ECO-COMPOSITES IN AERONAUTICAL STRUCTURES. POSSIBILITIES AND CHALLENGES

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STS5: New Aeronautical materials

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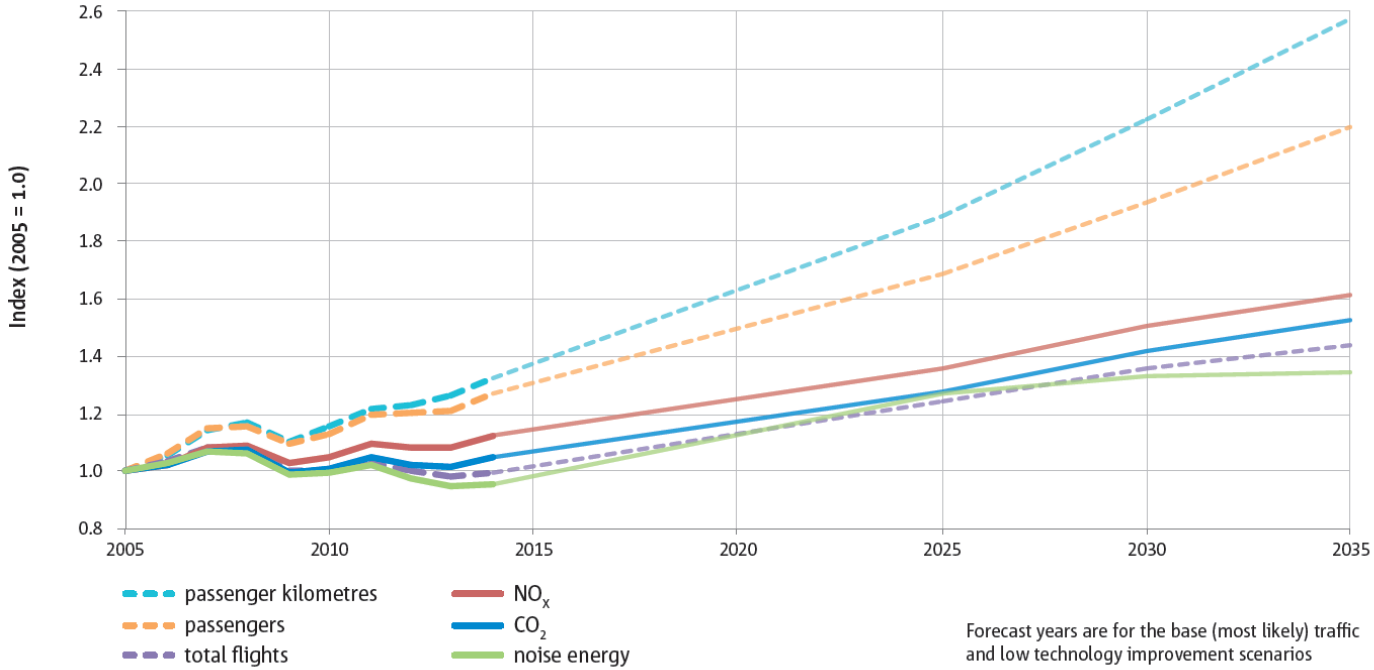
Environmental impact of aviation

Growing market for aviation [1]:

- Air traffic more than doubles in the next 20 years
- 4.5 % growth of passenger traffic p.a. until 2035
- 32.425 passenger aircraft required over the next 20 years

Noise and emission forecast [2]



[1] Airbus Global Market Forecast 2016-2035

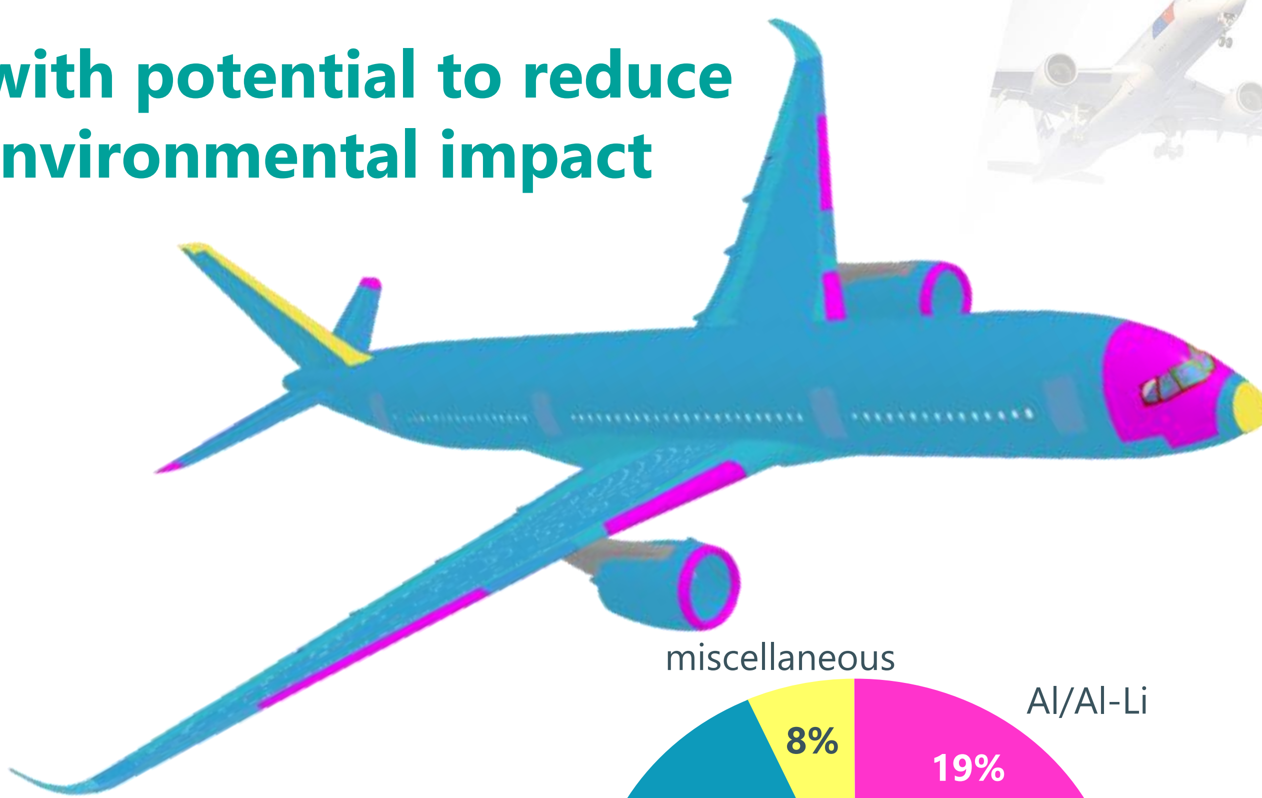
[2] European Aviation Environmental Report 2016

Measures with potential to reduce aviations environmental impact

- Aircraft configuration
- Propulsion / alternative fuels
- Aerodynamics
- Trajectory / flight path
- Energy management
- …
- **Lightweight design**
  - **Fibre Reinforced Composites**
    - **CFRP, GFRP, GLARE, …**

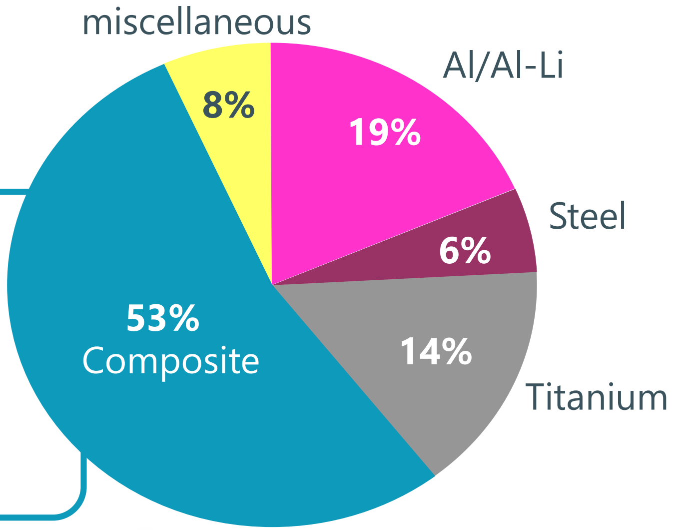
ECO COMPASS

Measures with potential to reduce aviations environmental impact



CFRP:

- Wings
- Centre wing box and keel beam
- Tall cone
- Skin panels
- Frames, stringers and doublers
- Doors (passenger and cargo)



Measures with potential to reduce aviations environmental impact

- Aircraft configuration
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- **Lightweight design**
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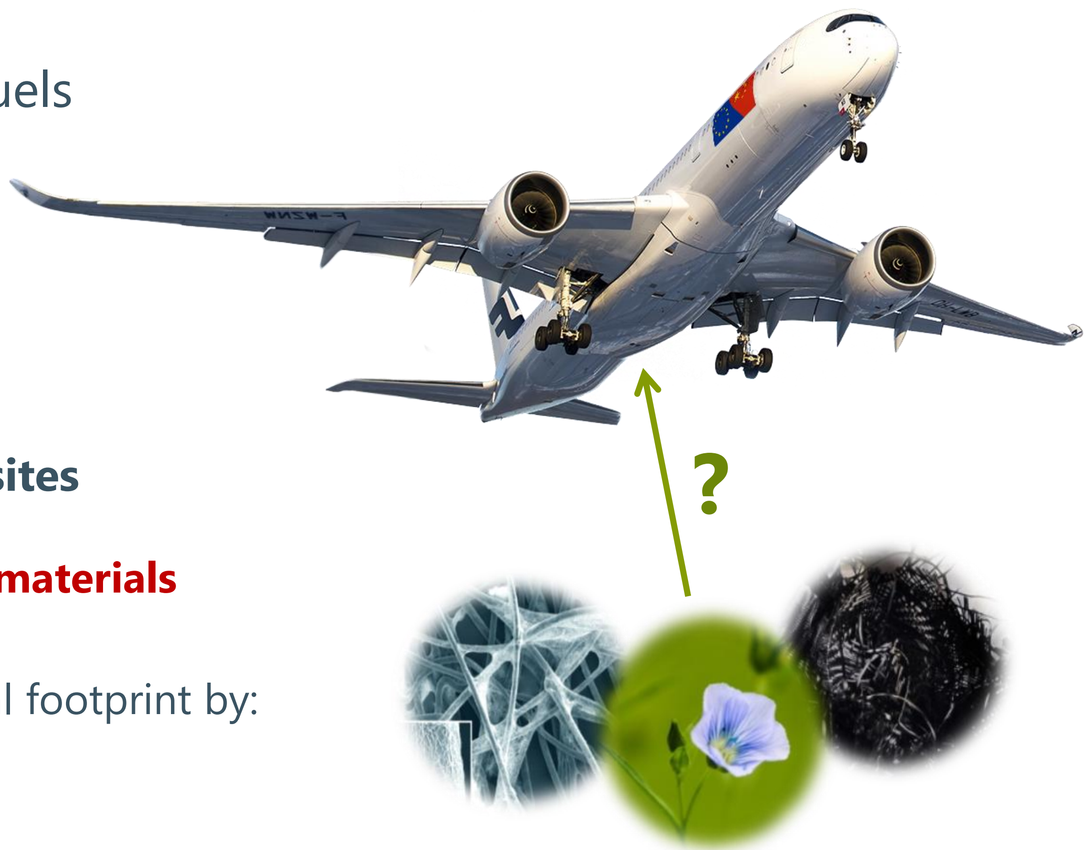
  → All synthetic / man-made materials

- Further reduction of ecological footprint by:

  → Bio-based materials?

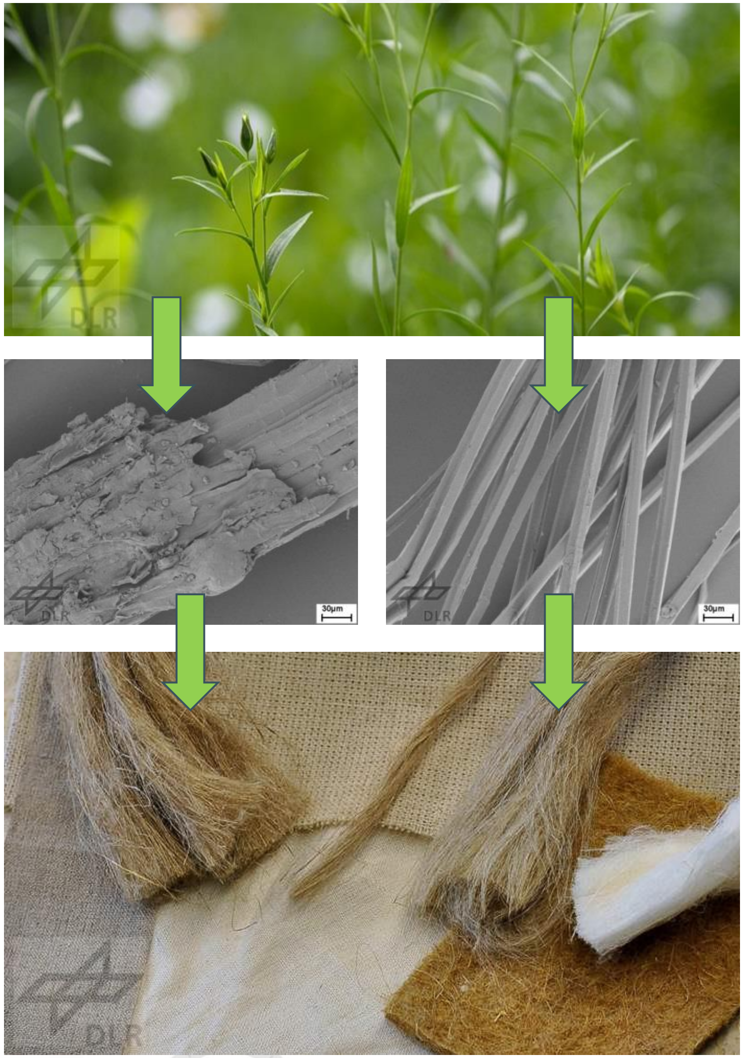
  → Recycled materials?

  → Function Integration?



Bio-composites: challenges

- Fulfillment of demanding requirements in aviation
  - Mechanical properties
  - Fire properties
    - Heat Release
    - Flammability
    - Smoke Density & Toxicity
    - Flame penetration resistance (Cargo)
- Variable fibre properties
- Durability (Resistance to climate, UV, cleaning agents)
- Modifications and their effects on environmental impacts
- Prediction of material behaviour by modelling and simulation

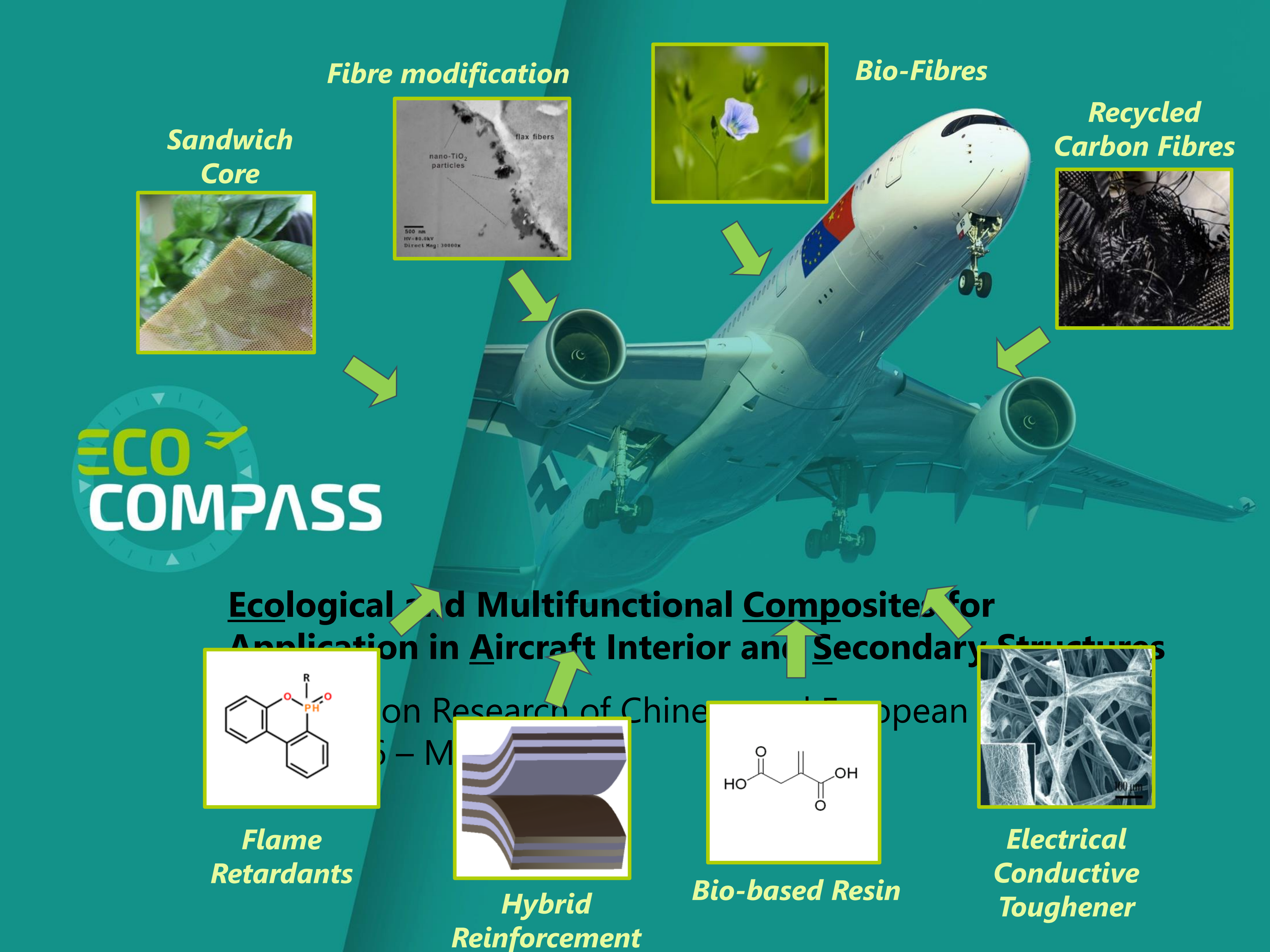


Fibre properties

Fibre type		Density	Price	Young's modulus	Tensile Strength	Elongation	Length	Diameter	Moisture content	Cellulose content
		[g/cm³]	[USD/kg]	[GPa]	[MPa]	[%]	[mm]	[µm]	[wt-%]	[wt-%]
Synthetic	Carbon HS	1.7-1.8	66-110	200-250	3500-4900	1.4-2.1	-	5-10	-	-
	Carbon HM	1.9	200	350-550	2700-4400	0.7-1.2	-	5-10	-	-
	Carbon IM	1.8	100	250-350	5400-6300	1.9-2.2	-	5-10	-	-
	Aramid meta	1.38	15-33	12-20	700-850	15-30	-	10-20	< 8	-
	Aramid para	1.44	n/a	58-124	2500-4100	2.4-3.3	-	~12	< 8	-
	S/R-glass	2.46-2.49	20-37	85-87	3000-3600	4.0-5.0	-	9-11	-	-
	E-glass	**2.55-2.6**	**1.63-3.26**	**72-85**	**1900-2050**	**1.8-4.5**	-	**5-24**	-	-
Fruit	Coir	1.15-1.22	0.25-0.5	4-6	135-240	15-35	20-150	10-460	8	32-43.8
	Cotton	1.52-1.56	2.1-4.2	7-12	350-800	5-12	10-60	10-45	7.85-8.5	82.7-90
Bast	**Flax**	**1.42-1.52**	**2.1-4.2**	**75-90**	**750-940**	**1.2-1.8**	**5-900**	**12-600**	**8-12**	**62-72**
	Hemp	1.47-1.52	1.0-2.1	55-70	550-920	1.4-1.7	5-55	25-500	6.2-12	68-74.4
	Jute	1.44-1.52	0.35-1.5	35-60	400-860	1.7-2.0	1.5-120	20-200	12.5-13.7	59-71.5
	Ramie	**1.45-1.55**	**1.5-2.5**	**38-44**	**500-680**	**2.0-2.2**	**900-1200**	**20-80**	**7.5-17**	**68.6-85**
Leaf	Sisal	1.4-1.45	0.6-0.7	10-25	550-790	4.0-6.0	900	8-200	10-22	60-78
Grass	Bamboo	0.6-1.1	0.5	11-32	140-800	2.5-3.7	1.5-4	25-40	-	26-65

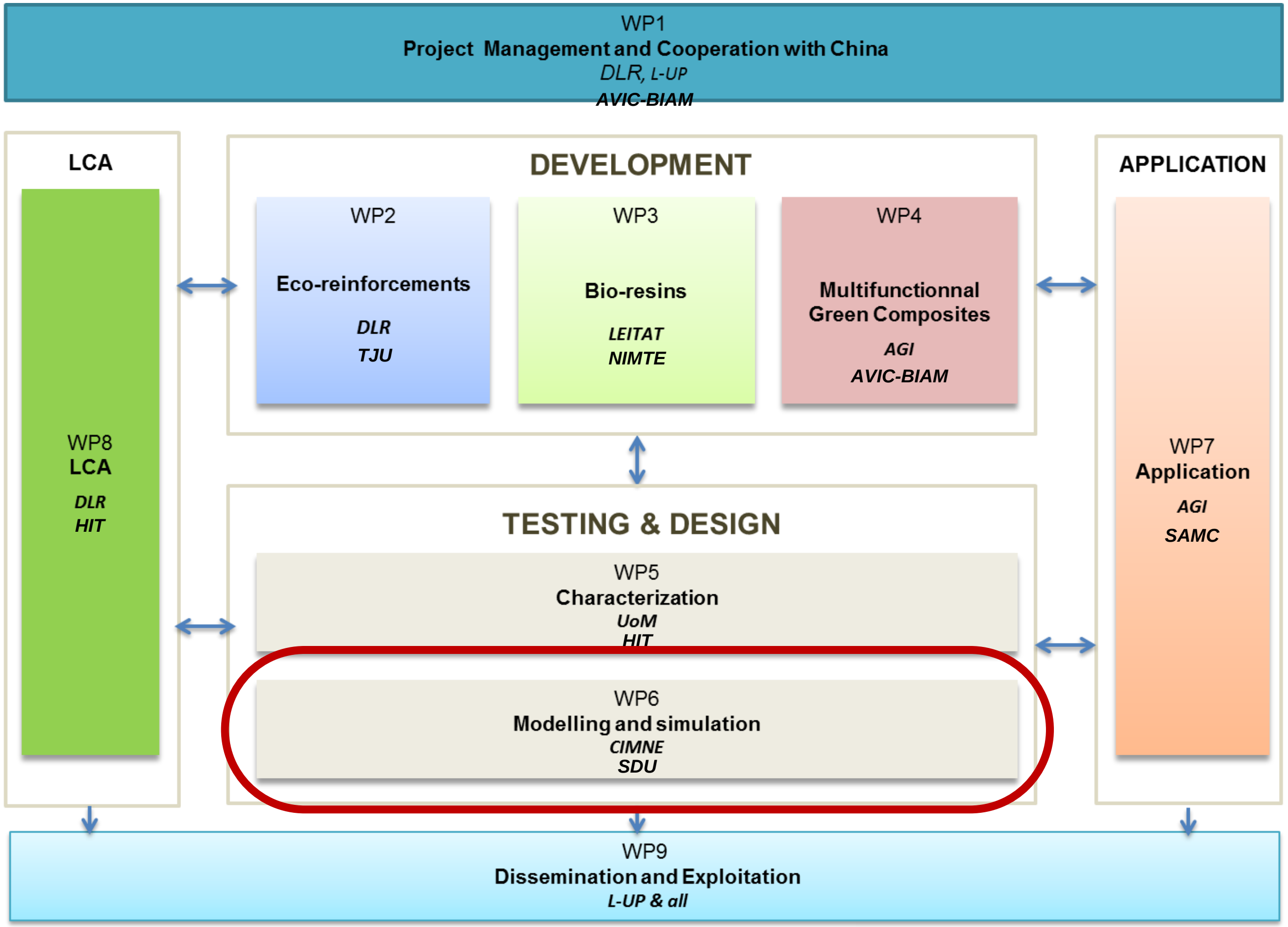
Valid for interior and secondary structures, where the strength requirements are lower

Based on [Dicker et al. / Composites: Part A 56 (2014) 280-289]



Fibre modification
Bio-Fibres
Sandwich
Core
Recycled
Carbon Fibres
flax fibers
nano-TiO2
particles
ECO
COMPASS
Ecological
Multifunctional Composites
Aircraft Interior
Secondary
Flame
Retardants
Hybrid
Reinforcement
Bio-based Resin
Electrical
Conductive
Toughener

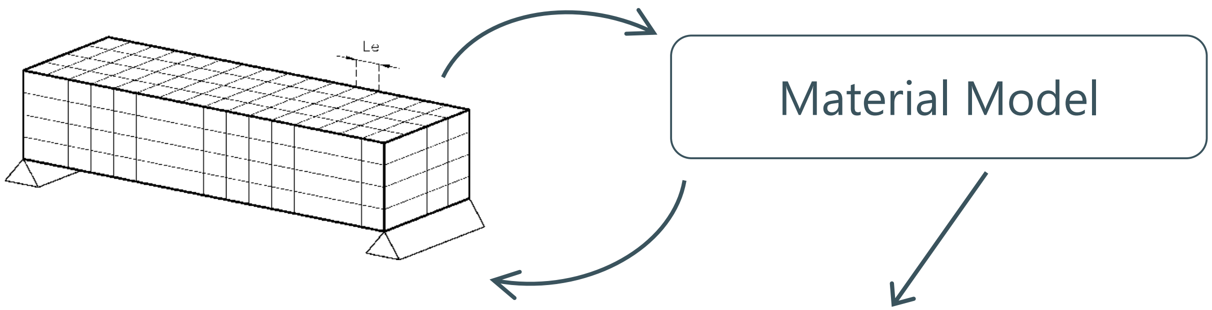
Eco-compass project



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:

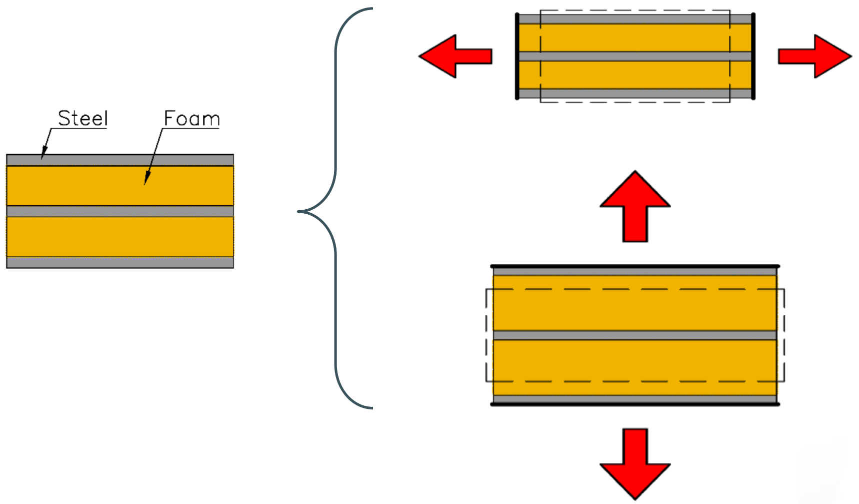


- Bulk materials → Constitutive equations
- Composites → Orthotropic approximation
  Lamination theories
  Homogenization procedures

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 behavior

$\varepsilon_1 = \varepsilon_2 = \ldots = \varepsilon_n$

Serial behavior

$\sigma_1 = \sigma_2 = \ldots = \sigma_n$

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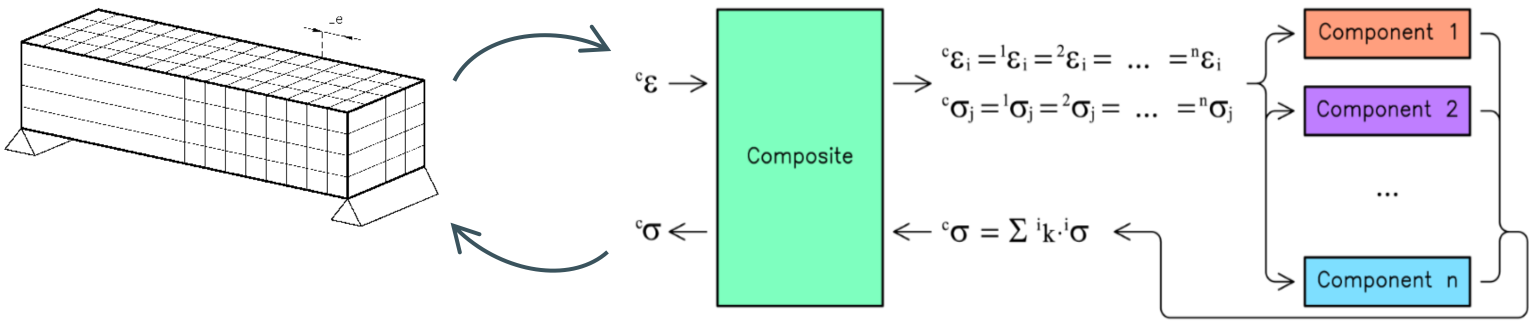
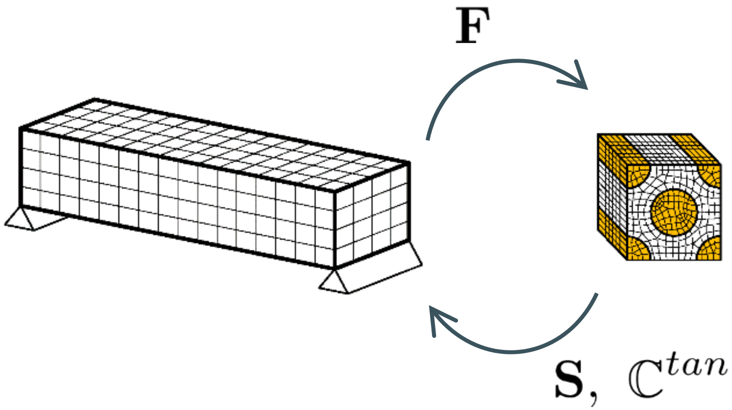


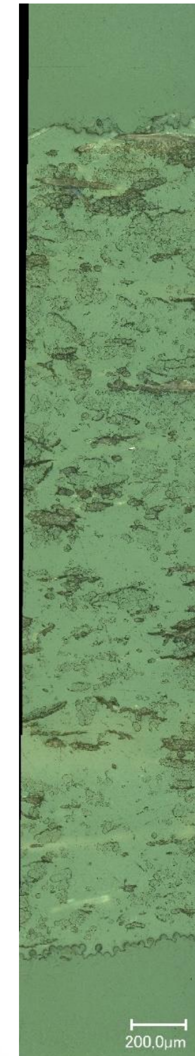
Proposed procedures to characterize composites

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



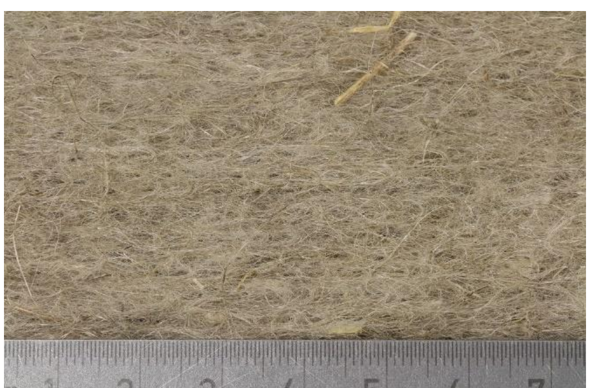
Analysis of non-woven composites



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.

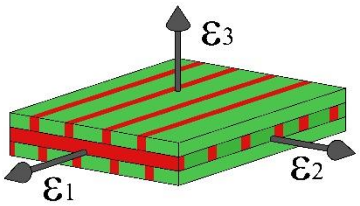
Current work has focused on the characterization of non-woven flax composites. These will be simulated making use of both procedures in order to account for specifies such as fibre alignment and curviness.

The material has been manufactured and tested at DLR.



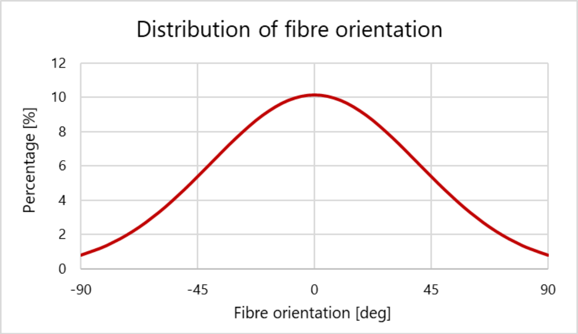
Analysis of non-woven composites

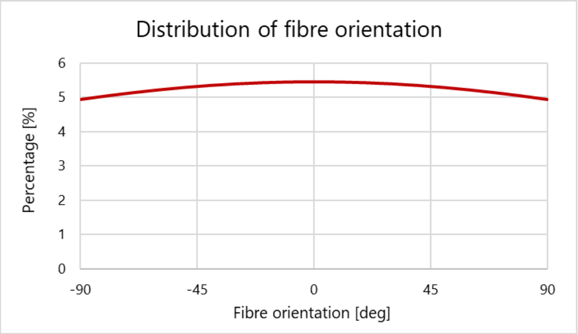
Fibre orientation will be considered defining several layers in an integration point.



1) Parallel RoM to determine strain in layers: $^{C}\varepsilon = {}^{L1}\varepsilon = \dots = {}^{Ln}\varepsilon$
2) SP RoM to obtain layer stresses: $^{Li}\varepsilon \longrightarrow {}^{Li}\sigma$
3) Parallel RoM to obtain composite stress: $^{C}\sigma = \sum {}^{Li}k \, {}^{Li}\sigma$

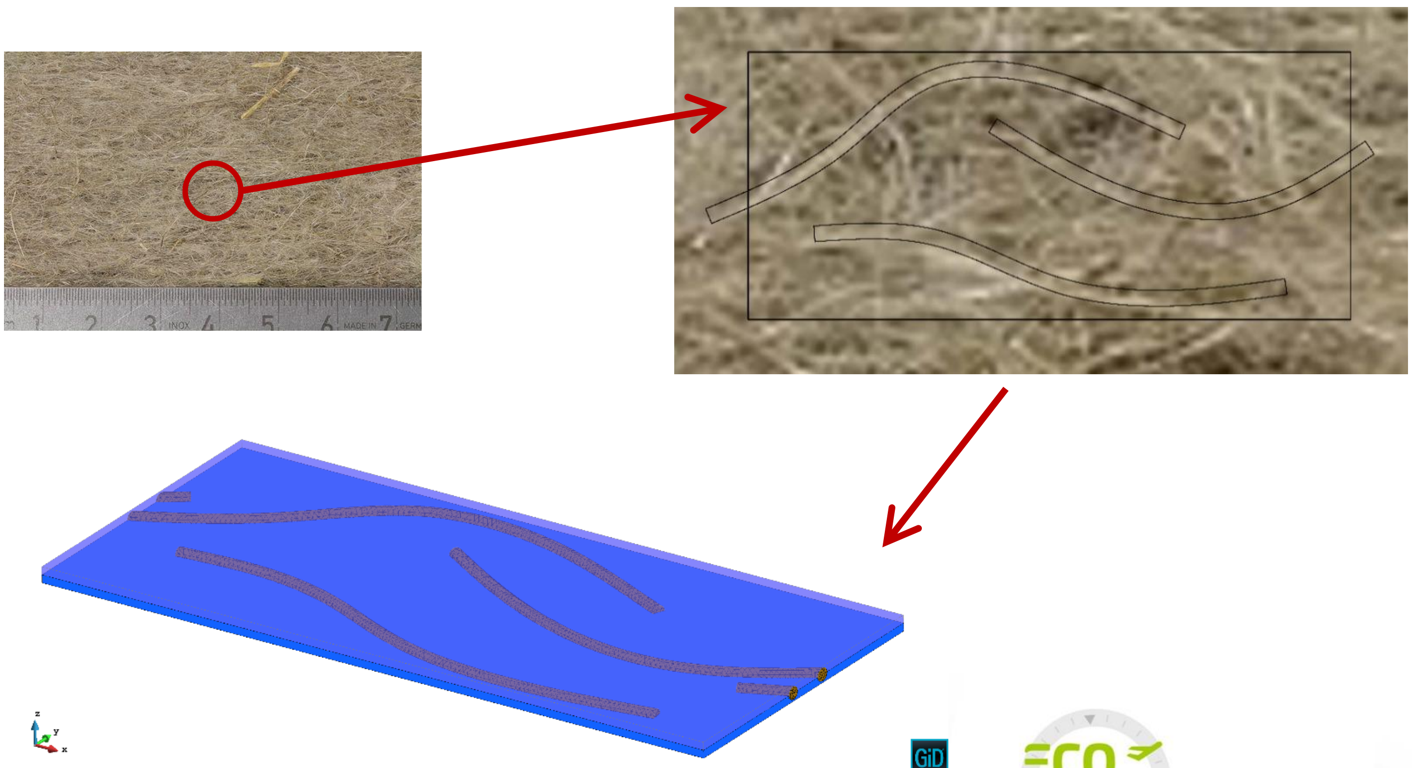
Their volumetric participation will be determined by a statistical distribution based on material observation and numerical calibration.





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:

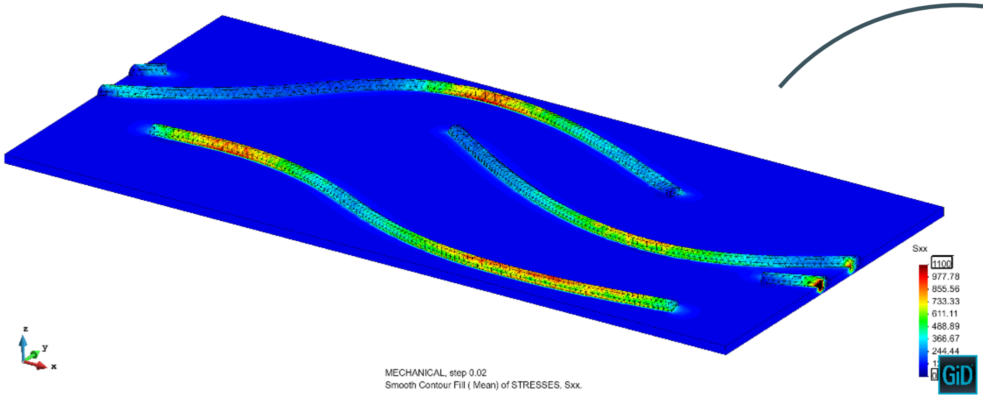


Analysis of non-woven composites

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:

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

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



$$E_{composite} = 3770 MPa$$

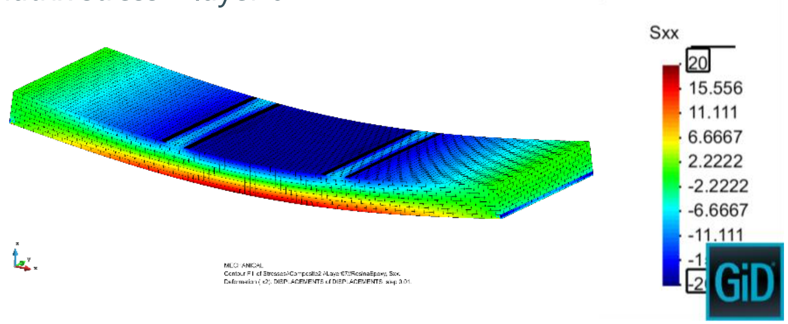
↓

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

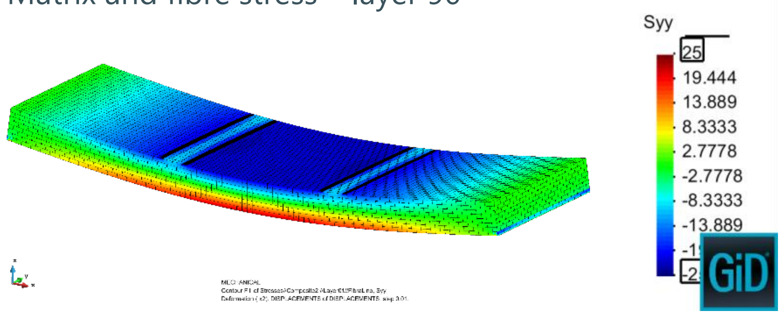
Analysis of non-woven composites

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.

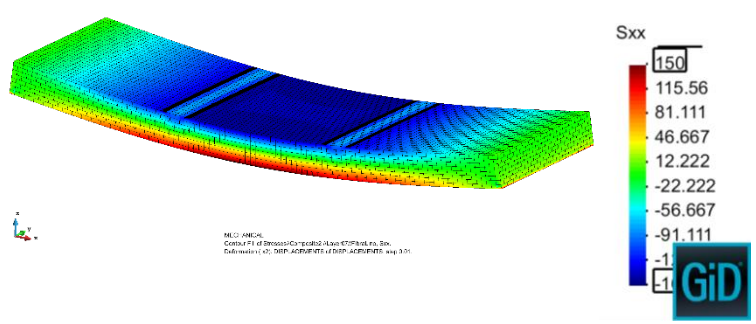
Matrix stress – layer 0º

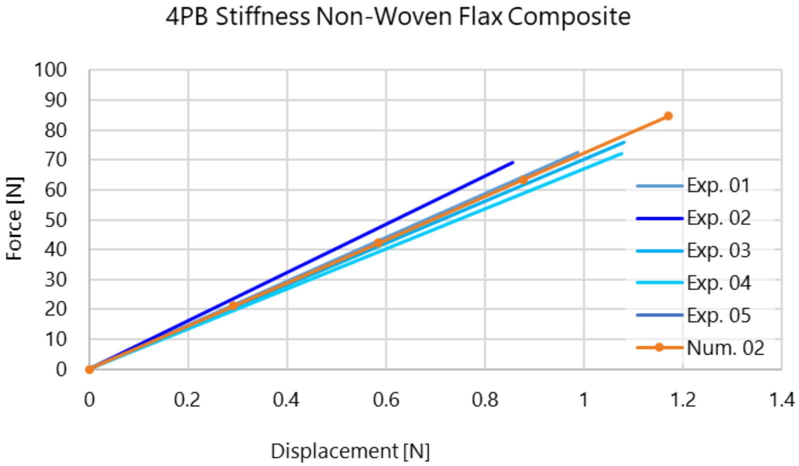


Matrix and fibre stress – layer 90º



Fibre stress – layer 0º





Summary

- Eco-composites can be an excellent option to improve the environmental footprint of aerospace structures.
- Their mechanical parameters make them appropriate for interiors and secondary structures.
- There are still many challenges to be solved, though: fire performance, aging, large properties variabilities, etc. Eco-compass project is aimed to improve some of these properties
- 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.
- 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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