



NUMERICAL CHARACTERIZATION OF NON- WOVEN ECO-COMPOSITES FOR AERONAUTICAL STRUCTURES

**Xavier Martinez, Gonçal Seguí,
Gabriel Bugada and Sergio Oller**

**8TH EASN-CEAS
INTERNATIONAL WORKSHOP
ON MANUFACTURING FOR
GROWTH AND INNOVATION**

SEPTEMBER 6th 2018, GLASGOW

Work funded from:

- *The European Union's Horizon 2020 research and innovation programme under grant agreement No 690638*
- *The Ministry for Industry and Information of the People's Republic of China under grant agreement No [2016]92*



Numerical analyses in ECO-COMPASS project



OBJECTIVE: Eco-compass project seeks improving the knowledge of eco-composites, to facilitate their use in aeronautical structures (interiors and secondary structures)



To achieve this goal, it is necessary a good knowledge of the material performance, as well as good analysis tools

Numerical analyses in ECO-COMPASS project



WP6. Modelling and simulation

Objectives:

- Validation of analysis tools for the numerical analysis of eco-composites and eco-components.
- Development of new numerical tools for achieving good agreement between numerical and experimental analysis.
- Application in optimum design of new eco-composites in terms of the mechanical and electromagnetic characteristics of each component.

This will be achieved with the following **TASKS**:

- 6.1 Parameters for numerical analysis
- 6.2 Numerical analysis of eco-composites
- 6.3 Numerical analysis of electromagnetic compatibility and conductivity
- 6.4 Simulation method of lightning strike protection
- 6.5 Evaluation of lightning strike damage resistance
- 6.6 Modeling of vibration and noise reduction
- 6.7 Design optimization of eco-composites



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6.1 Parameters for numerical analysis



Most of the numerical models that will be used are based on multiscale procedures. Therefore, it is necessary to obtain material data for all composite constituents, as well as for the composite.

1 FIBRE DATA

1.1 FIBRE CONSIDERED

FIBRE TYPE	
MANUFACTURER	
COMMERCIAL NAME	

1.2 BASIC MATERIAL PROPERTIES

Property	
Young Modulus	
Poisson ratio (if possible)	
Shear modulus (if possible)	
Density	
Specific Heat Capacity	
Thermal Conductivity	
Coefficient of thermal expansion	
Electrical Conductivity	

1.3 FAILURE PARAMETERS

Property	
Stress-strain or force-displacement graph in tensile direction (if possible, with some indication of failure mechanism)	

2 MATRIX DATA

2.1 MATRIX CONSIDERED

MATRIX TYPE	
MANUFACTURER	
COMMERCIAL NAME	

2.2 BASIC MATERIAL PROPERTIES¹

Property	
Young Modulus	
Poisson ratio	
Shear modulus	
Density	
Specific Heat Capacity	
Thermal Conductivity	
Coefficient of thermal expansion	
Electrical Conductivity	

2.3 FAILURE PARAMETERS

Property	
Stress-strain or force-displacement graph in tensile directions (if possible, with some indication of failure mechanism)	

4 COMPOSITE DATA

4.1 COMPOSITE CONSIDERED

FIBRE IN COMPOSITE	
MATRIX IN COMPOSITE	
CORE IN COMPOSITE	
COMPOSITE NAME	

4.2 COMPOSITE ARCHITECTURE

Property	Value	Units
Layup		
Fibre volumetric participation in layer		
Matrix volumetric participation in layer		
Layer thickness		
Core thickness		
In case of having other additives, reinforcements, agglomerates, etc. in the composite, description of those.		

4.3 BASIC COMPOSITE PROPERTIES

Property	
Young Modulus in different directions	



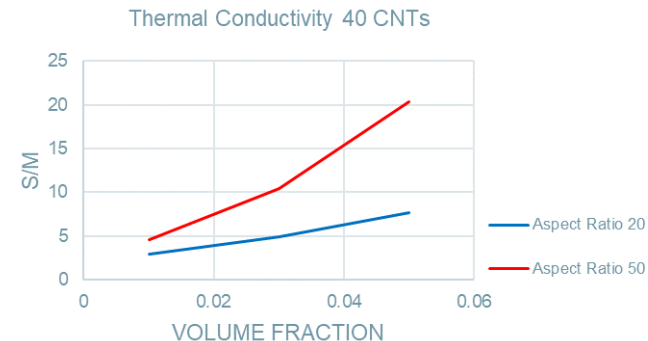
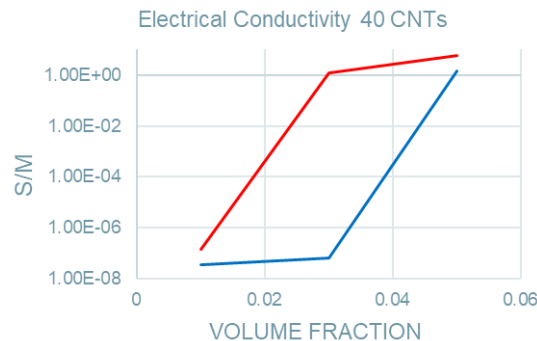
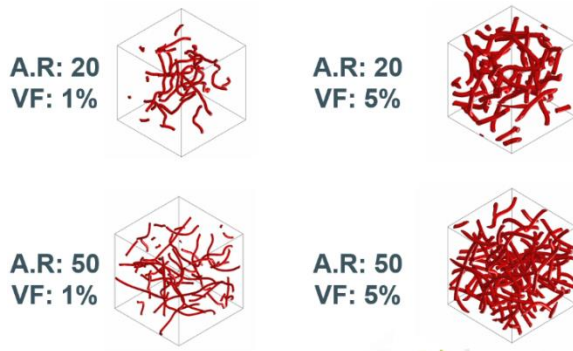
WPS
GA n° 690639

6.3 Numerical analysis of electromagnetic compatibility and conductivity



Carbon nanotubes improve the electromagnetic compatibility and the conductivity response of composite materials.

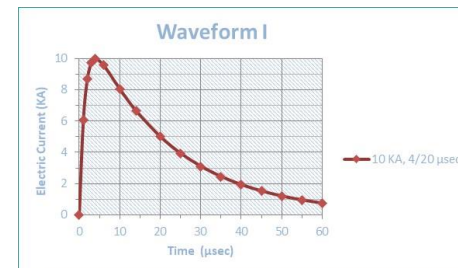
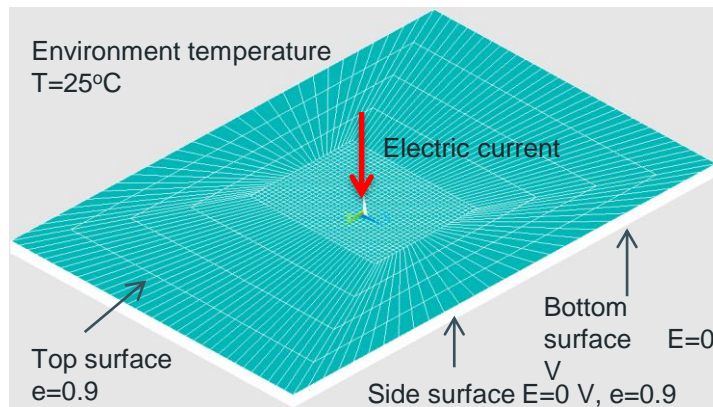
Different RVE models have been created in order to evaluate the dependence of these properties in different parameters, such as: number of CNTs embedded in the matrix, their volume fraction, their aspect ratio and their curvature.



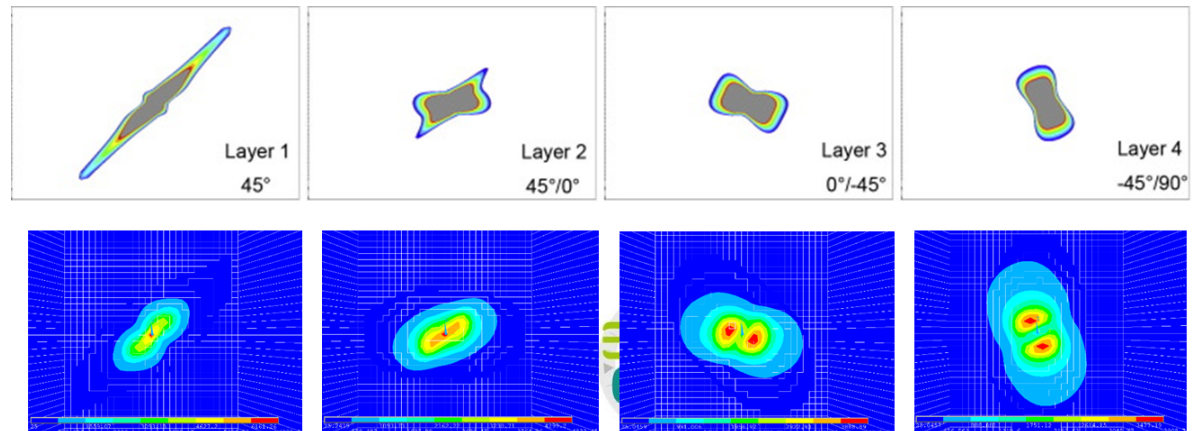
6.4 Simulation method of lighting strike protection



A new thermo-mechanical model has been developed to simulate the effect of a lighting strike on the composite.



A good agreement is obtained between numerical and experimental results



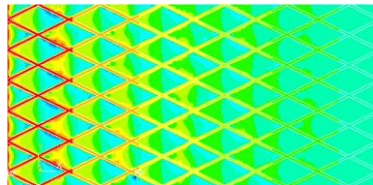
6.5 Evaluation of lighting strike damage resistance



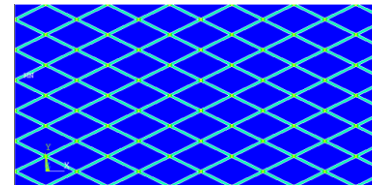
This task has developed a lightning damage prediction model for interlayer electrically modified CFRPs

Different RVEs have been developed to analyse the equivalent resistivity calculation of expanded foils.

Voltage



Current



An experimental campaign has been conducted to evaluate the effect of having expanded foils. Experimental results will be compared with numerical ones



CFRP without LSP



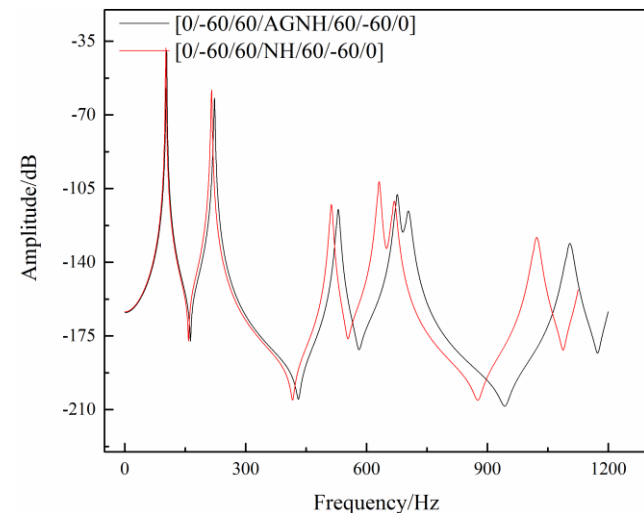
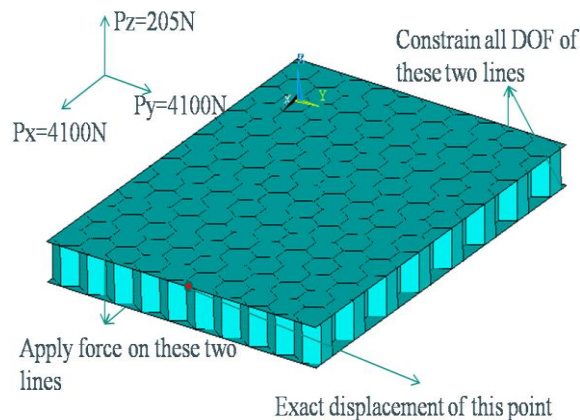
CFRP with LSP

6.6 Modeling of vibration and noise reduction



The damping properties of Nomex honeycombs (NH) and green honeycombs (AGNH) will be evaluated numerically and experimentally

Results provided by micro-models have been used as a referenced to compare the results provided by different plate formulations.

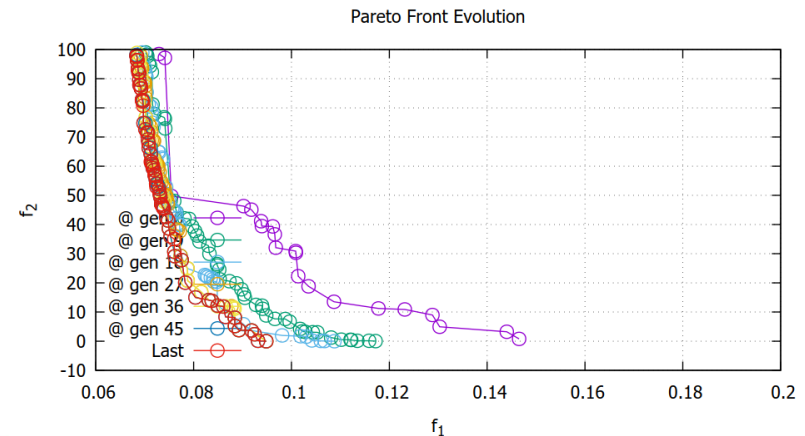
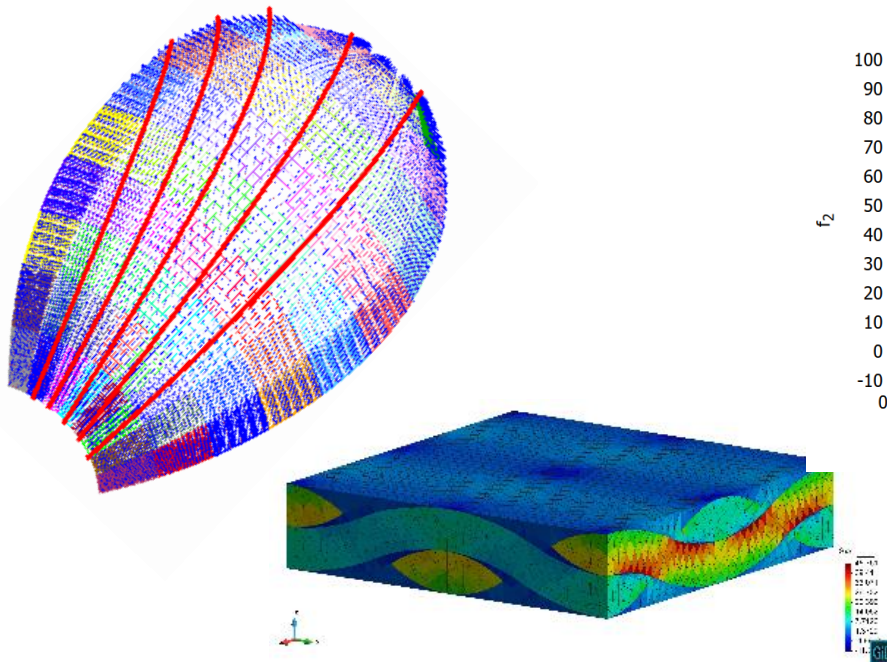


An experimental campaign has been conducted to compare the vibration response of NH and AGNH. Numerical models are under development.

6.7 Design optimization of eco-composites



The multiscale finite element code has been coupled with an optimization code. With the resulting numerical tool, it is possible to conduct a double-scale optimization, in which the performance of the macro-model is optimized by modifying the macro-model and the micro-model configuration.

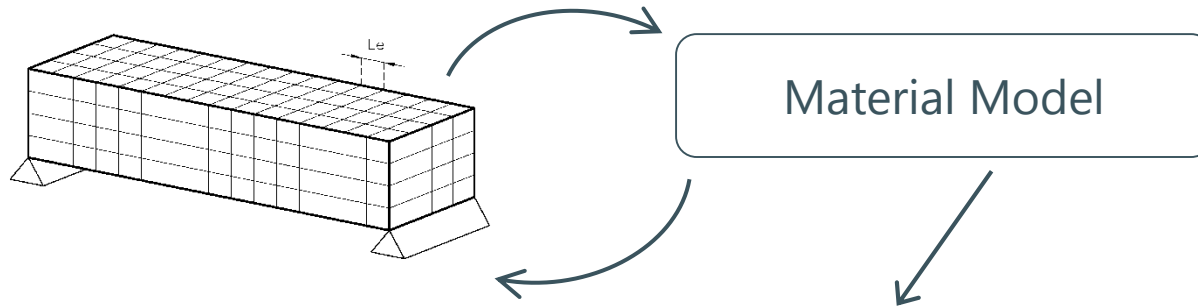


Structural analysis



A structural analysis requires of a mathematical model to describe the mechanical response of the material.

These models vary depending on the complexity of the material response:



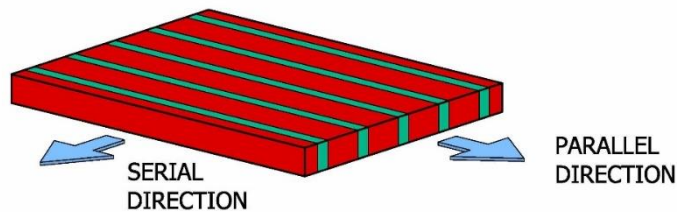
- Bulk materials → Constitutive equations
- Composites → Orthotropic approximation
Lamination theories
Homogenization procedures

Proposed procedures to characterize composites



Two different strategies are considered to characterize composites in the framework of Eco-compass project. Both of them based on homogenization procedures:

1. Phenomenological Homogenization (serial-parallel mixing theory)



Parallel direction
$$\begin{cases} {}^c\epsilon_P = {}^m\epsilon_P = {}^f\epsilon_P \\ {}^c\sigma_P = {}^mk^m\sigma_P + {}^fk^f\sigma_P \end{cases}$$

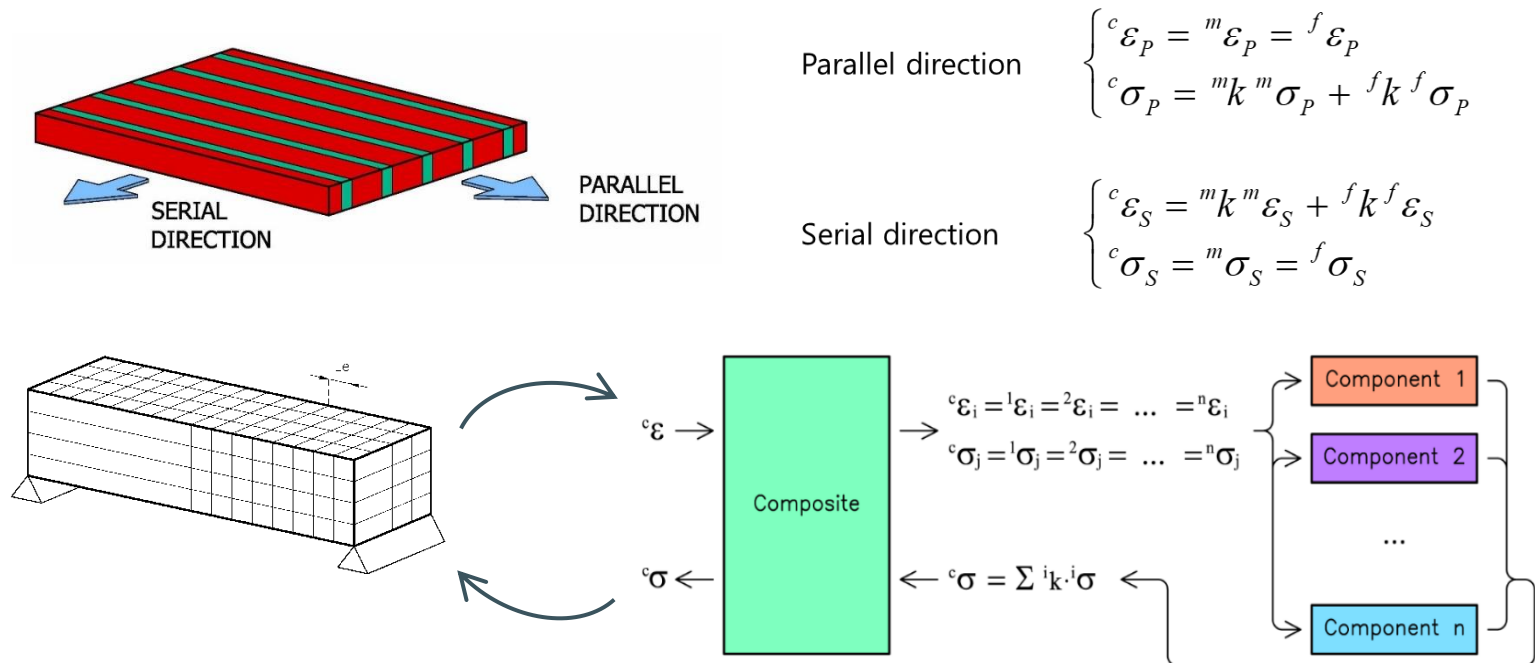
Serial direction
$$\begin{cases} {}^c\epsilon_S = {}^mk^m\epsilon_S + {}^fk^f\epsilon_S \\ {}^c\sigma_S = {}^m\sigma_S = {}^f\sigma_S \end{cases}$$

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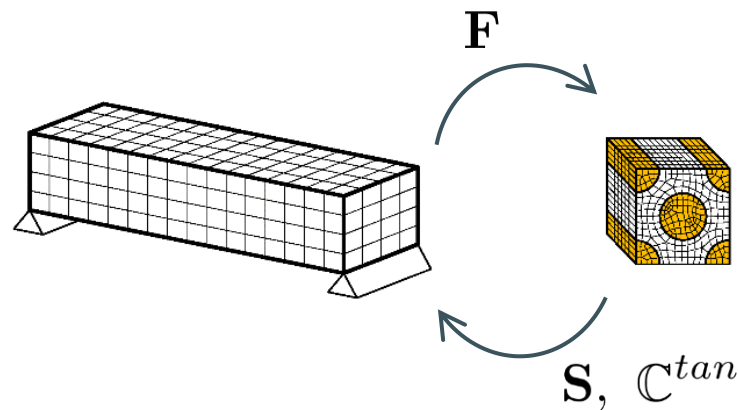


Proposed procedures to characterize composites



Two different strategies are considered to characterize composites in the framework of Eco-compass project. Both of them based on homogenization procedures:

1. Phenomenological Homogenization (serial-parallel mixing theory)
2. Full multiscale procedure



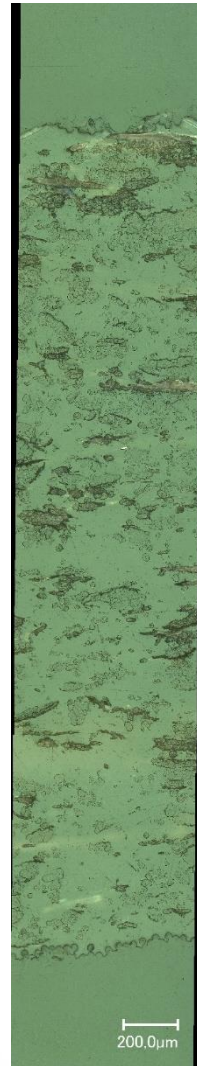
Analysis of non-woven composites



Both formulations will be applied to the simulation of eco-composites in the framework of Eco-compass project, identifying the most adequate for the different materials studied in the project.

Current work has focused on the characterization of non-woven flax composites. These will be simulated making use of both procedures in order to account for specifics such as fibre alignment and curviness.

The material has been manufactured and tested at DLR.

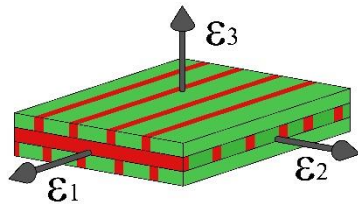


Analysis of non-woven composites



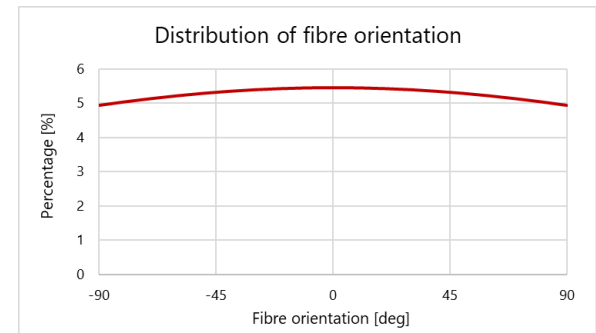
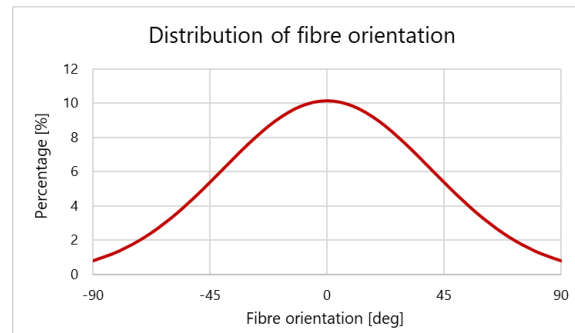
The numerical characterization of this material requires the use of both homogenization strategies presented.

Fibre orientation is considered defining several layers in an integration point.



- 1) Parallel RoM to determine strain in layers: ${}^c\boldsymbol{\varepsilon} = {}^{L_1}\boldsymbol{\varepsilon} = \dots = {}^{L_n}\boldsymbol{\varepsilon}$
- 2) SP RoM to obtain layer stresses: ${}^{L_i}\boldsymbol{\varepsilon} \rightarrow {}^{L_i}\boldsymbol{\sigma}$
- 3) Parallel RoM to obtain composite stress: ${}^c\boldsymbol{\sigma} = \sum {}^{L_i}k {}^{L_i}\boldsymbol{\sigma}$

The volumetric participation of each layer is determined by a statistical distribution based on material observation and numerical calibration.



Analysis of non-woven composites



To obtain the mechanical performance of each layer, it is not possible to use the serial-parallel mixing theory with the nominal values of the material mechanical parameters.

The iso-strain hypothesis is fulfilled
if fibres are straight



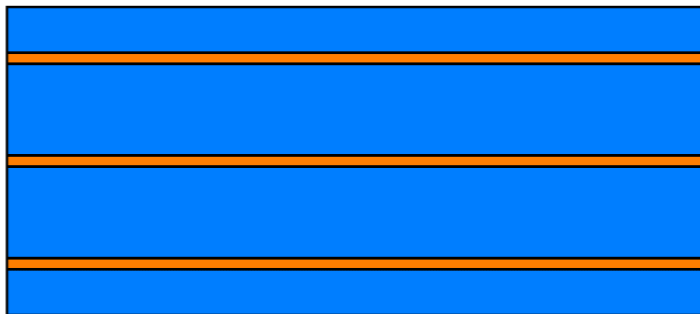
$$\left. \begin{array}{l} E_{flax} = 50 \text{ GPa} \\ E_{epoxy} = 2.7 \text{ GPa} \\ 5.9\% \text{ Fibres} \end{array} \right\} E_c = 5.5 \text{ GPa}$$

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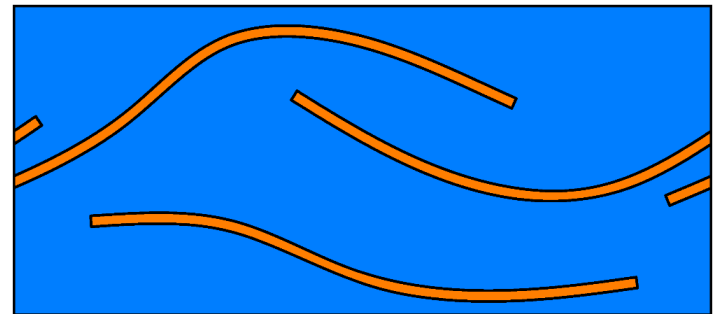
$$E_{flax} = 50 \text{ GPa}$$

$$E_{epoxy} = 2.7 \text{ GPa}$$

5.9% Fibres

$$E_c = 5.5 \text{ GPa}$$

Fibres in a non-woven composite are curved



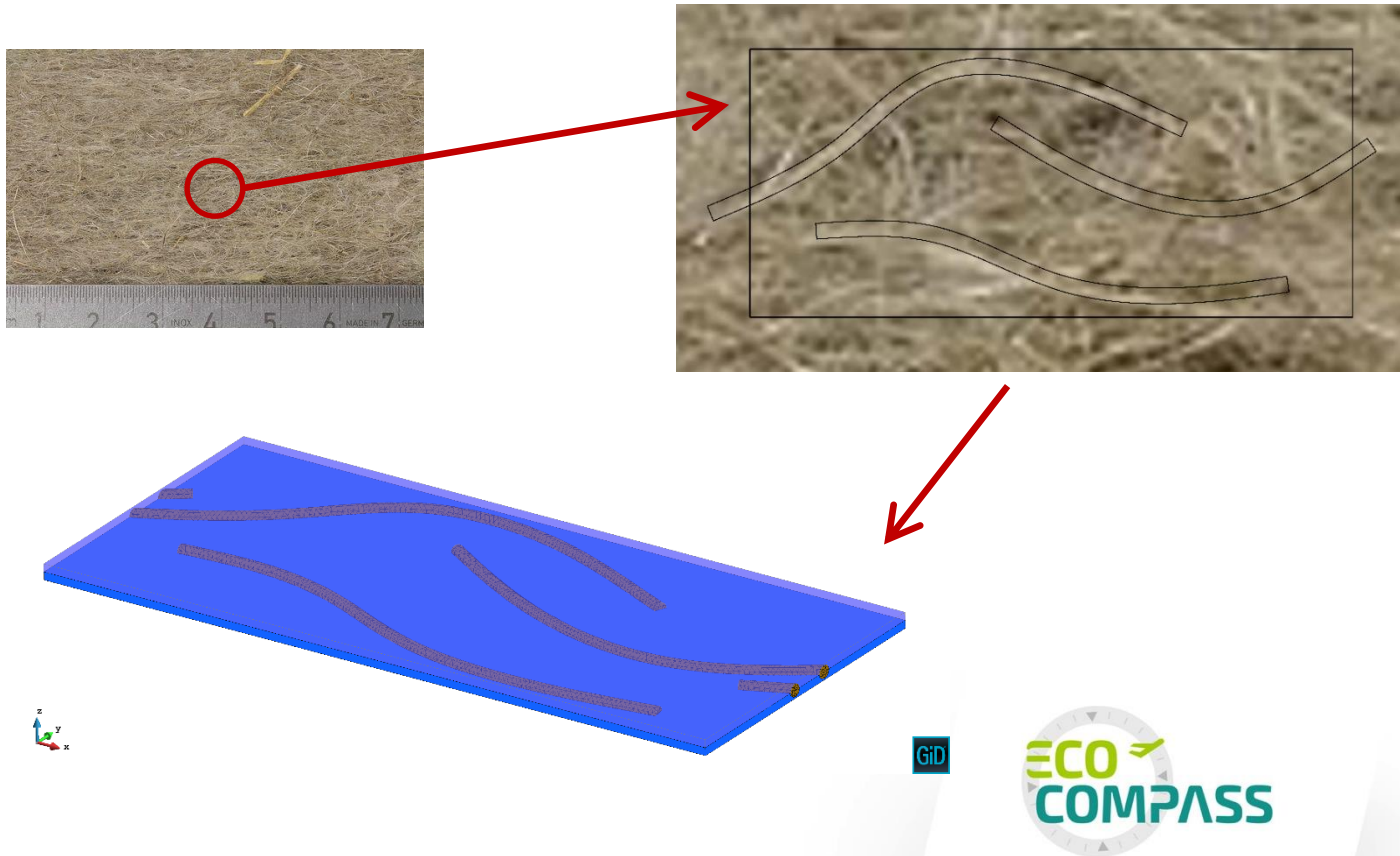
$$E_c < 5.5 \text{ GPa}$$



Analysis of non-woven composites



Fibre curviness is taken into account defining homogenized properties for fibre material. These properties are obtained from a micro-model:



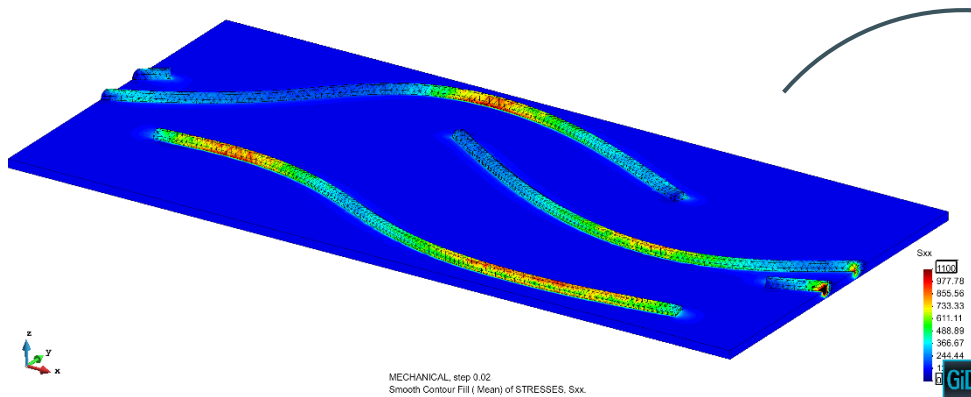
Analysis of non-woven composites



The analysis of the Representative Volume Element analysed provides an homogenized elastic stiffness of the composite, which can be used to calculate an equivalent stiffness of the curved flax fibre:

$$E_{flax} = 50 \text{ GPa}$$

$$E_{epoxy} = 2.7 \text{ GPa}$$



$$E_{composite} = 3.77 \text{ GPa}$$



$$E_{flax}^{equiv} = 20.7 \text{ GPa}$$

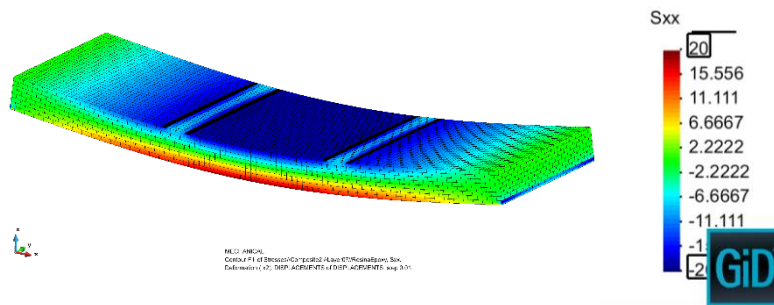


Analysis of non-woven composites

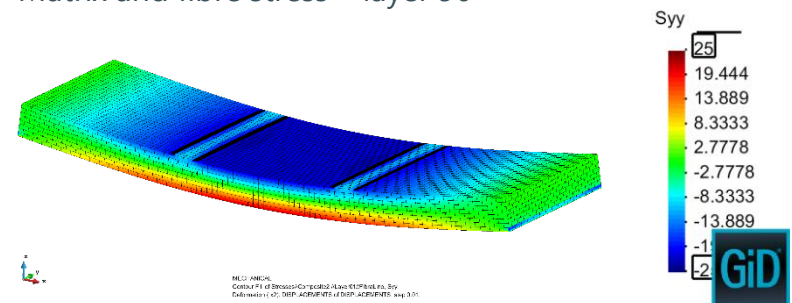


The equivalent stiffness of flax fibres is used together with the serial parallel mixing theory, assuming a random orientation of the fibres in the composite, provides a good approximation of the flax non-woven composite stiffness.

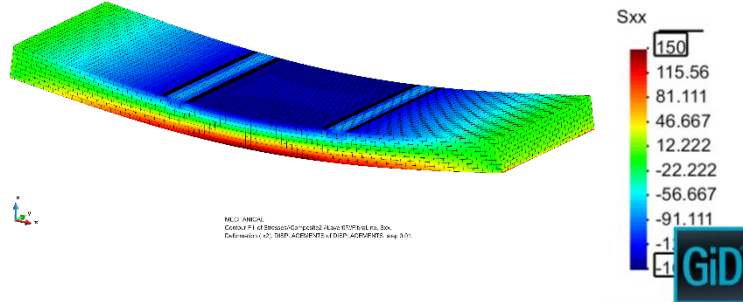
Matrix stress – layer 0°



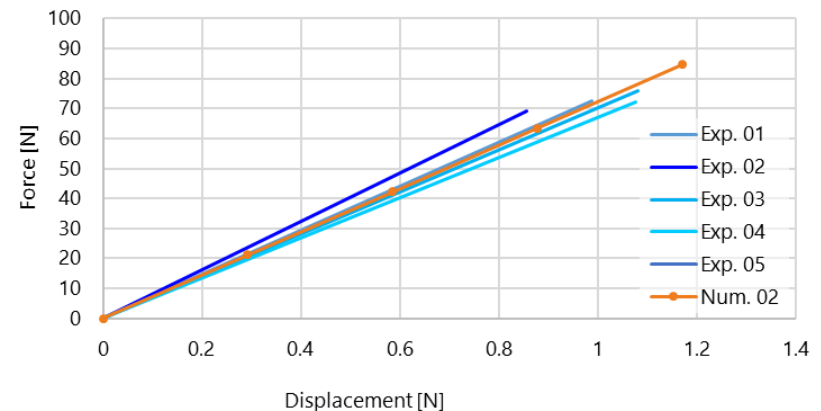
Matrix and fibre stress – layer 90°



Fibre stress – layer 0°



4PB Stiffness Non-Woven Flax Composite



Summary



- Eco-composites can be an excellent option to improve the environmental footprint of aerospace structures. To facilitate the use of these materials, it is also necessary to improve analysis techniques.
- It has been shown that homogenization procedures are an excellent tool to account for the complex behaviour of these materials.
- The Representative Volume Element developed is used as a representative composite micro-configuration. The real one does not have periodicity.
- The variability in the composite geometry should be taken into account with the development of different micro-models, which will provide average composite properties.
- Further developments will be necessary to account for other micro-mechanical phenomena (i.e. existence of fibre bundles) and for the non-linear performance of the composite.



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THANK YOU FOR YOUR ATTENTION !

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