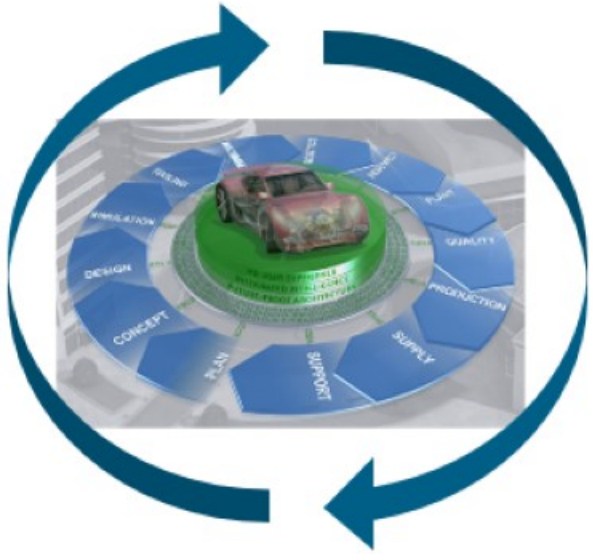
at right place



### Multi-Physics



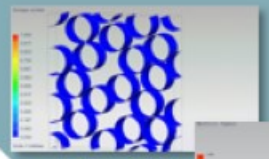

manufacturing



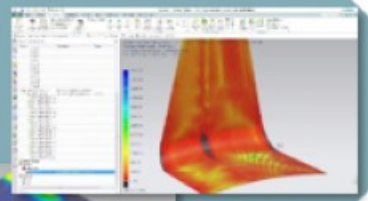

**PLM - process linking and data management**

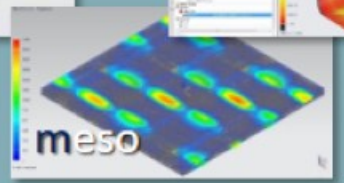
### Multi-Scale

µicro



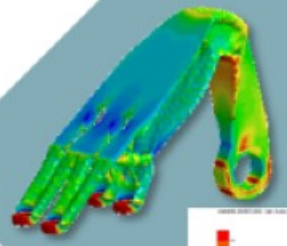
Macro

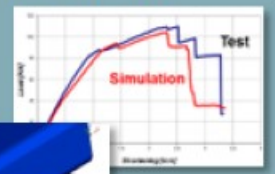


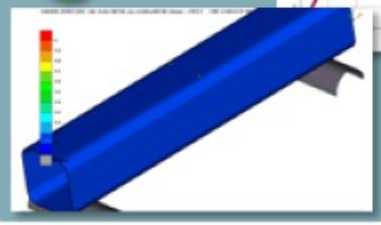



### Multi-Attribute

applications





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# Composite manufacturing simulation

## Typical thermoset composite manufacturing steps

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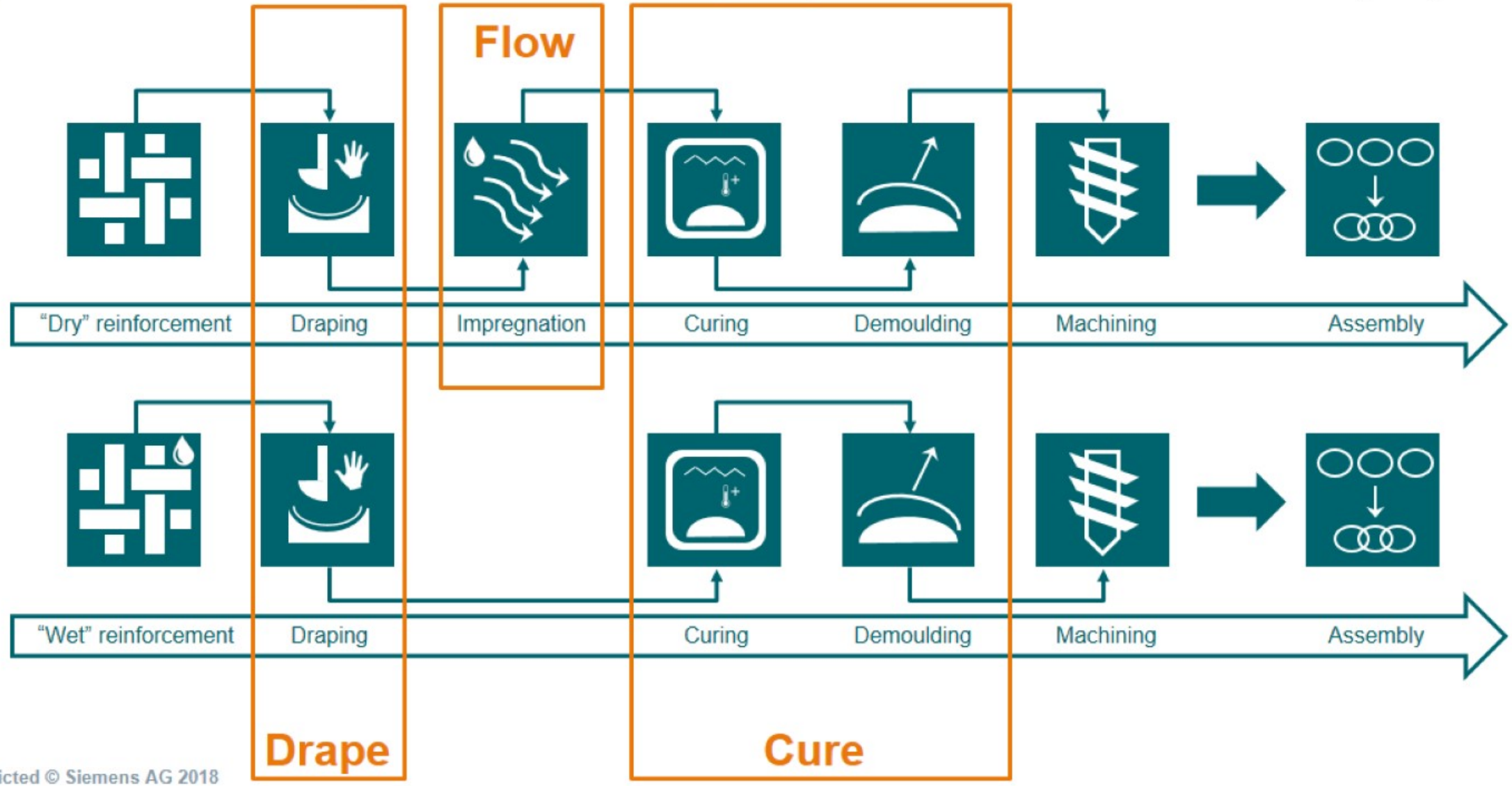


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# Composite manufacturing simulation
## Workflow example for RTM manufacturing

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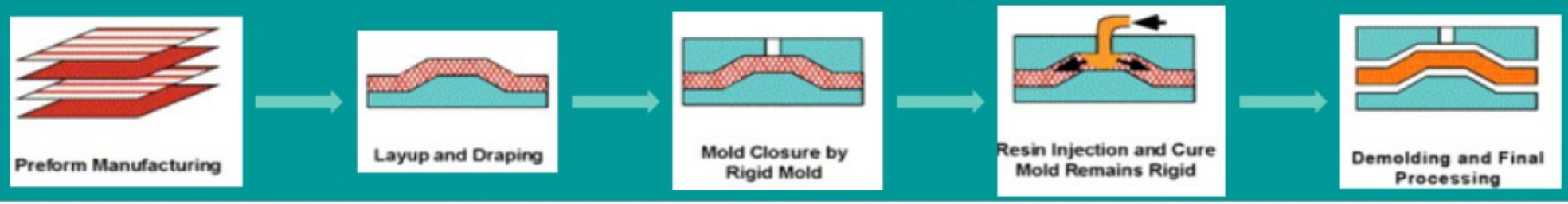
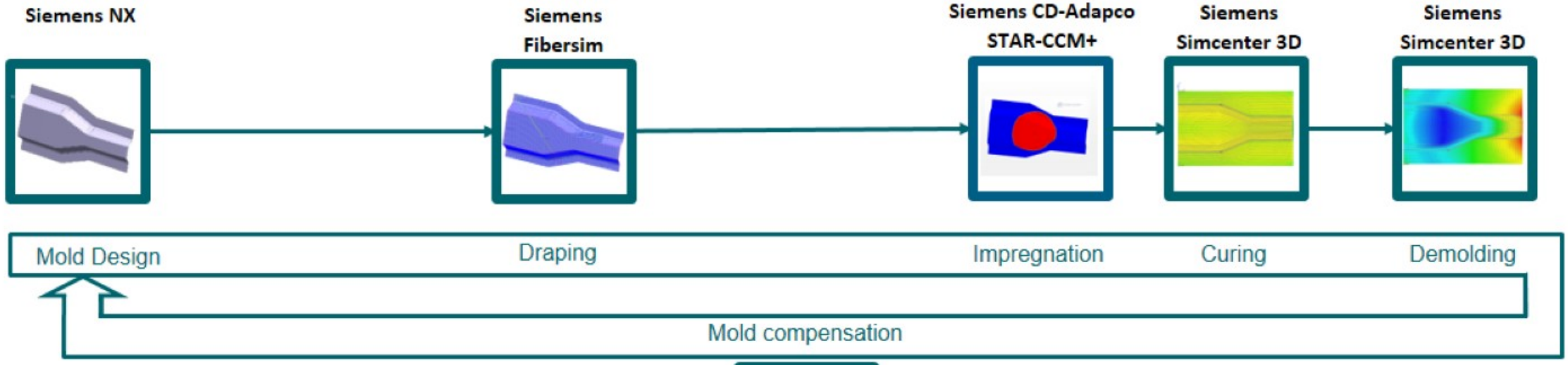
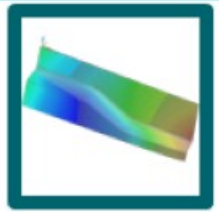
Ingenuity for life

Newly emerging objective: closing the loop between as-designed and as-manufactured products

* P. Šimáček, S.G.Advani, Role of acceleration forces in numerical simulation of mold filling processes in fibrous porous media, Composites Part A, 37, 11,1970-1982



OmniCAD
(Siemens partner)

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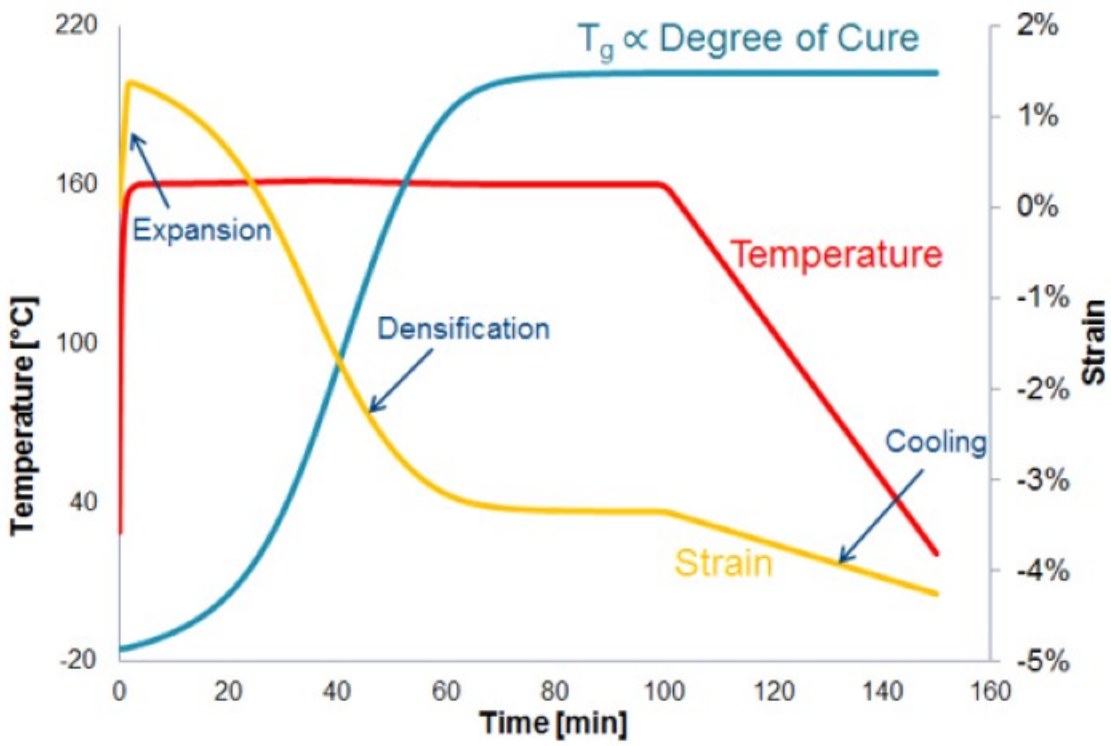
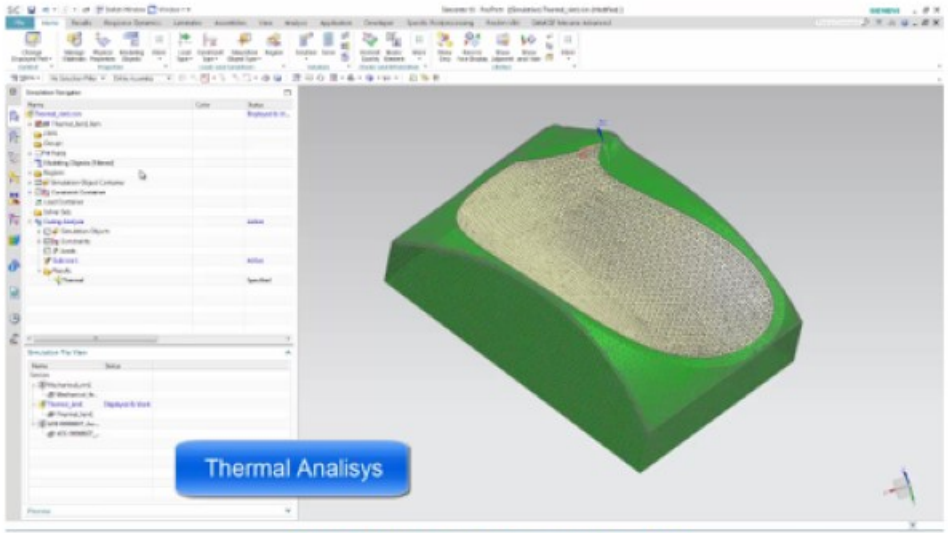
# Curing simulation

## Demoulding: assess the effect of curing

Distortion occurs during the **demoulding of the part** and arises due to **residual stress** build-up coming from (a) densification of the matrix, (b) difference in thermal expansion coefficient between fiber and matrix and (c) mould-composite interaction.




By taking into account the ***change in elastic modulus*** during the densification and cooling, the residual stresses and strains can be estimated:




**Available in Simcenter 3D**

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# Infusion simulation taking draping into account
## using Fibersim and STAR-CCM+

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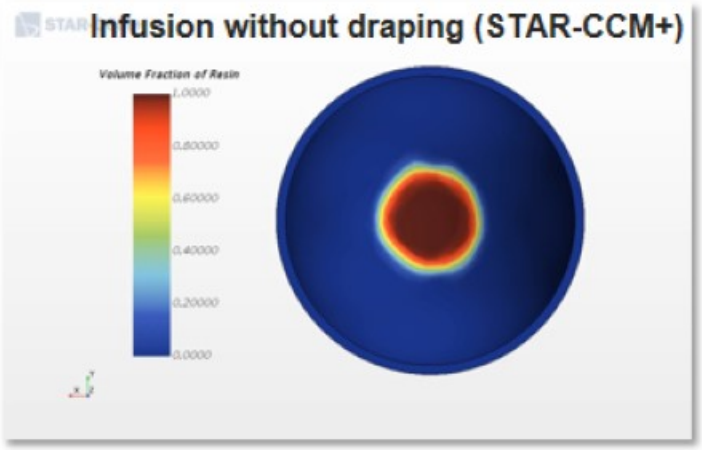
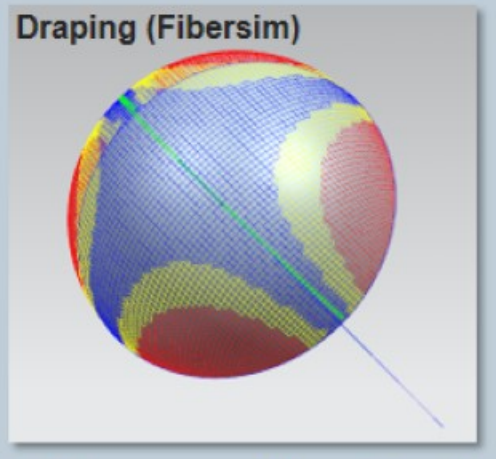
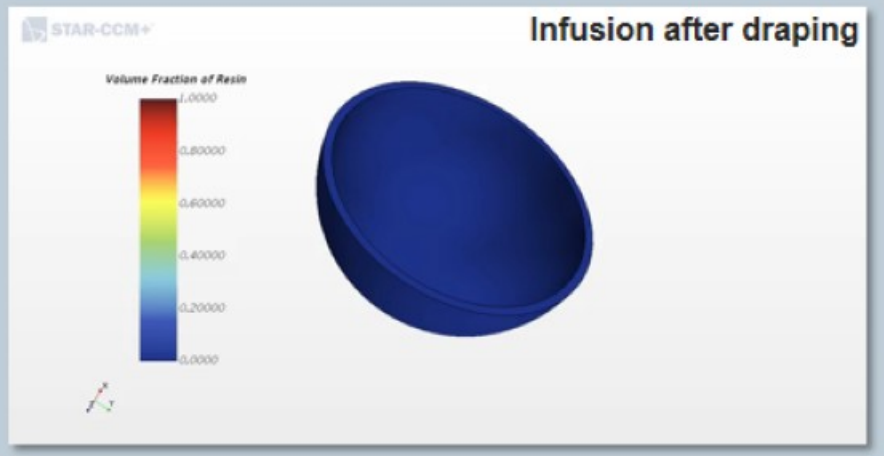
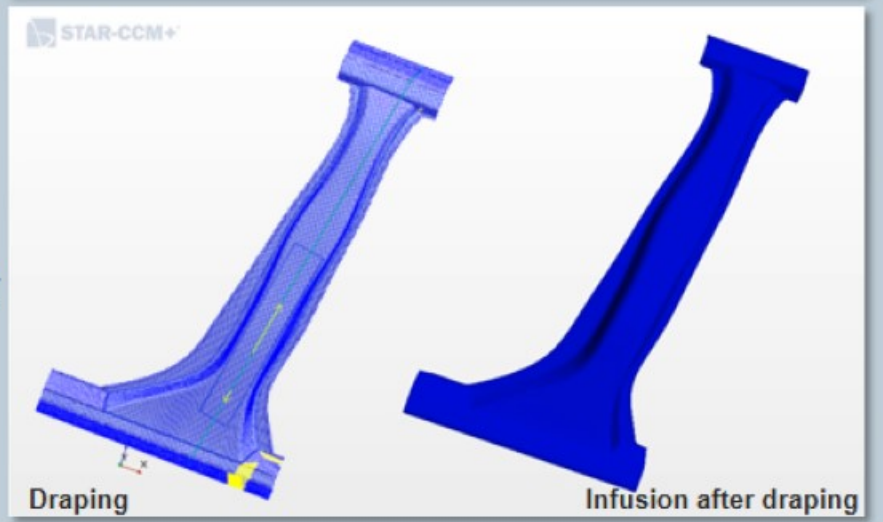



Infusion simulation, without taking draping into account




Influence of the draping of the reinforcement is taken into account by an analytical relationship between the in-plane shear and permeability. †

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† C. Demaria, Edu Ruiz, F. Trochu, In-Plane Anisotropic Permeability Characterization of Deformed Woven Fabrics by Unidirectional Injection. Part II: Prediction Model and Numerical Simulations

# Composite manufacturing simulation

## Example for RTM manufacturing- short fibers

**Released solution: Injection molding of short-fiber composites**

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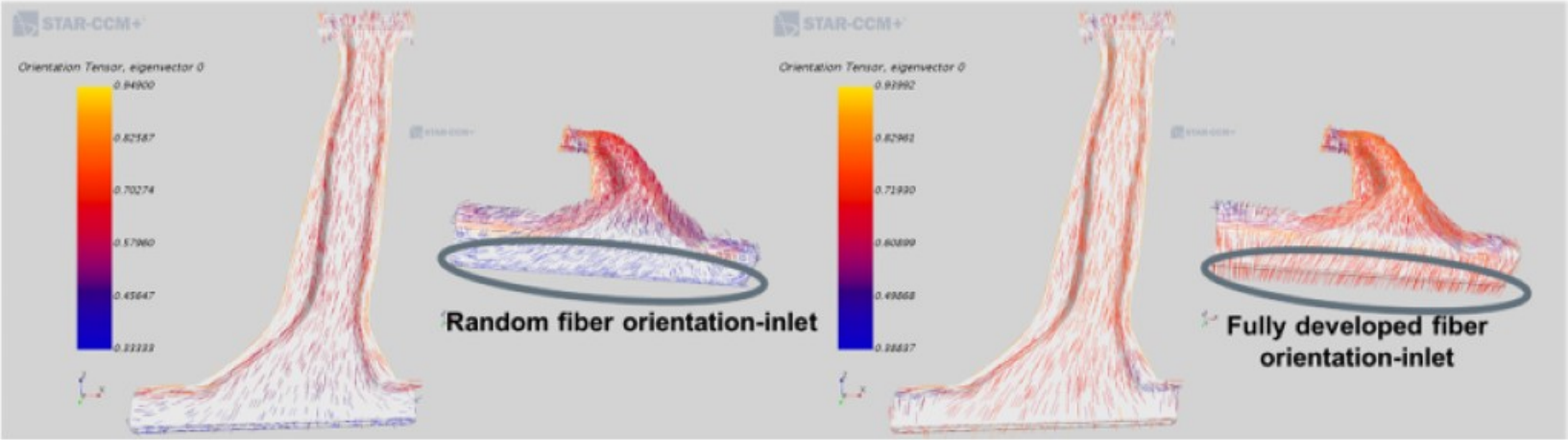
**Random fiber orientation condition at the inlet** **Fully developed fiber orientation condition at the inlet**



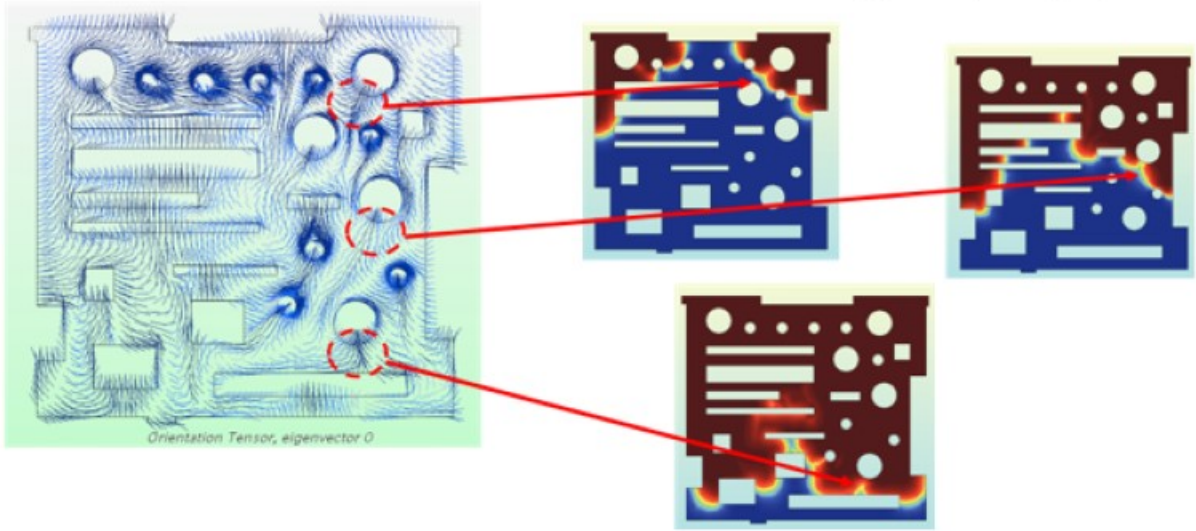

**Viscous Flow 13.06**

**Fiber orientation-Motherboard injection slip wall condition**

**Fiber orientation-B-pillar**

Fiber orientation predictions

3 different time instances of filling process (Filled region)

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# Our vision towards engineering with complex materials

## Simcenter 3D - RTD activities to serve the industries

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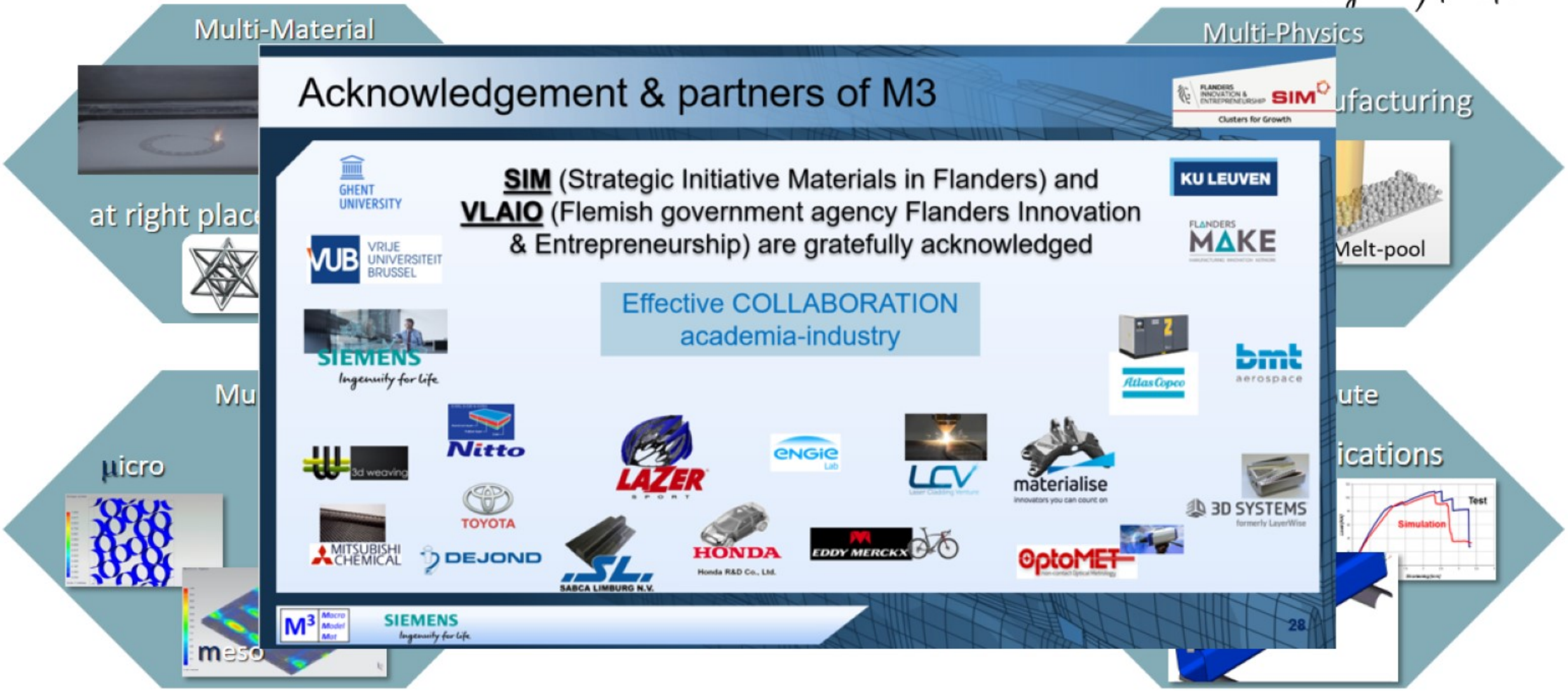


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