HOMOGENIZATION PROCEDURES FOR THE ANALYSIS OF ECO-COMPOSITE FOR AERONAUTICAL STRUCTURES

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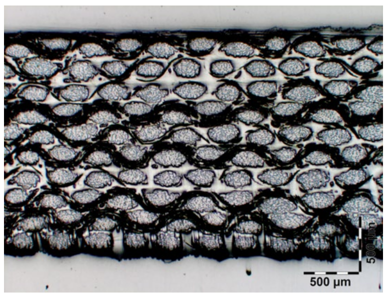
Introduction

In order to reduce the environmental footprint of composites in aeronautical structures, ECO-COMPASS project seeks improving the knowledge of eco-composites, to facilitate their use in aeronautical structures (interiors and secondary structures)

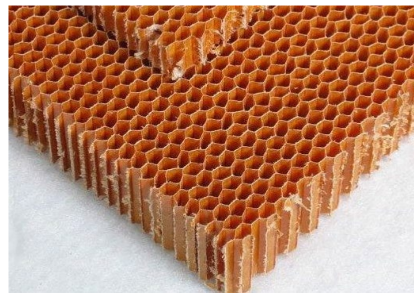
To achieve this goal, it is necessary a good knowledge of the material performance, as well as good analysis tools

Introduction

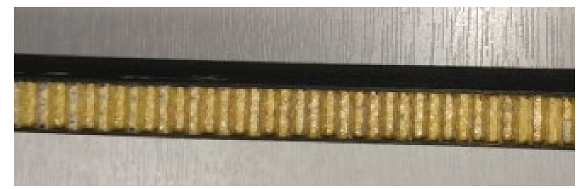
The internal micro-structure of eco-composites makes difficult their simulation using standard procedures



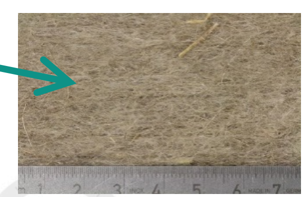
Ramie reinforced rosin woven composite



Paper honeycomb



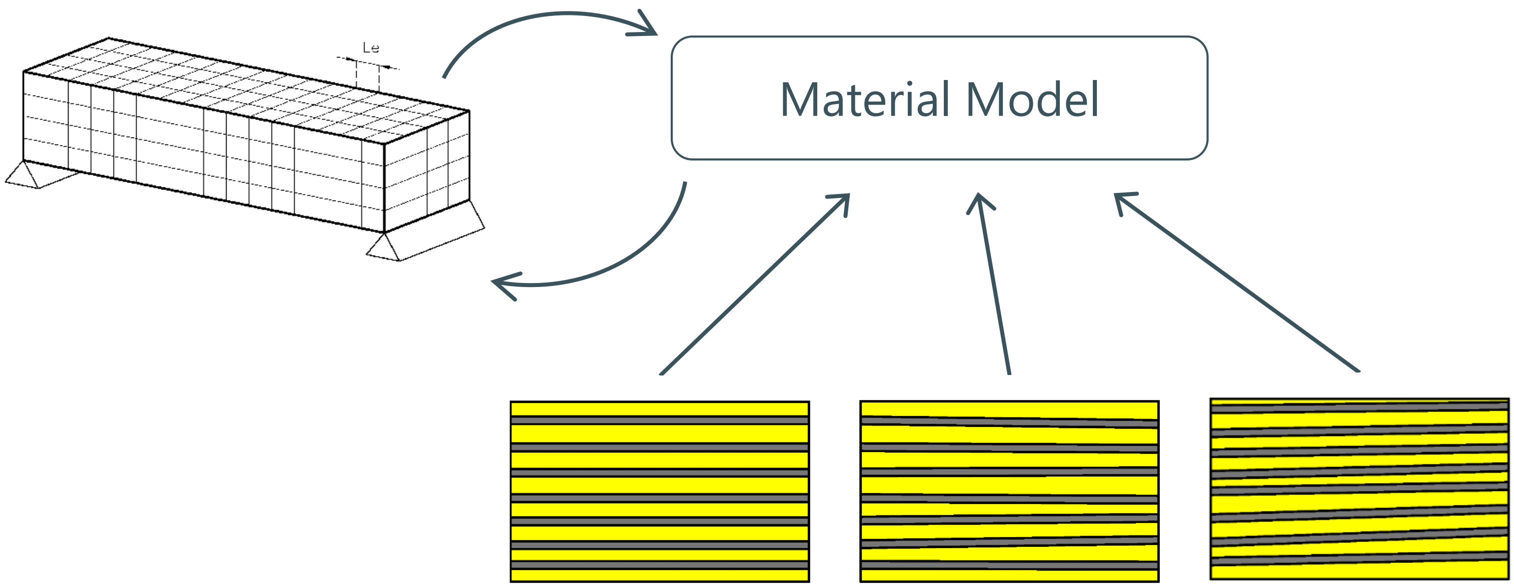
Recycled carbon and flax non-woven composite



Homogenization methods

This work proposes the use of HOMOGENIZATION procedures to characterize eco-composites.

An homogenization procedure is based on the assumption that exist a set of equations or a representative element that can provide a response equivalent to the one provided by the actual material.



Homogenization methods

Two different strategies will be used:

1. Serial-parallel mixing theory
2. Numerical multiscale homogenization

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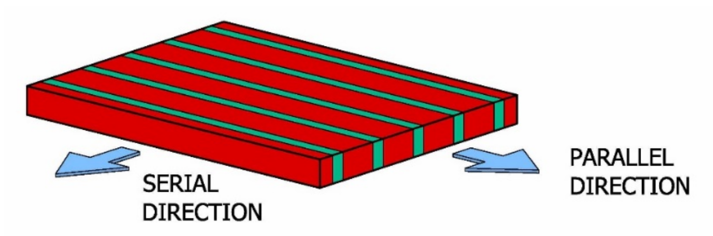

Parallel direction
$$\begin{cases} {}^{c}\varepsilon_P = {}^{m}\varepsilon_P = {}^{f}\varepsilon_P \\ {}^{c}\sigma_P = {}^{m}k\,{}^{m}\sigma_P + {}^{f}k\,{}^{f}\sigma_P \end{cases}$$

Serial direction
$$\begin{cases} {}^{c}\varepsilon_S = {}^{m}k\,{}^{m}\varepsilon_S + {}^{f}k\,{}^{f}\varepsilon_S \\ {}^{c}\sigma_S = {}^{m}\sigma_S = {}^{f}\sigma_S \end{cases}$$

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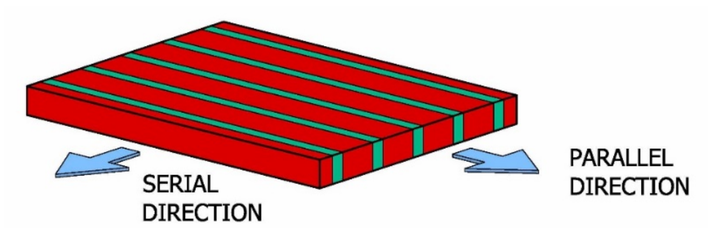

Parallel direction

$$\begin{cases} {}^c\varepsilon_P = {}^m\varepsilon_P = {}^f\varepsilon_P \\ {}^c\sigma_P = {}^mk\,{}^m\sigma_P + {}^fk\,{}^f\sigma_P \end{cases}$$

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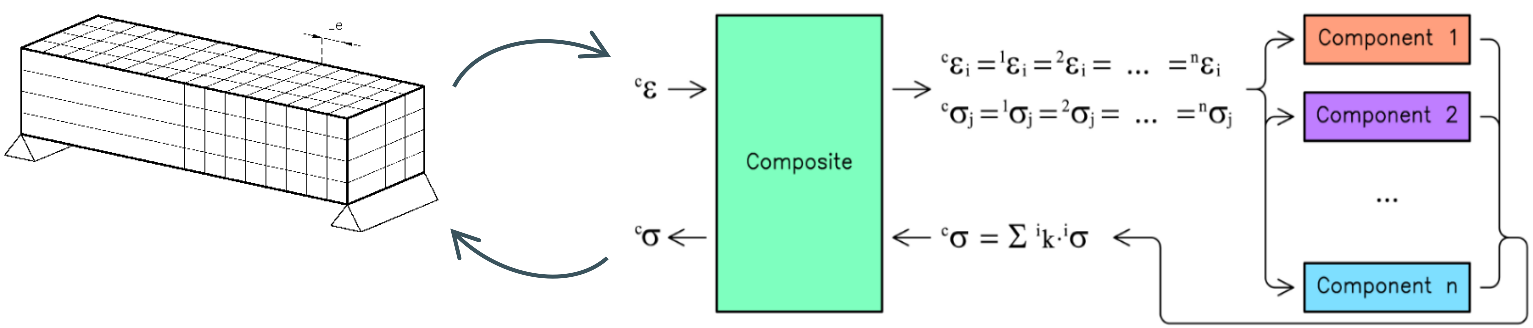

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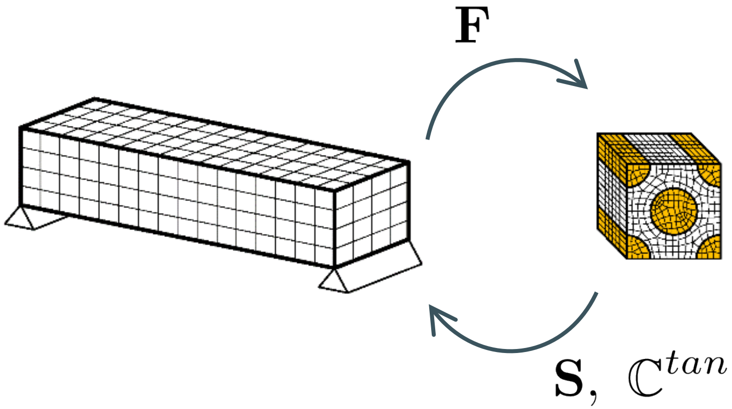


Homogenization methods

Two different strategies will be used:

1. Serial-parallel mixing theory
   - Very good computational performance in linear and non-linear range
   - Capable of capturing failure phenomena such as matrix cracking, fibre failure, delamination, etc.
   - No so good accuracy in case of complex interactions between components
2. Numerical multiscale homogenization
   - Great accuracy in material characterization
   - Very high computational cost. Unaffordable in the non-linear range

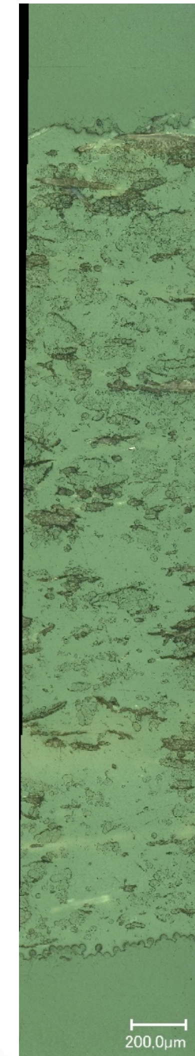
They can be combined, taking advantage their respective strengths.

Analysis of non-woven composites

Both formulations have been applied to the simulation non-woven flax composites, in linear and non-linear range.

The material has been manufactured and tested at DLR.

The procedure followed has allowed taking into account several material parameters such as fibre orientation, curviness, matrix cracking and fibre failure.



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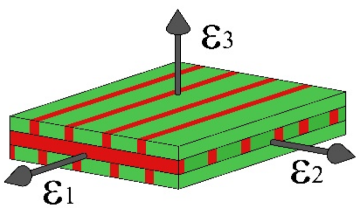
Analysis of non-woven composites

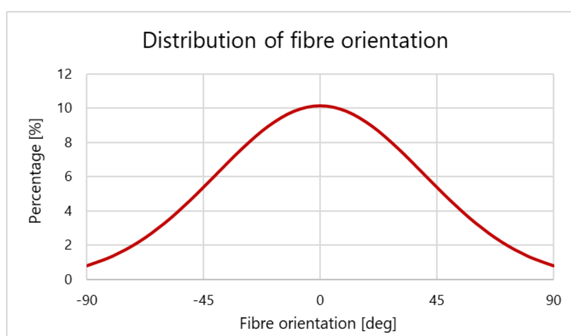
Characterizing the composite with a full multiscale procedure would be computationally unaffordable, due to the high level of heterogeneity. For this reason, **fibre orientation** is considered defining several layers in an integration point.

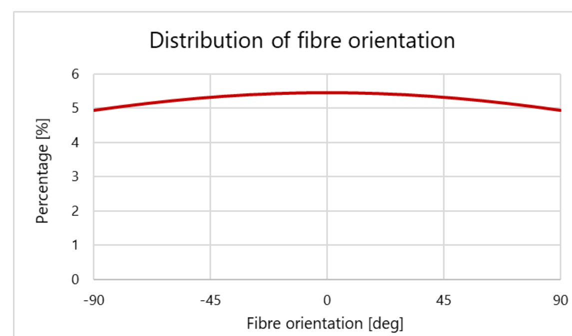


1) Parallel RoM to determine strain in layers: $\varepsilon_c = \varepsilon_{L1} = \cdots = \varepsilon_{Ln}$

2) SP RoM to obtain layer stresses: $\begin{cases} \varepsilon_{Li} = \varepsilon_{Fi} = \varepsilon_{Mi} \\ \sigma_{Li} = k_{Fi} \cdot \varepsilon_{Fi} + k_{Mi} \cdot \varepsilon_{Mi} \end{cases}$

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

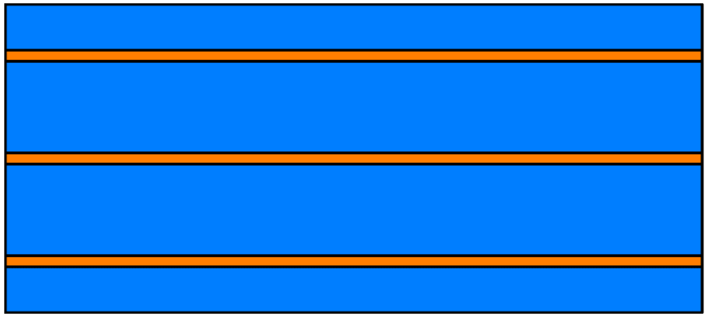




Analysis of non-woven composites

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



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

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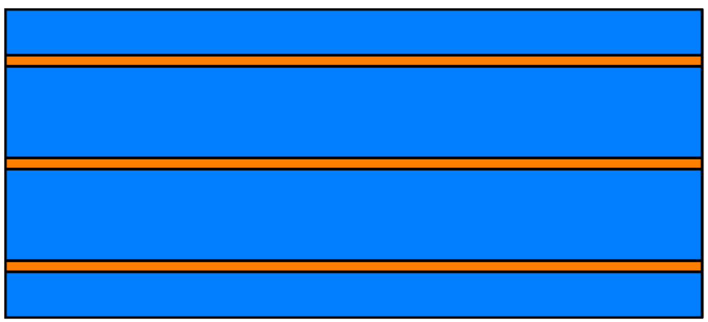


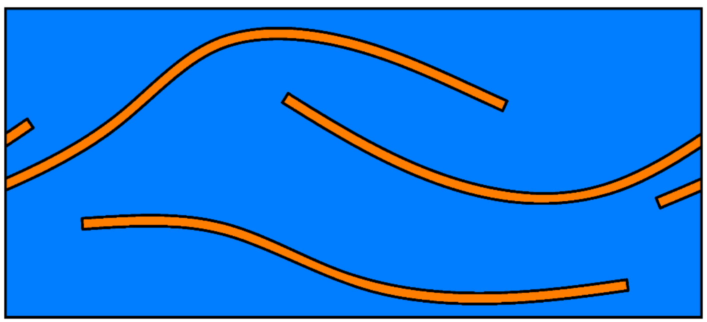
$E_{flax} = 50\ GPa$

$E_{epoxy} = 2.7\ GPa$

5.9% Fibres

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

Fibres in a non-woven composite are curved



$E_c < 5.5 GPa$

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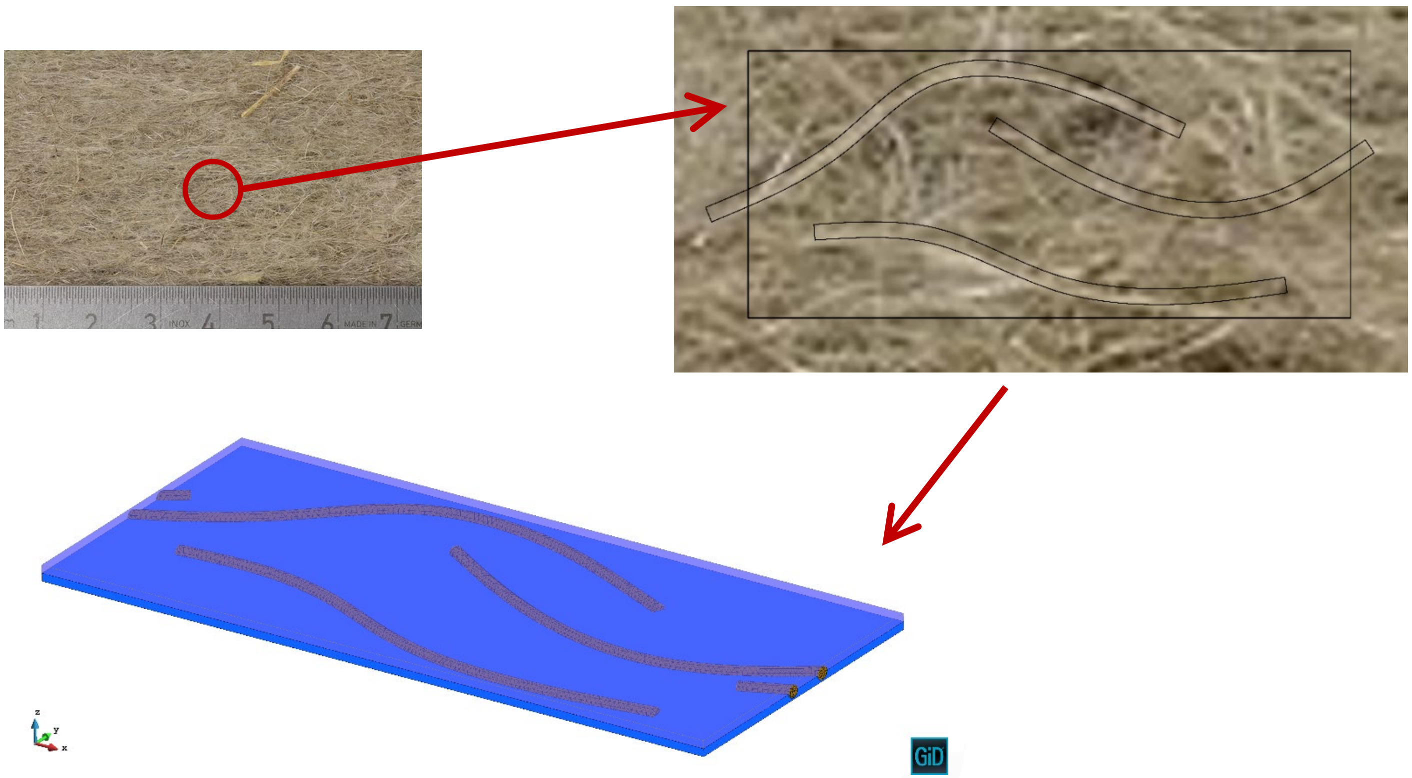
Analysis of non-woven composites

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

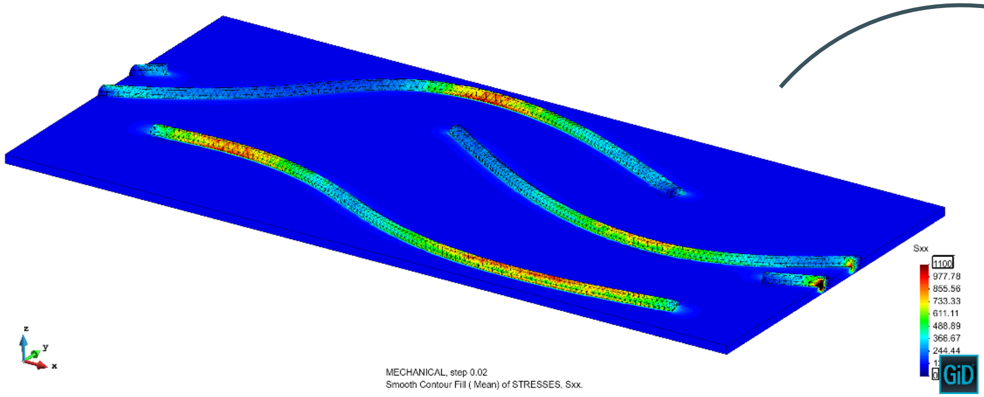


Analysis of non-woven composites

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:

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

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



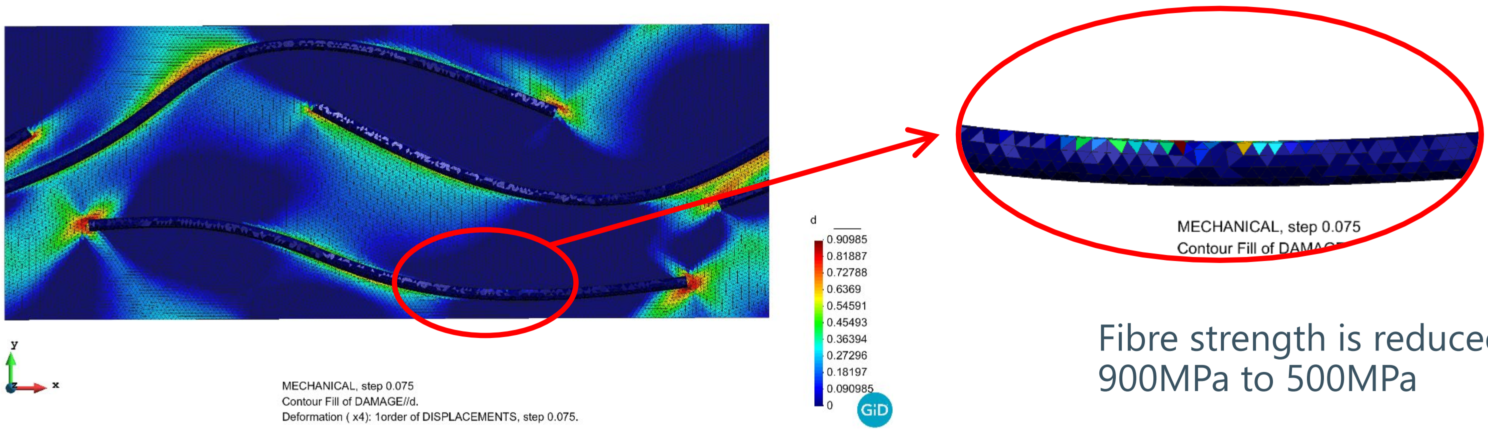
$$E_{composite} = 3.77 GPa$$

$$\downarrow$$

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

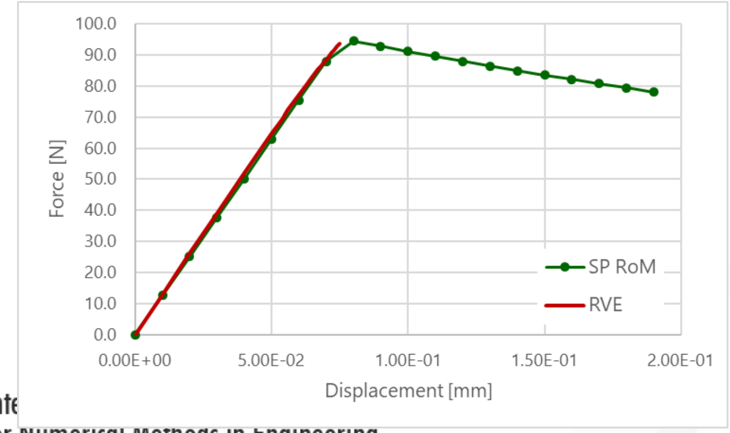
Analysis of non-woven composites

The micro-model also provides the stress value associated to fibre failure, which allows redefining the maximum fibre stress:



Fibre strength is reduced from 900MPa to 500MPa

Response comparison RVE vs SP RoM



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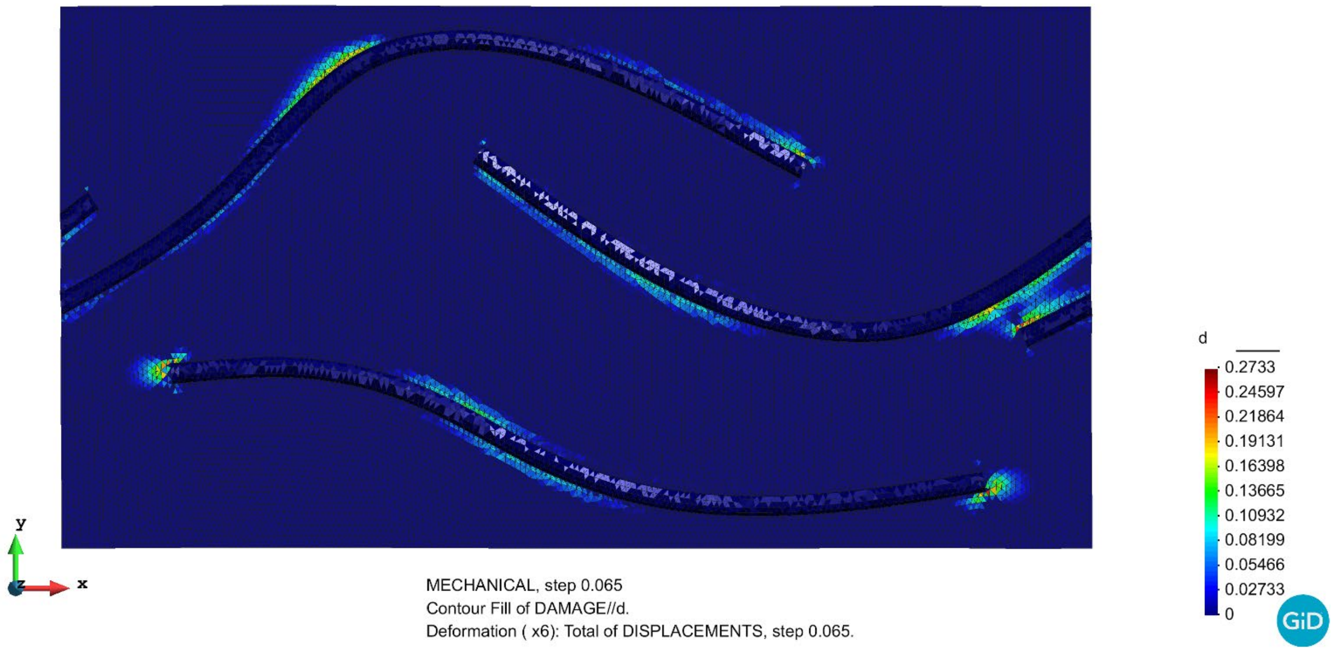
Analysis of non-woven composites

Applying a transversal load to the micro-model, it shows that failure is produced at the interface between fibre and matrix:

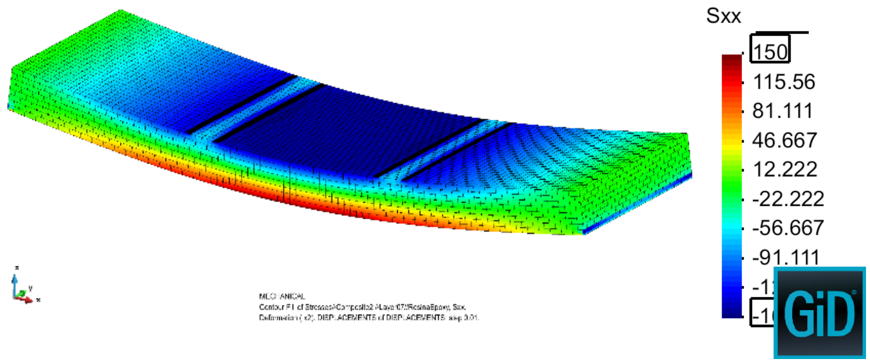


Several studies show that this strength is in the order of 20-30 MPa.

A value of 20 MPa is defined for matrix transversal strength.

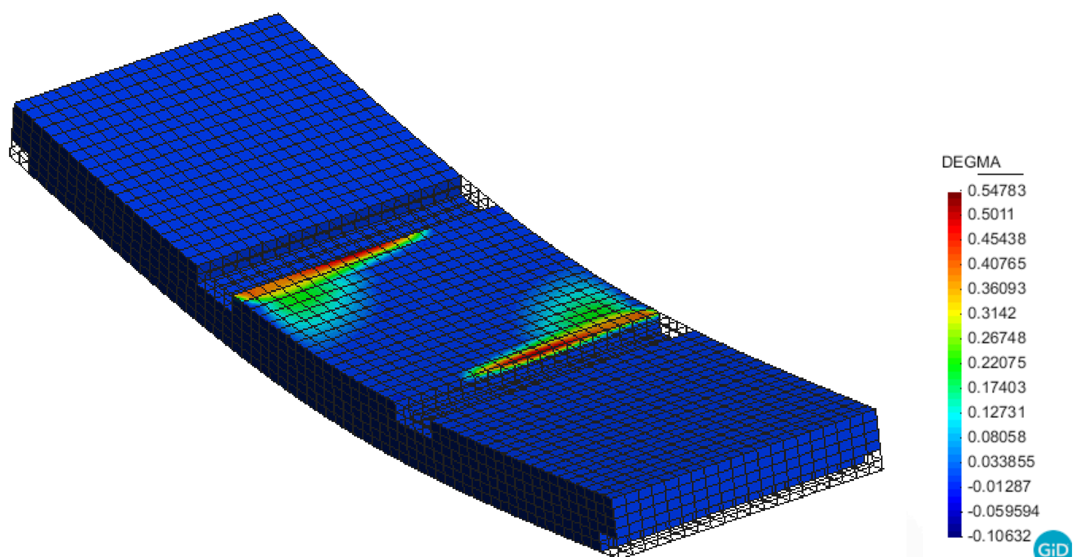
Analysis of non-woven composites

The formulation defined is applied to a 4PB test model.



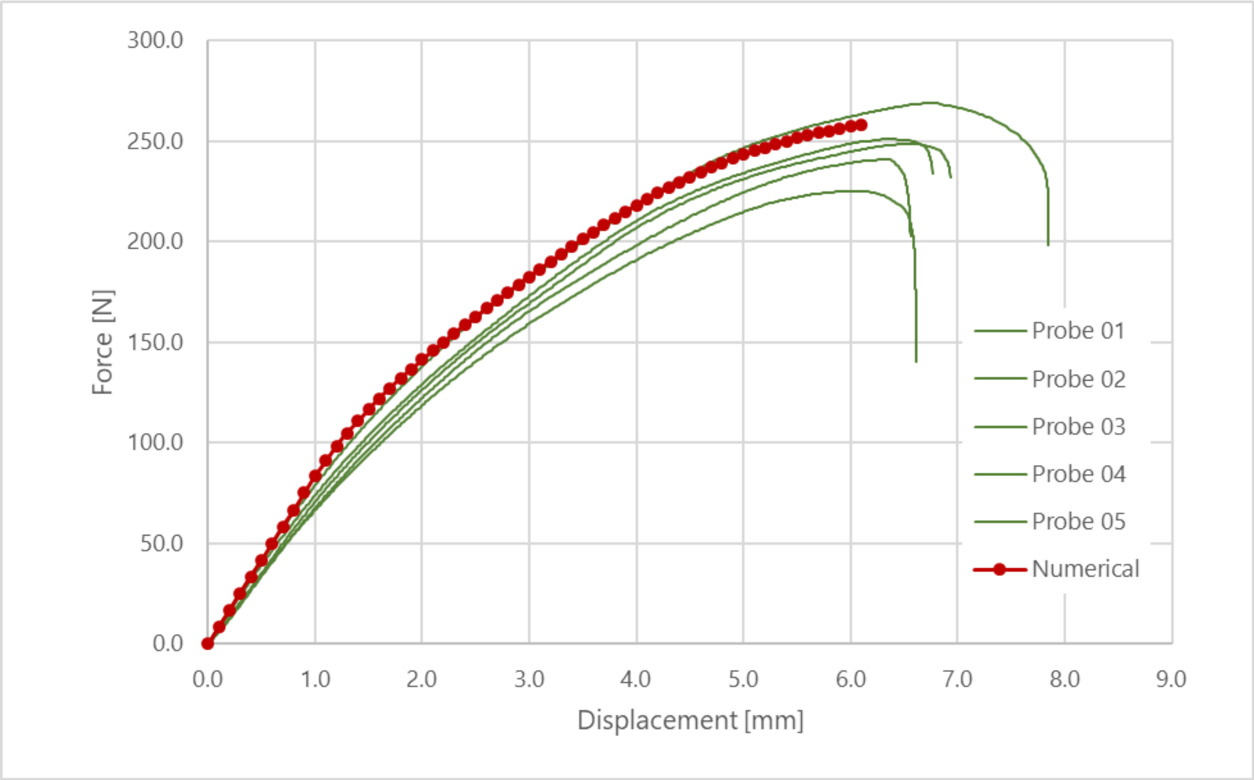
Stress in fibres at 0º at the initial steps of the simulation

Damage in the first fibres that fail (fibres at 30º)



Analysis of non-woven composites

The final response obtained from the numerical simulation has a very good agreement with the results provided by the experimental campaign:



Concluding remarks

- 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.
- Different homogenization procedures can be combined to improve the computational cost and accuracy of the numerical analysis.
- The analysis performed has shown the capabilities of the formulation. This analysis can be improved taking into account other factors such as the variability in fibre misalignments, variations in fibre diameter, existence of fibre bundles, etc.

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