ECO-COMPOSITES IN AERONAUTICAL STRUCTURES. POSSIBILITIES AND CHALLENGES

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ECCM ECFD 2018
STS5: New Aeronautical materials

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- 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
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

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, ...
Measures with potential to reduce aviation's environmental impact

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

Materials:
- Al/Al-Li: 19%
- Steel: 6%
- Titanium: 14%
- Composite: 53%
- Miscellaneous: 8%
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, ...
  → 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

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<td>66-110</td>
<td>200-250</td>
<td>3500-4900</td>
<td>1.4-2.1</td>
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<td>5-10</td>
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<td>2700-4400</td>
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<td>100</td>
<td>250-350</td>
<td>5400-6300</td>
<td>1.9-2.2</td>
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<td>12-20</td>
<td>700-850</td>
<td>15-30</td>
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<td>85-87</td>
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<td>1.63-3.26</td>
<td>72-85</td>
<td>1900-2050</td>
<td>1.8-4.1</td>
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<td><strong>Fruit</strong></td>
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<td>550-920</td>
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<td>25-500</td>
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<td>400-860</td>
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<td>550-790</td>
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<td>1.5-4</td>
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Based on [Dicker et al. / Composites: Part A 56 (2014) 280-289]

Valid for interior and secondary structures, where the strength requirements are lower.
Ecological and Multifunctional Composites for Application in Aircraft Interior and Secondary Structures

Cooperation Research of Chinese and European partners

April 2016 – March 2019

Fibre modification

Bio-Fibres

Recycled Carbon Fibres

Sandwich Core

Flame Retardants

Hybrid Reinforcement

Bio-based Resin

Electrical Conductive Toughener
Eco-compass project
Structural analysis

A structural analysis requires 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
\[ \sigma_1 = \sigma_2 = \ldots = \sigma_n \]
Proposed procedures to characterize composites

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1. Phenomenological Homogenization (serial-parallel mixing theory)
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

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

1) Parallel RoM to determine strain in layers: $\varepsilon_c = \varepsilon_1 = \ldots = \varepsilon_n$
2) SP RoM to obtain layer stresses: $\varepsilon_i \rightarrow \sigma_i$
3) Parallel RoM to obtain composite stress: $\sigma_c = \sum k_i \sigma_i$

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:
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:

\[ E_{\text{flax}} = 50 \text{ GPa} \]
\[ E_{\text{epoxy}} = 2.7 \text{ GPa} \]

\[ E_{\text{composite}} = 3770\text{MPa} \]
\[ E_{\text{equiv flax}} = 20.7 \text{ GPa} \]
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.
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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