GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
BETREUT VOM
PTKA Projektträger Karlsruhe
Karlsruher Institut für Technologie
FORSCHUNGS CAMPUS
öffentlich-private Partnerschaft für Innovationen

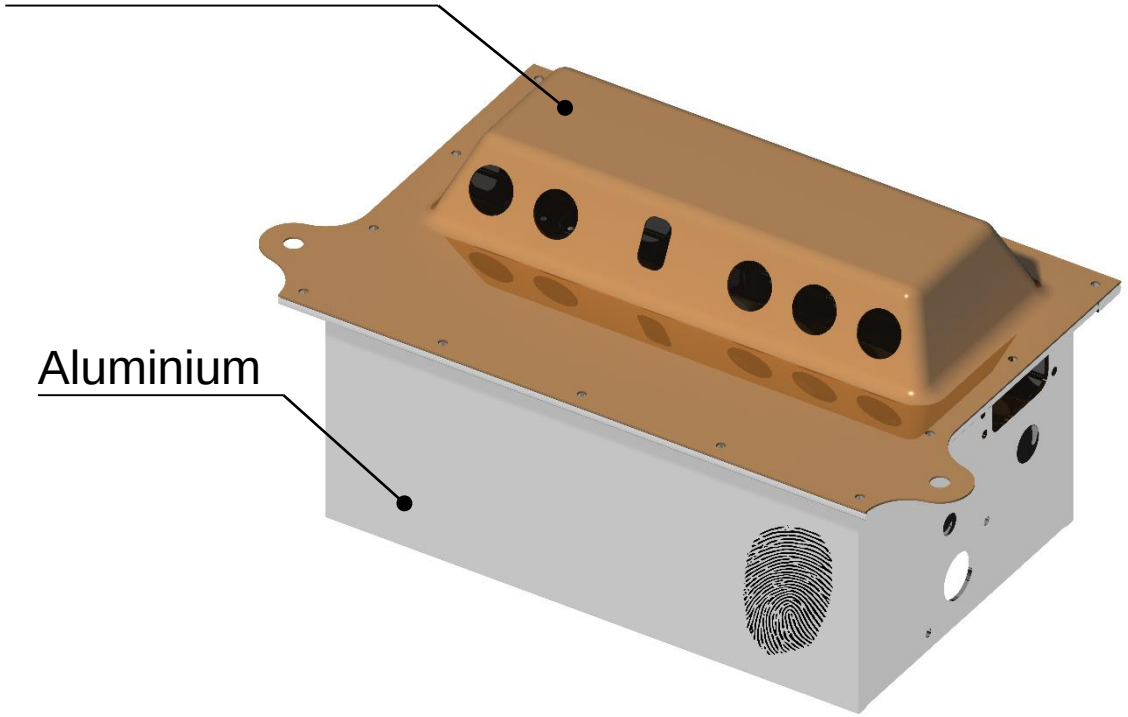
A closed multiscale simulation framework for the simulation of woven composite structures

Mathieu Vinot, Tobias Behling, Martin Holzapfel, Nathalie Toso

German Aerospace Center (DLR)
Institute of Structures and Design
Stuttgart – Germany

The project ‘Digital Fingerprint’ in the ARENA2036

GFK woven composite with epoxy resin
- Automated RTM manufacturing
- Integrated temperature and acceleration sensors

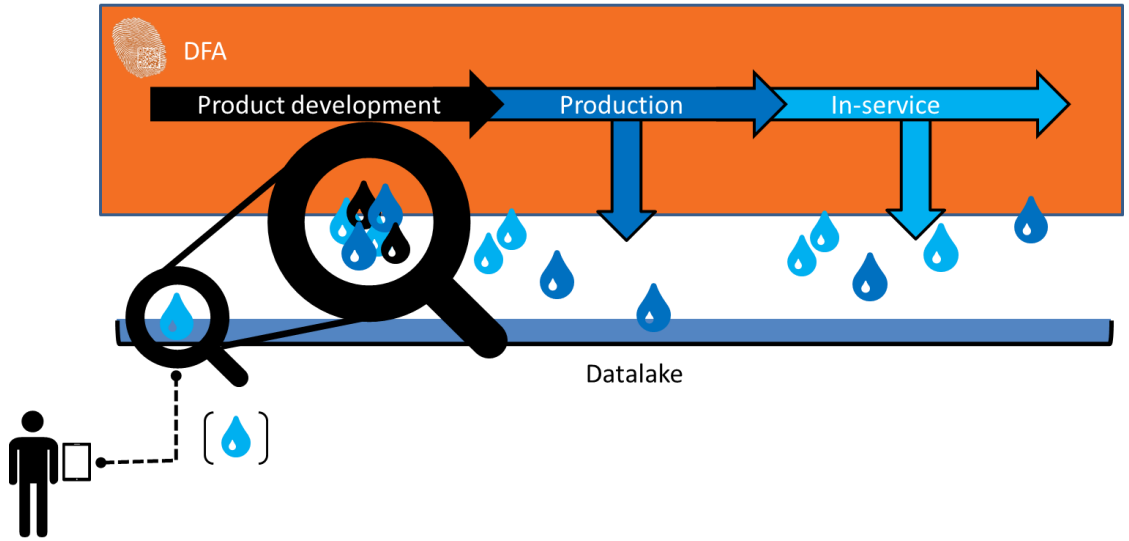


Goals

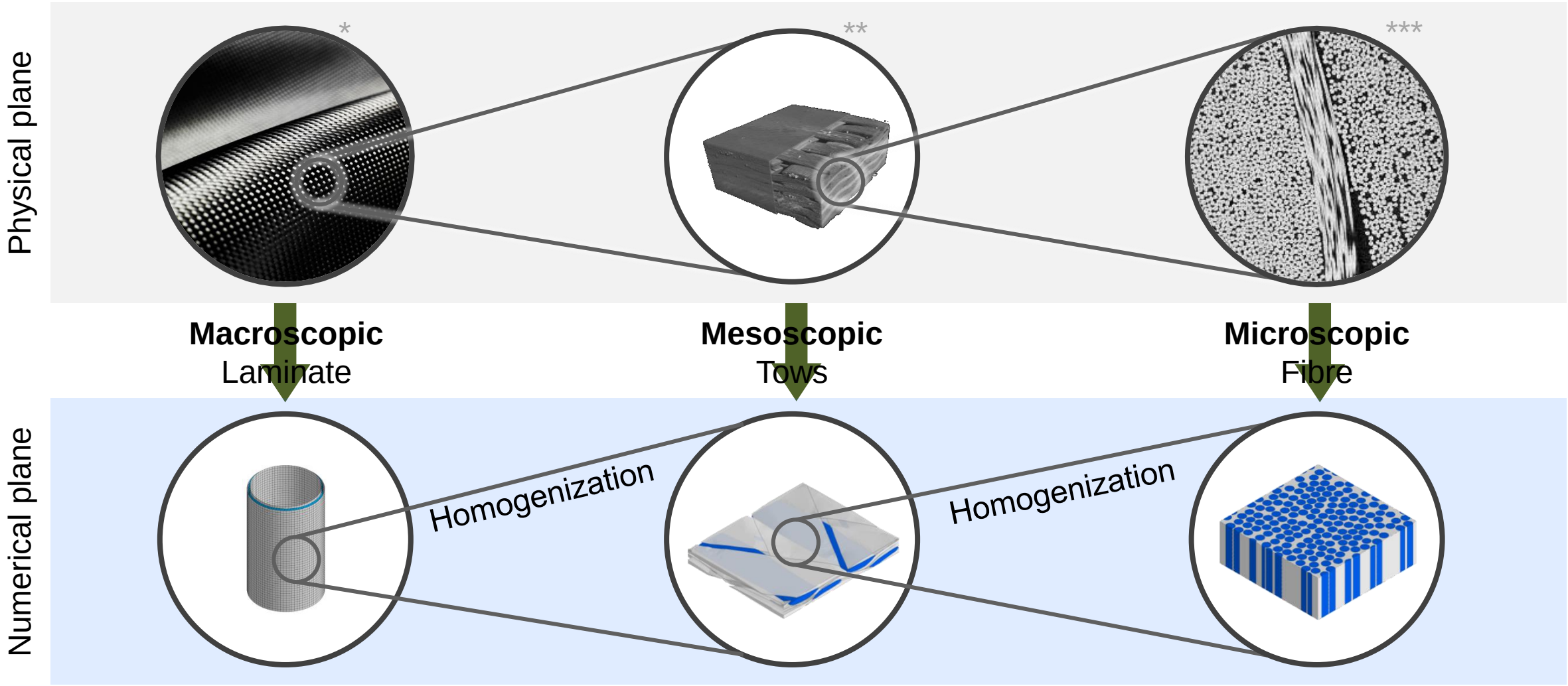
– Sizing and manufacturing of a multi-material high voltage car component

– Intelligent part evolution through data postprocessing during the product lifecycle

– Complete virtual material characterization



Multiscale simulation as an alternative to experimental tests

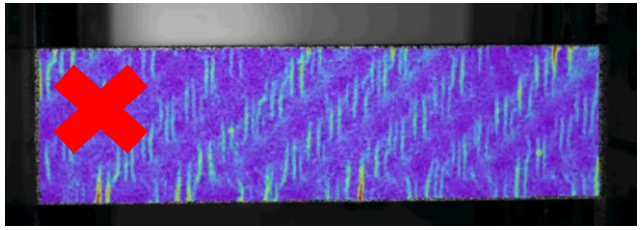


* http://www.sailingscuttlebutt.com
** https://www.nts.com/ntsblog/x-ray-computed-tomography-scanning-composite-materials/
*** http://www.azom.com

What are the benefits of multiscale simulation?

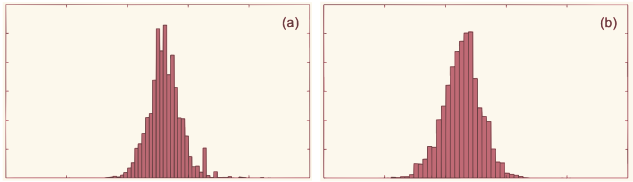
Cost reduction

- Reduction of complex and cost-intensive mechanical tests
- Manufacturing-free material characterization technique



Increase in confidence

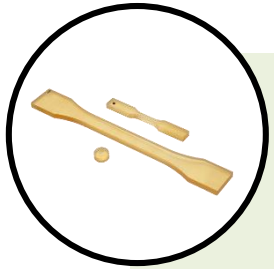
- Analysis of potential scatters in manufacturing and of their consequences
- Simulation of a larger number of specimens and configurations



Conceptual investigation

- Pre-study for new material combinations
- Pre-investigation of bio-composites (bio-resins / bio-fibres)

https://www.just-auto.com/interview/sustainable-composites-for-lightweight-applications/
https://delcotex.de/de/news/einzelansicht?tx_news_pi1%5Bnews%5D=46&cHash=6e953005a5abfbd89e532f6ac63f50ea



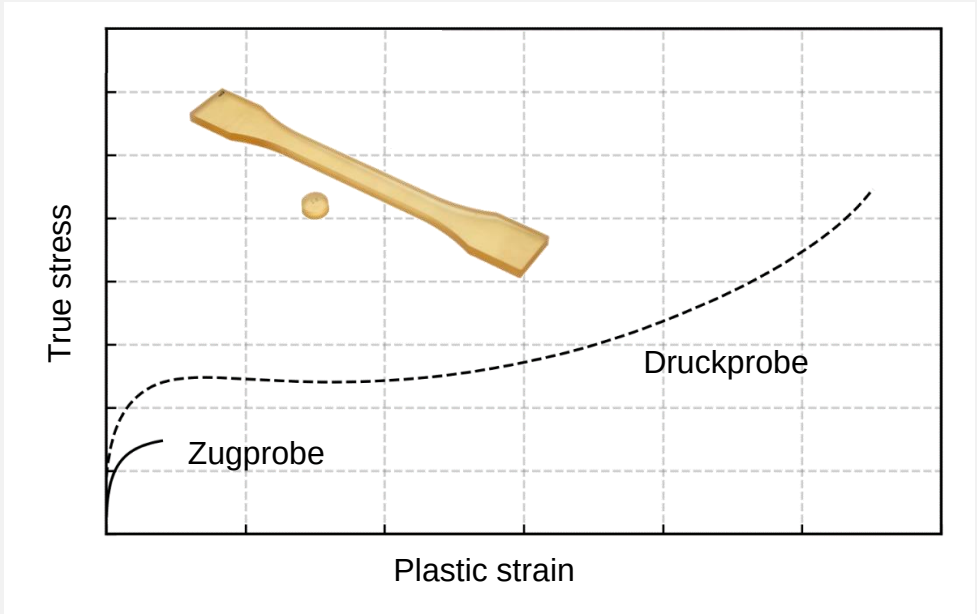
Material characterization

Necessary material characterization

classical method

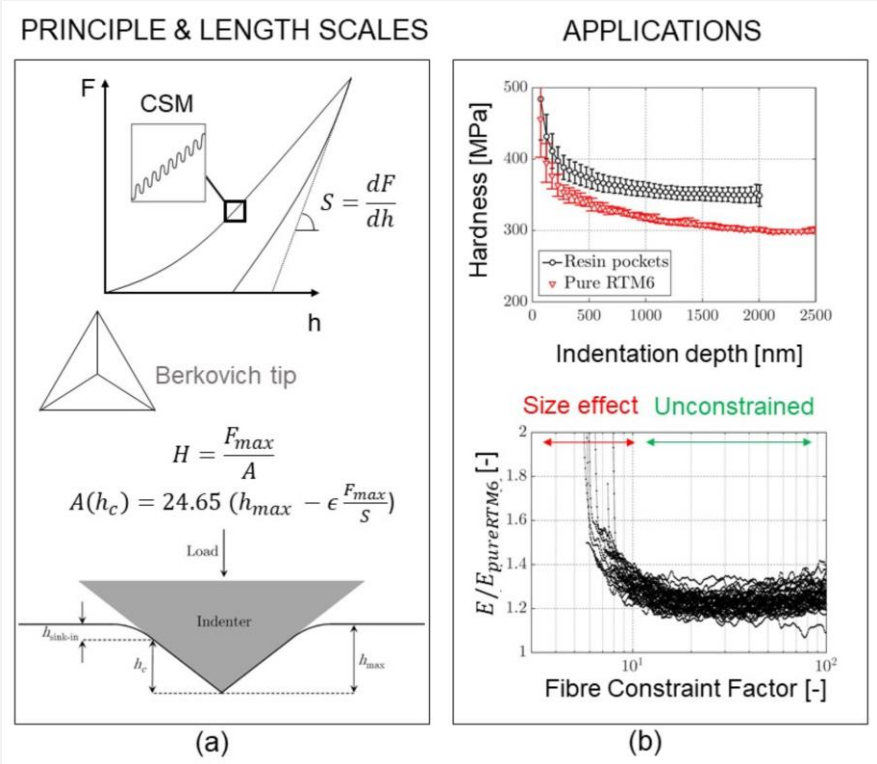
Characterization of the neat resin only

– Tension, compression and shear tests
– Generation of a *MAT_187_SAMP card
– Element erosion with *MAT_ADD_DIEM



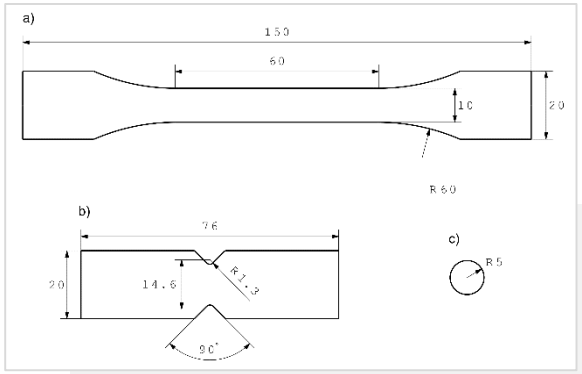
alternative method

Nanoindentation



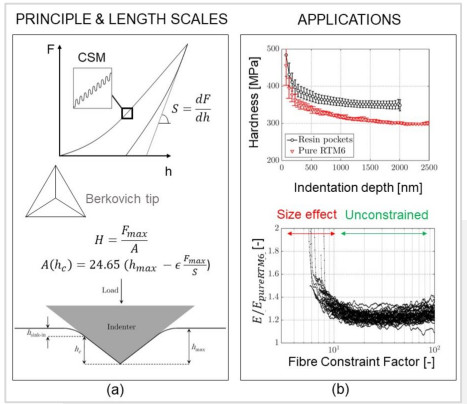
T. Pardoen, N. Klavzer, S. Gayot, F. Van Loock, J. Chevalier and e. al., "Nanomechanics serving polymer-based composite research," *Comptes Rendus Physiques*, pp. 331-352, 2021.

Necessary material characterization



+ Standardised test methodology
+ Load-dependent behaviour and failure
+ Straight-forward material card MAT_187

- Potential deviation from in-situ properties
- No consideration of manufacturing

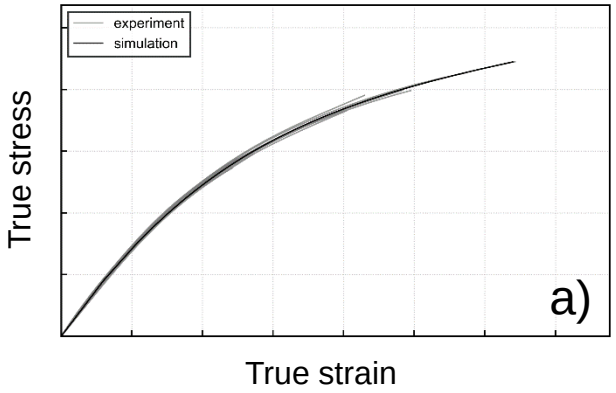


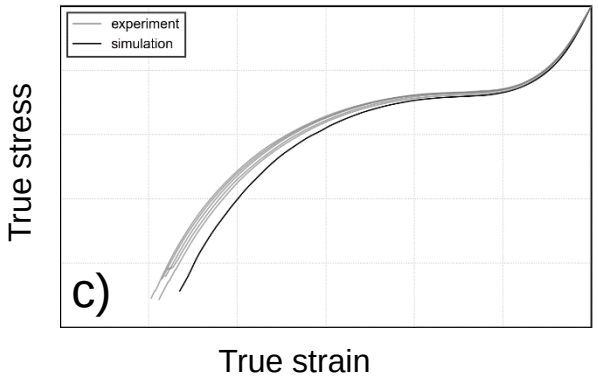
+ Measurement of in-situ properties
+ Manufacturing dependent material behaviour

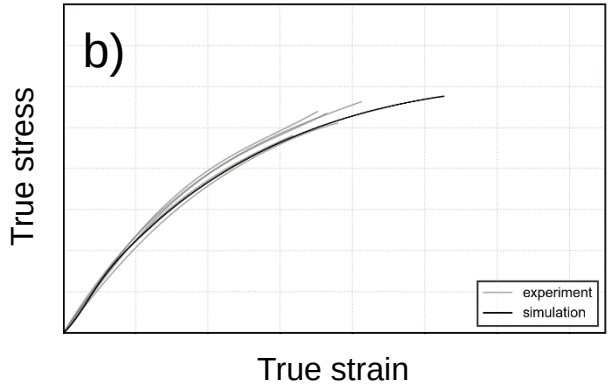
- Reverse engineering necessary
- Higher effort for complex material cards
- Potentially higher scatter in function of the chosen test domain

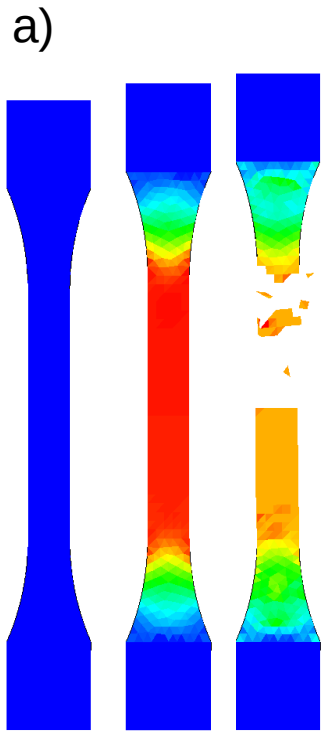
Validation of the material card

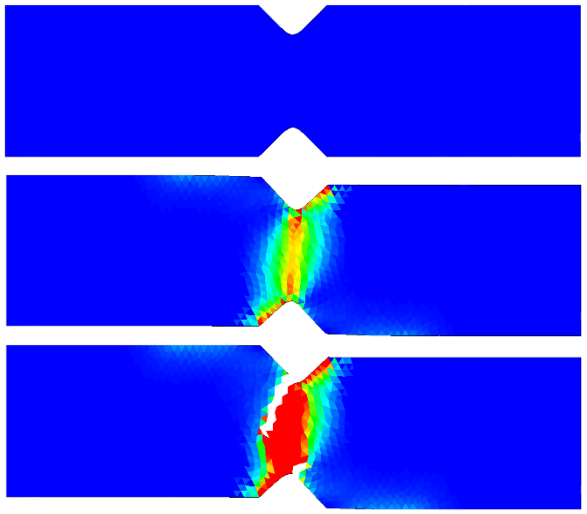
- Simulation of all tests on neat resin with TET13 elements
- Good correlation of triaxiality-dependent material failure

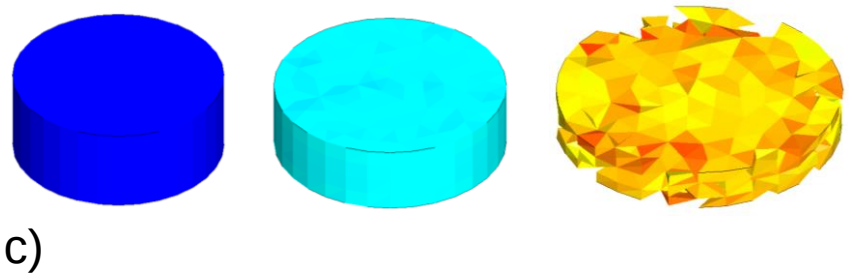


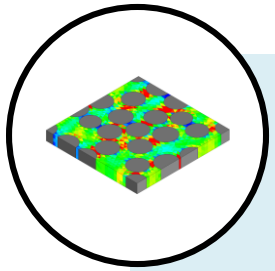








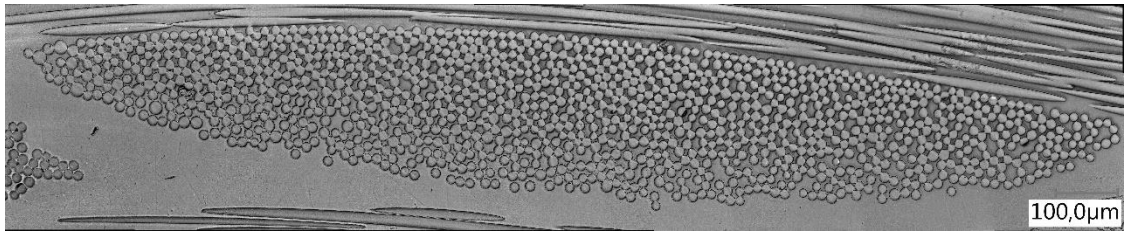


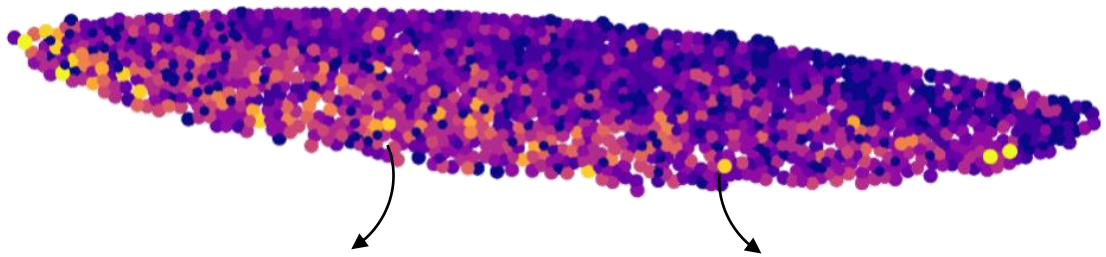


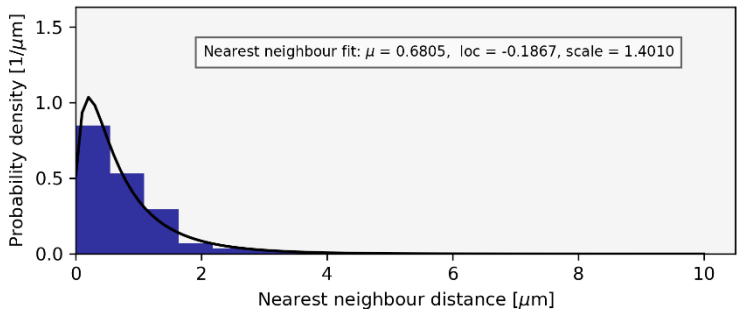
Microscale simulation

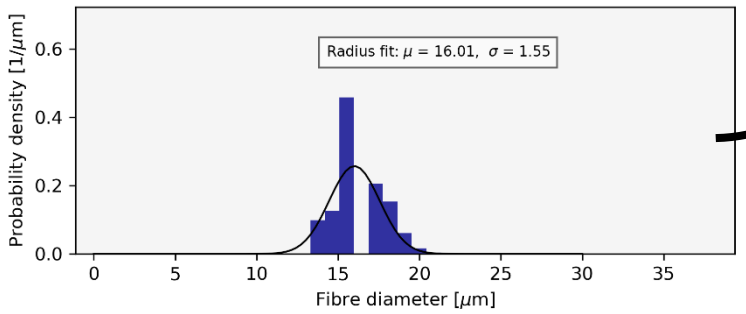
Generation of microscopic models

Postprocessing of micrographic pictures from infiltrated yarns (ImageJ)

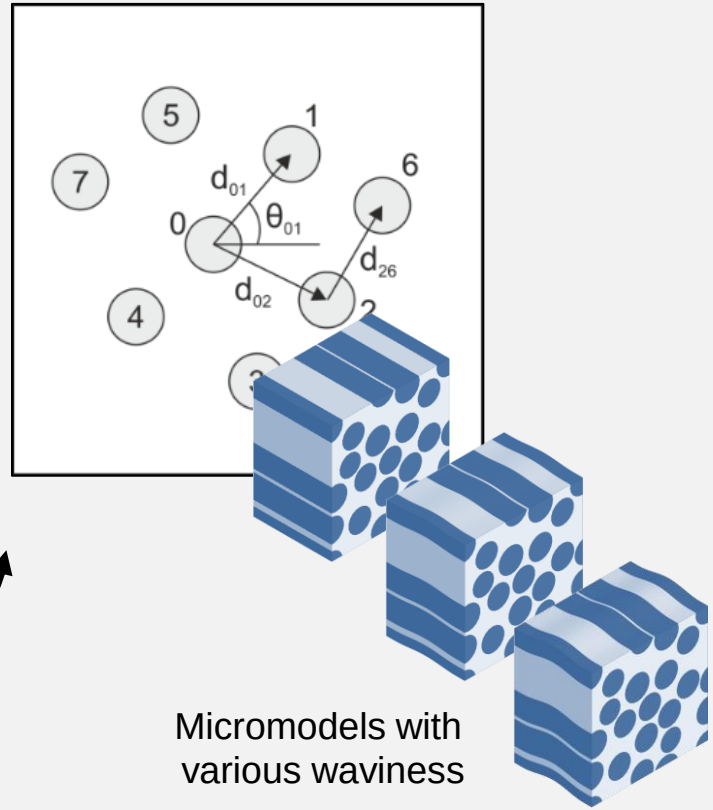








Python module
Nearest Neighbour Algorithm



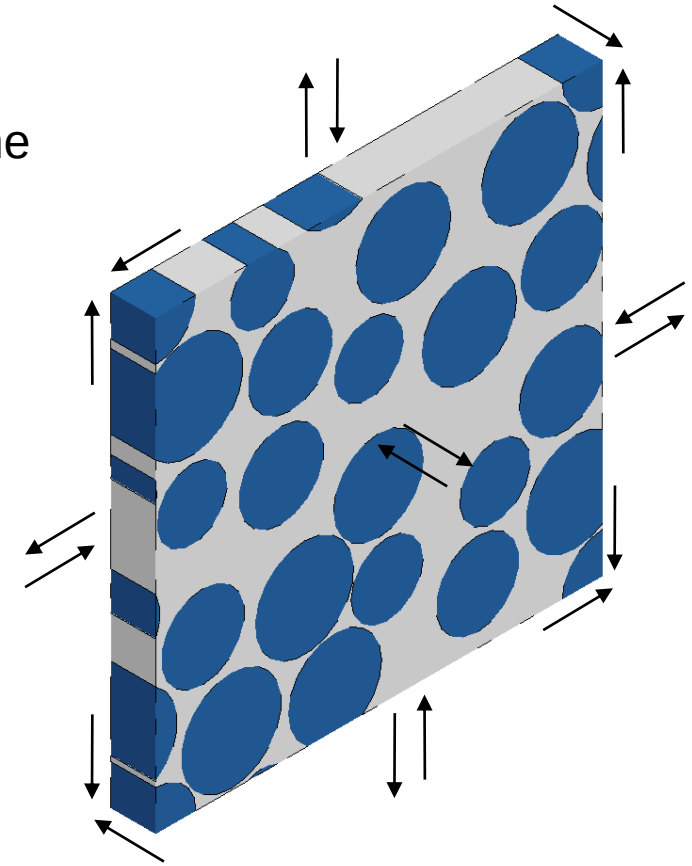
Micromodels with
various waviness

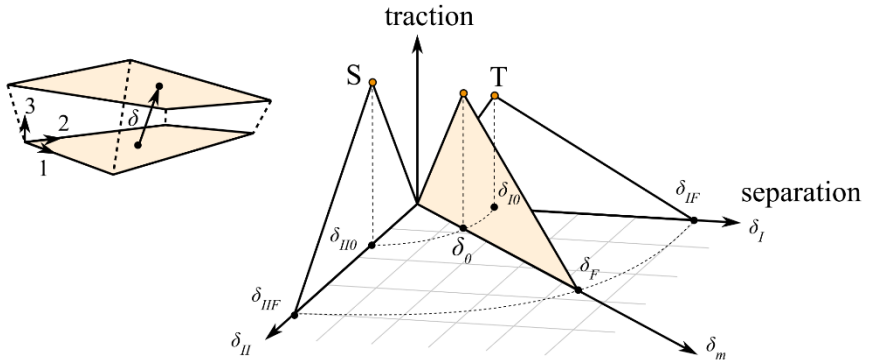
Microscale simulation

Characteristics of the FE models

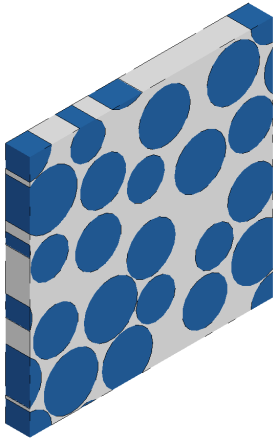
- Tetrahedron elements ELFORM 13 – coarse mesh for faster computing time
- Periodic boundary conditions via *CONSTRAINED_MULTIPLE_GLOBAL
- Load introduction through master nodes and beam elements

- Resin material MAT_187_SAMP-1
- Fibre material MAT_054 with axial failure only
- Tiebreak contact with bilinear traction-separation law option 9

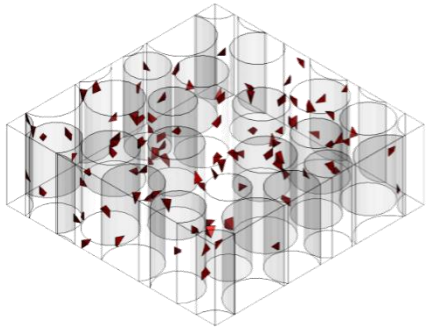


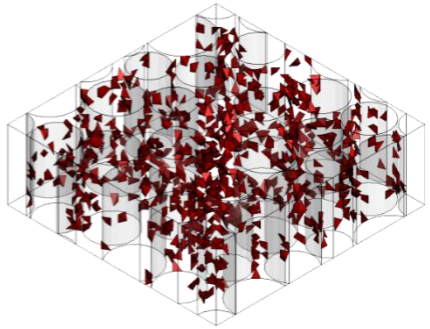


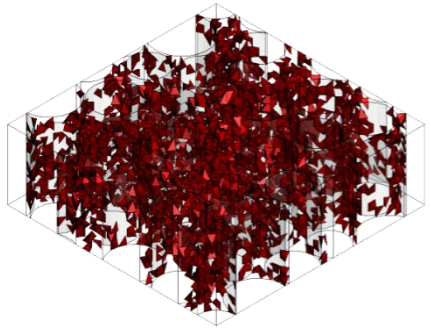
Modelling of voids with envyo®

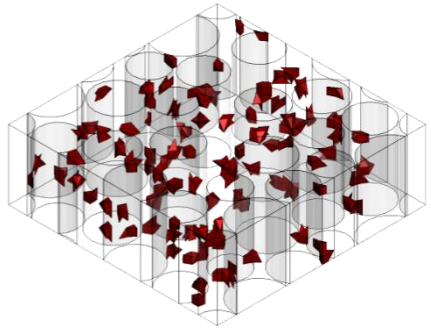


ENVYO









envyo algorithm

- Works with *MAT_157
- Automatic generation of void elements with local reduction of the mechanical properties
- Mechanical properties attributed in an element-wise manner with Gaussian distributions

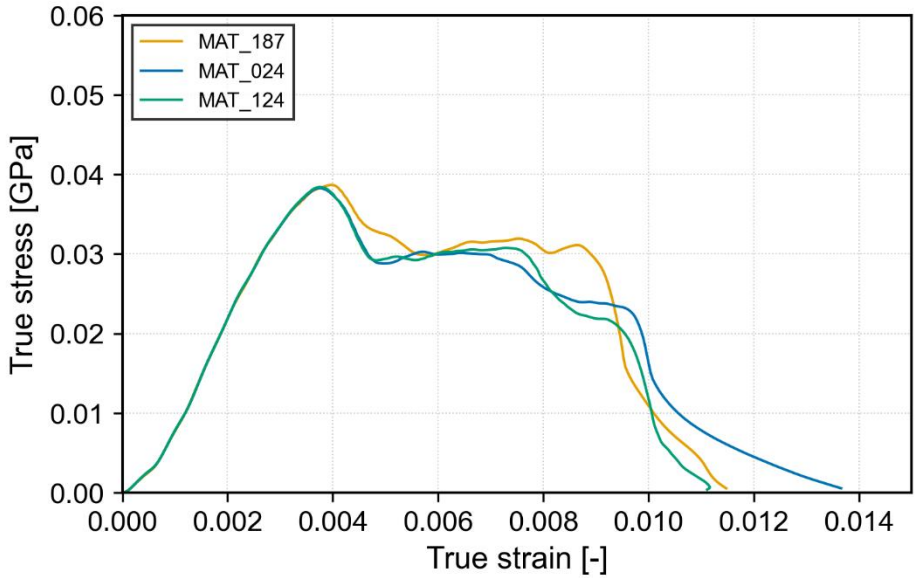
DLR

Influence of triaxiality in microscale simulation

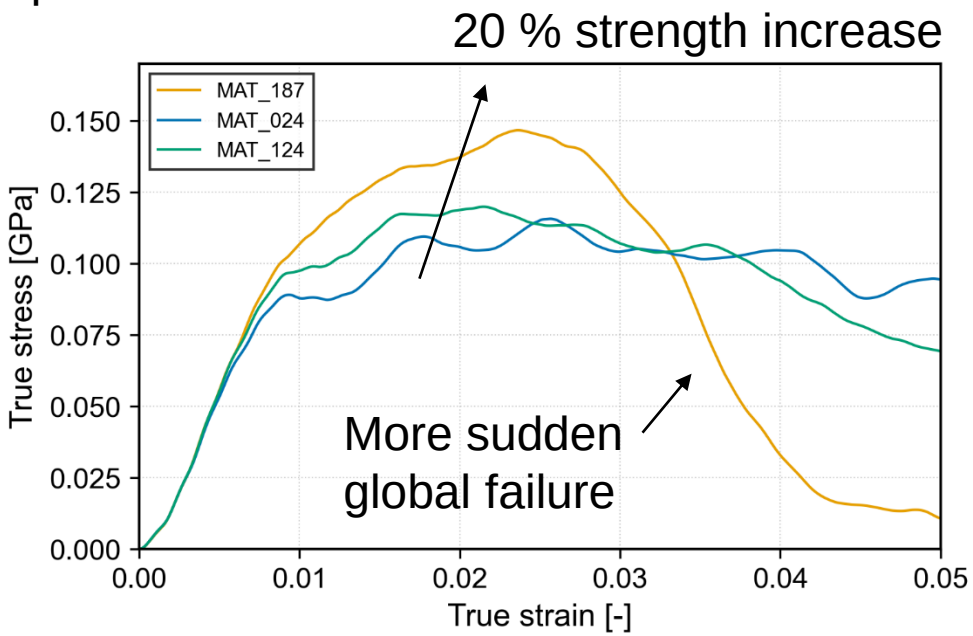
– Consideration of triaxiality-dependent failure and of compression and shear behaviour in MAT_187

– Low influence on tension-dominated load cases

– Higher influence on the behaviour under tranverse compression

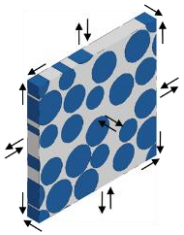


Transverse tension behaviour



Transverse compression behaviour

Homogenization of the microscopic model



– Generation of material cards *MAT_262 for unidirectional material

– Development of simulations for fracture toughnesses

***MAT_262** ***MAT_LAMINATED_FRACTRURE_DAIMLER_CAMANHO**

Card Summary:

Card 1. This card is required.

MID	RO	EA	EB	EC	PRBA	PRCA	PRCB

Card 2. This card is required.

GAB	GBC	GCA	AOPT	DAF	DKF	DMF	EFS

Card 3. This card is required.

XP	YP	ZP	A1	A2	A3	DSF	

Card 4. This card is required.

V1	V2	V3	D1	D2	D3	MANGLE	

Card 5. This card is required.

GXC	GXT	GYC	GYT	GSL	GXCO	GXTO	

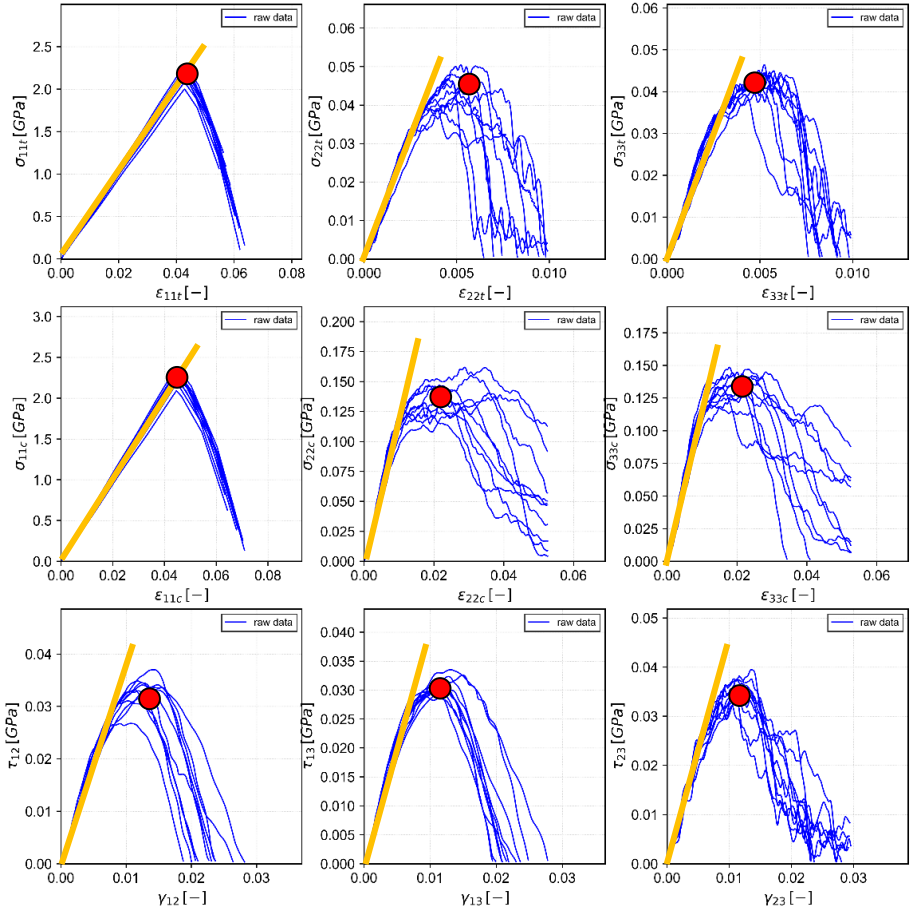
Card 6. This card is required.

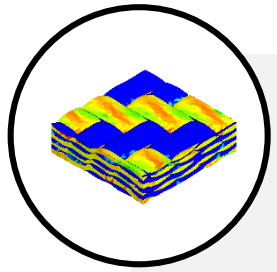
XC	XT	YC	YT	SL	XCO	XTO	

Card 7. This card is required.

FIO	SIGY	ETAN	BETA	PFL	PUCK	SOFT	DT

From LS-DYNA Manual Part II





Mesoscale simulation

Generation of mesoscopic models

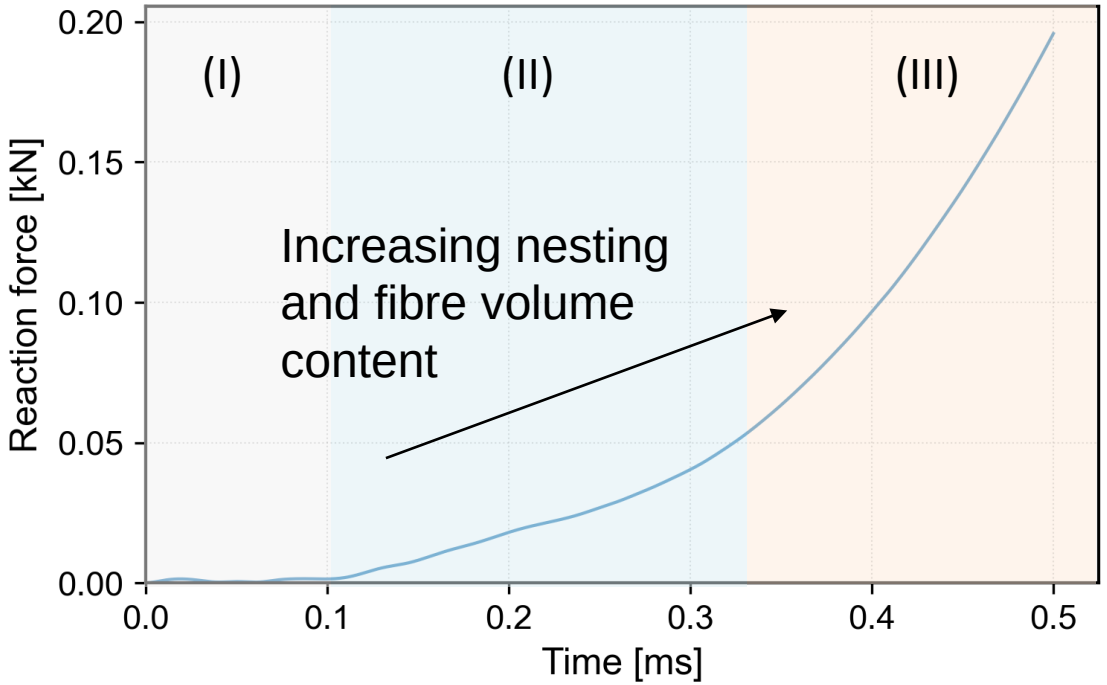
Generation of the FE model

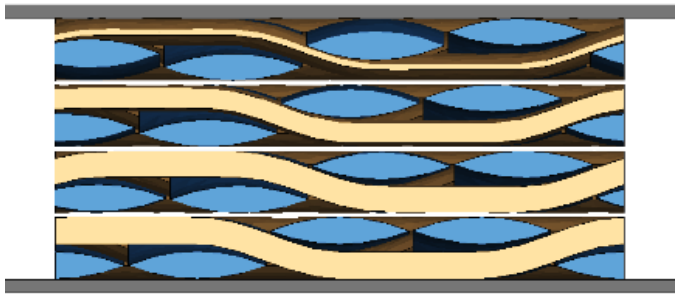
Automatic generation of the dry woven textile model with random layer nesting (TexGen)

- Consideration of tow size and number of filaments
- Assumption for the initial fibre density in the tows

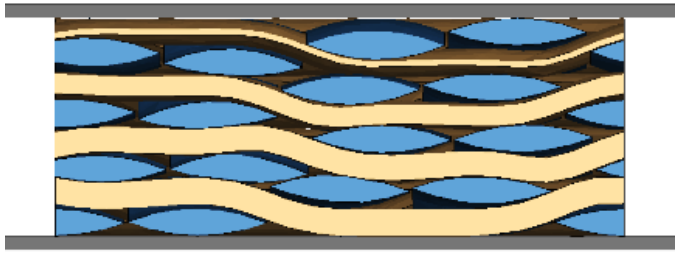
Need for compaction simulation

- Closing of the inter-layer gaps (I)
- Closing of the intra-layer gaps (II)
- Yarns compaction and deformation (III)

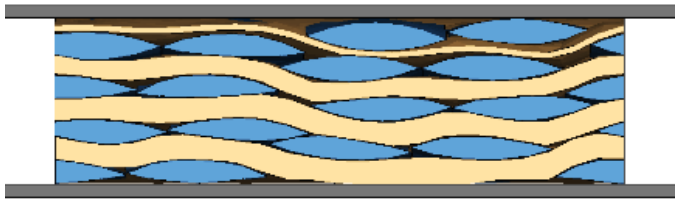




(I)



(II)



(III)

Generation of mesoscopic models

Generation of the FE model

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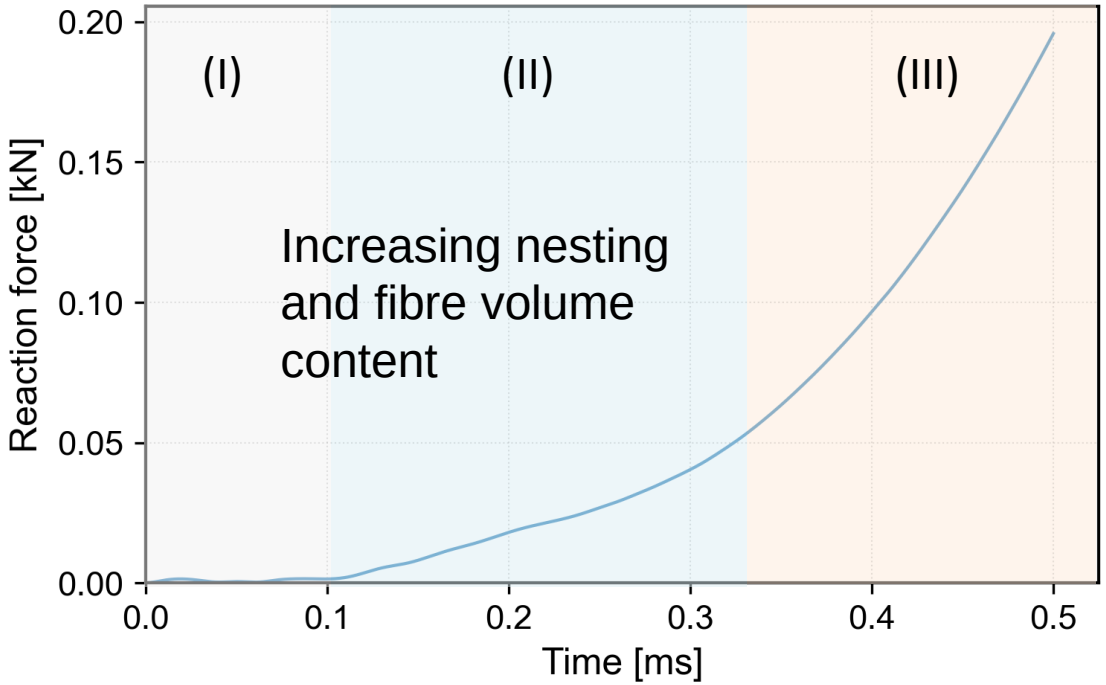
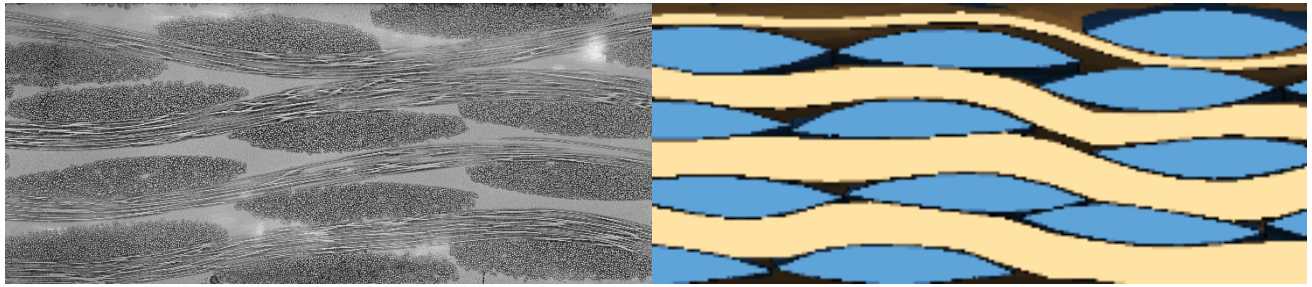


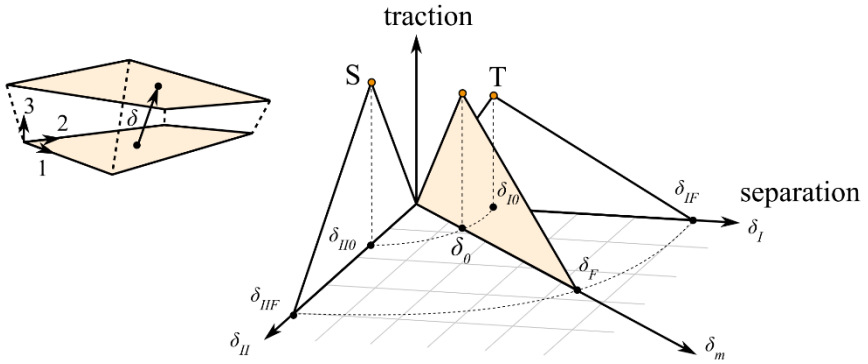


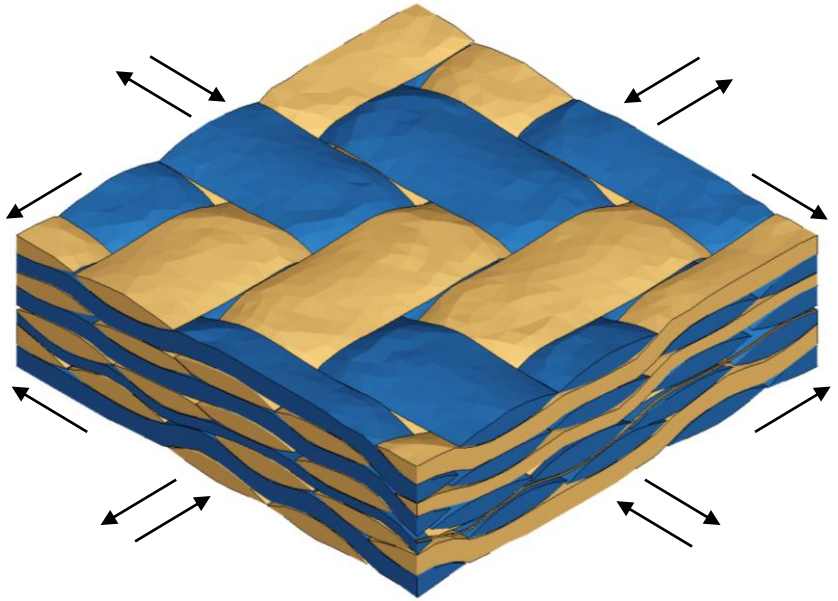
Mesoscale simulation

Characteristics of the FE models

- Tetrahedron elements ELFORM 13 – coarse mesh for faster computing time
- Periodic boundary conditions via *CONSTRAINED_MULTIPLE_GLOBAL
- Load introduction through master nodes and beam elements

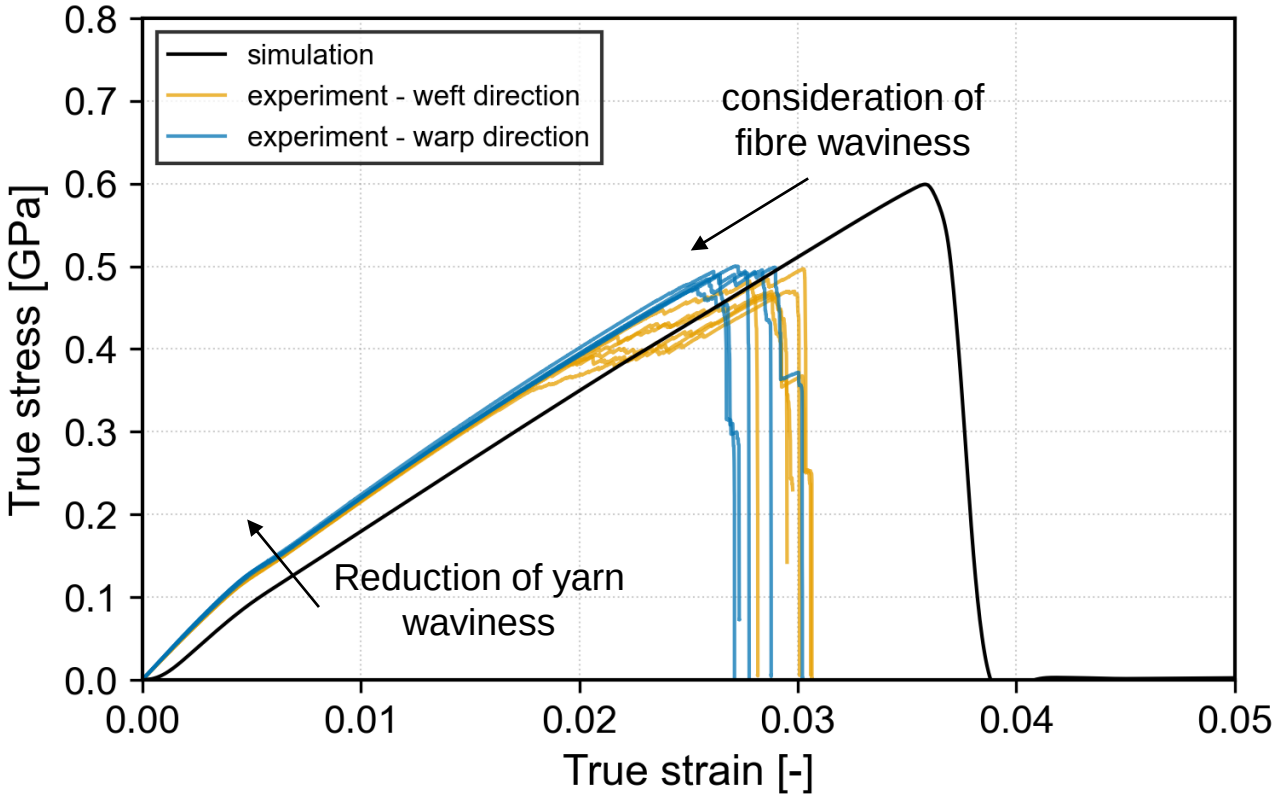
- Resin material MAT_187_SAMP-1 from microscale simulation
- Tow material MAT_262 from microscale simulation
- Tiebreak contact with bilinear traction-separation law option 9





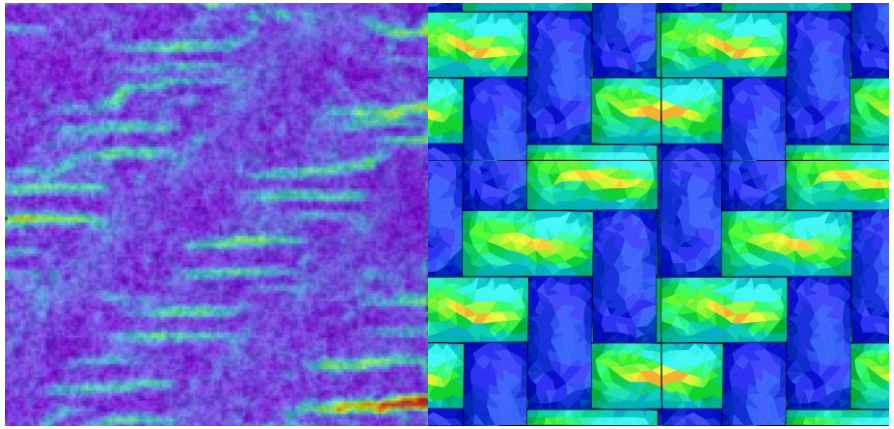
Comparison simulation - experiment

- Blind prediction of the material behaviour under tension in the warp direction



Longitudinal strain DIC field

Longitudinal strain FE simulation



	E_{11t} (GPa)	σ_{11t} (GPa)
Experiment	27.2	0.48
Simulation	18.8 (-31 %)	0.57 (+18 %)

Homogenization of the mesoscopic model

***MAT_058** ***MAT_LAMINATED_COMPOSITE_FABRIC**

Card Summary:

Card 1. This card is required.

MID	RO	EA	EB	EC	PRBA	TAU1	GAMMA1

Card 2. This card is required.

GAB	GBC	GCA	SLIMT1	SLIMC1	SLIMT2	SLIMC2	SLIMS

Card 3. This card is required.

AOPT	TSIZE	ERODS	SOFT	FS	EPSF	EPSR	TSMD

Card 4. This card is required.

XP	YP	ZP	A1	A2	A3	PRCA	PRCB

Card 5. This card is required.

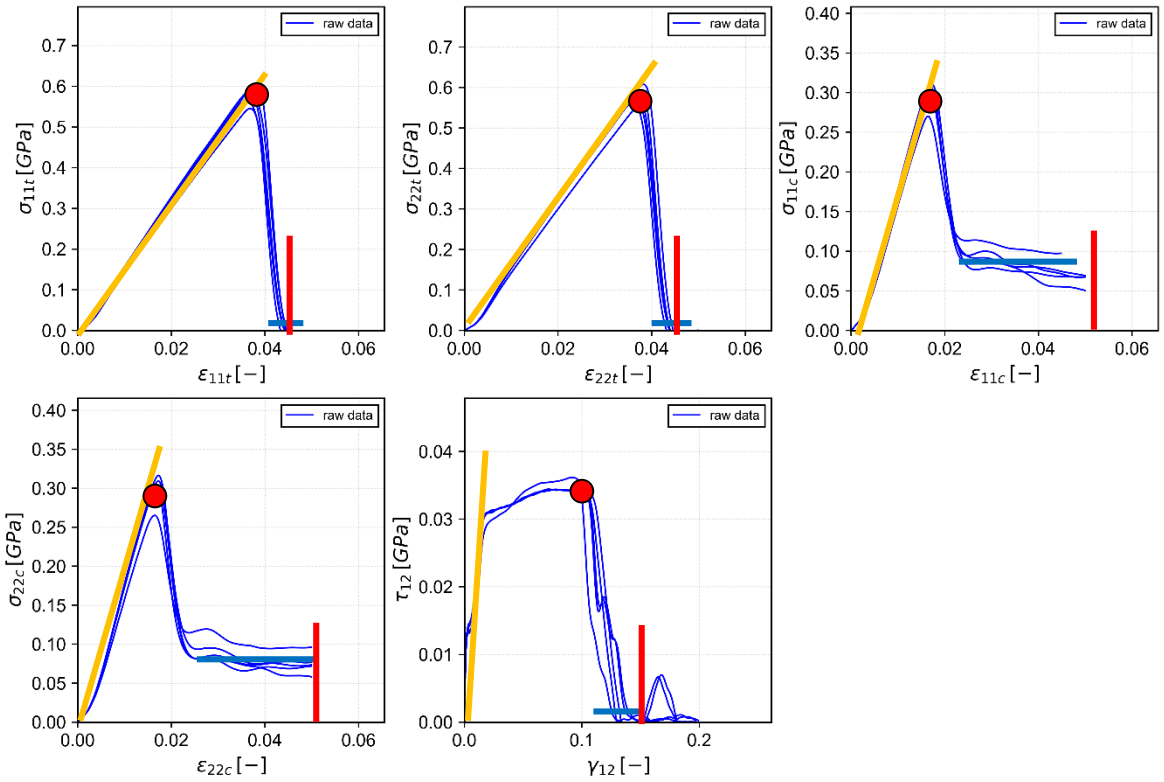
V1	V2	V3	D1	D2	D3	BETA	LCDFAIL

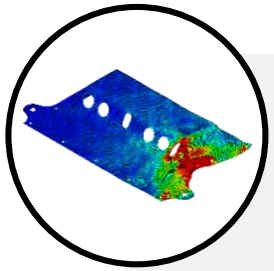
Card 6. This card is required.

E11C	E11T	E22C	E22T	GMS			

Card 7. This card is required.

XC	XT	YC	YT	SC			



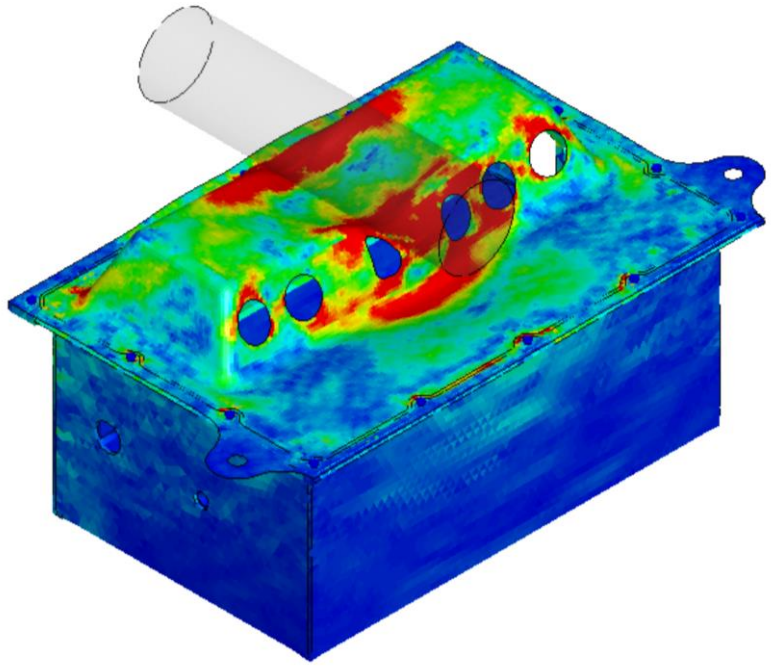


Macroscale simulation

Macroscale simulation

– Simulation of a generic crash scenario on the composite part (exemplary test case)

– Modelling of the composite parts with shell elements ELFORM 16



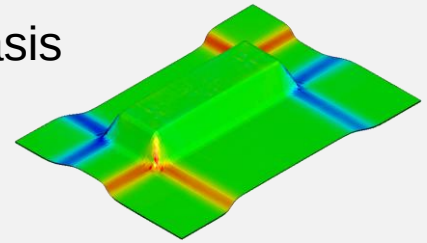
Potential extensions

– Consideration of randomly distributed properties with different material cards from mesoscale simulation

– Consideration of local fibre reorientations through draping process

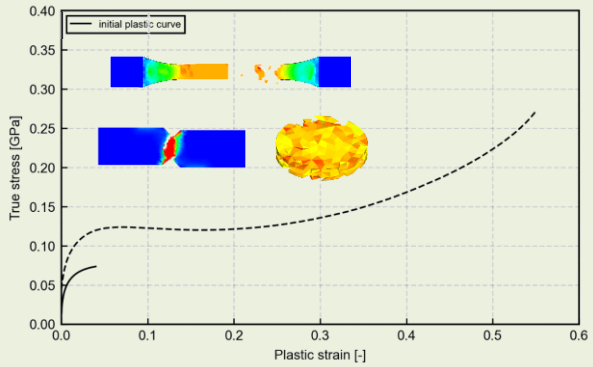
– Void generation with ENVYO on IP basis

ENVYO

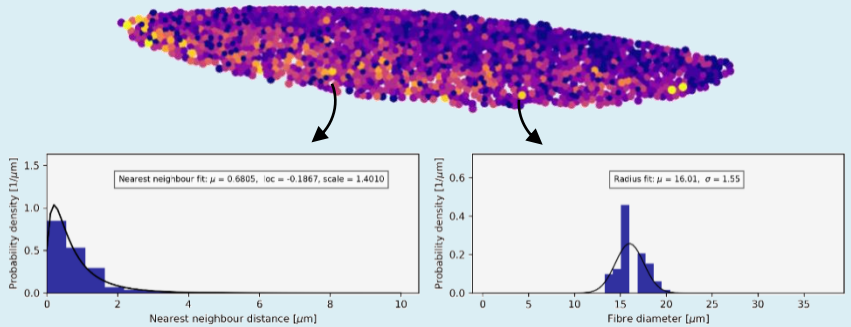


Conclusion and outlook

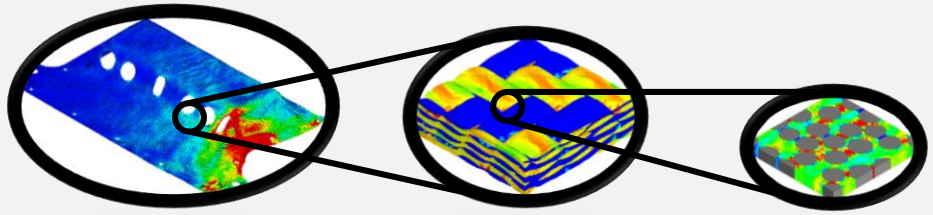
Generation of a SAMP-1 + DIEM card for an epoxy resin



Automatic statistical analysis of composite micrographs

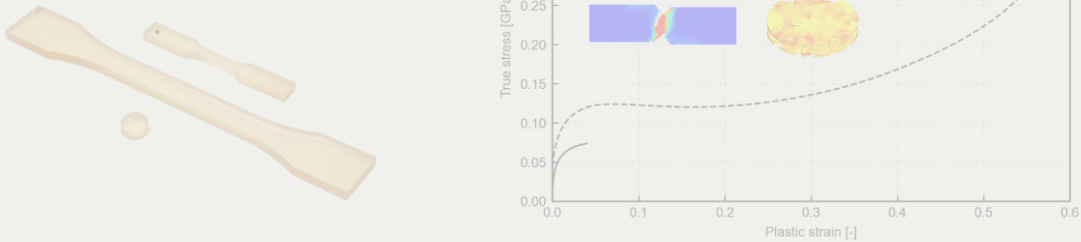


Development of a closed multiscale solution for woven composites

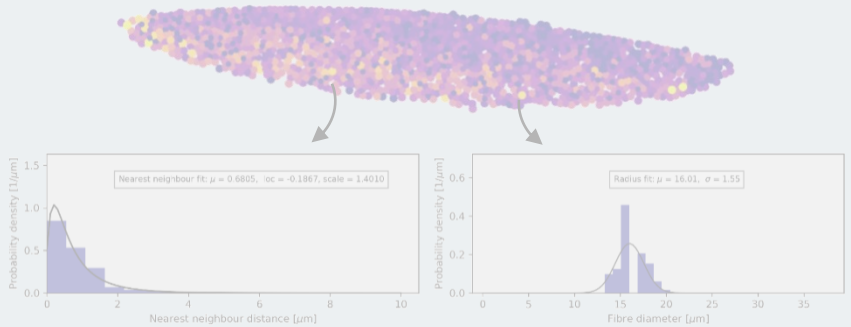


Conclusion and outlook

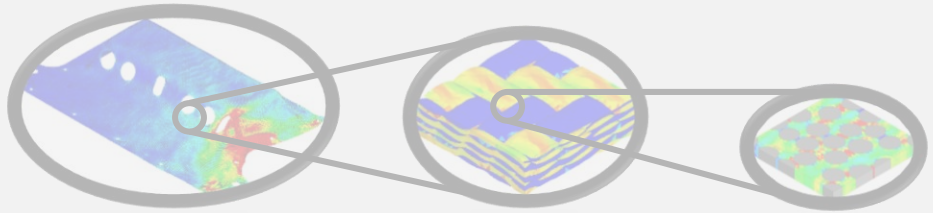
Generation of a SAMP-1 + DIEM card for an epoxy resin



Automatic statistical analysis of composite micrographs

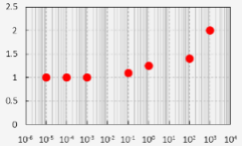


Development of a closed multiscale solution for woven composites



Extension of virtual testing for fracture toughnesses

Extension to strain-rate and temperature dependency



GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

BETREUT VOM
PTKA Projektträger Karlsruhe
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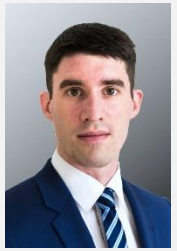
Thank you for your attention!



Vinot Mathieu
Institute of Structures and Design, Stuttgart
Departement for Structural Integrity
mathieu.vinot@dlr.de