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Elaboration of hybrid bio-composites with thermoplastic matrix: material formulation and modelling of the quasi-static behaviour

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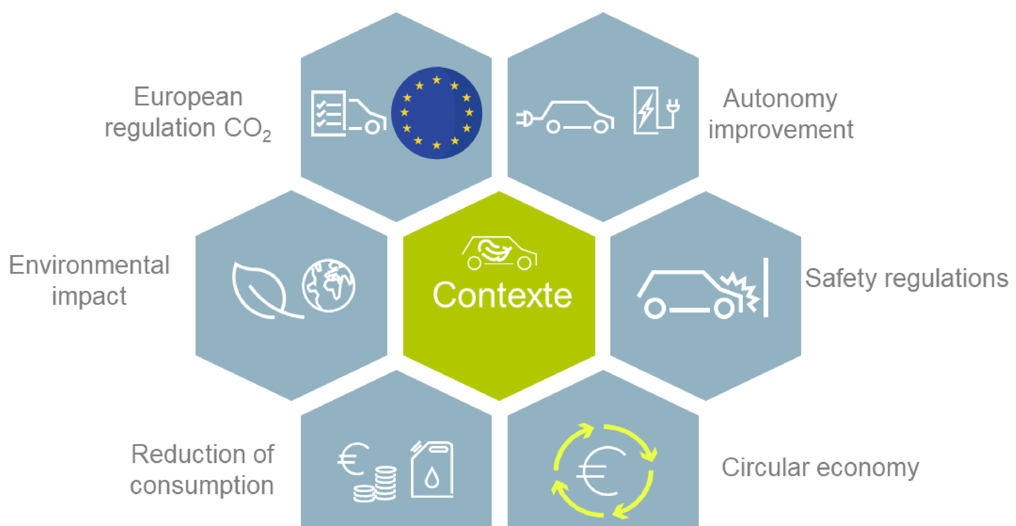
Abstract

Environmental impact is becoming increasingly important in the automotive industry, with car manufacturers looking to reduce CO2 emissions through cleaner engines and structural weight reduction. Composite materials offer an excellent alternative to standard steels with significant weight reduction and the ability to produce functional parts[1],[2],[3]. The main objective of this study is to investigate the potential of a new and unique hybrid bio-composite material combining flax and basalt fibers and PA11 polymer. This material design is studied with the idea of reducing the moisture sensitivity, variabilities and uncertainties of vegetal fibers by the presence of basalt fibers. The first step consists of developing a new hybrid composite material and studying its quasi-static mechanical behaviour when subjected to different humidity levels. Then, a multi-scale non-linear homogenization approach is proposed to support the interpretation of the characterization test results.

Context

- The application of composite materials remains limited in the automotive industry due to various technical, economic, and environmental constraints.
- On the economic aspect, the high price of fibers, such as carbon fibers, and the high manufacturing cost related to cycle time are the main obstacles to developing these materials.
- The environmental impact became increasingly critical with new European regulations for reducing the CO2 emission and the Carbone footprint of the life cycle automotive structures.



Objectives

Define a New concept for semi-structural automotive parts

- Integration of bio-composite materials in the automotive structure

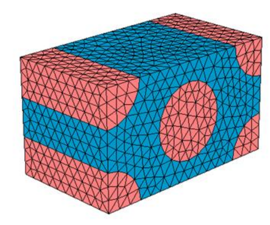
Good mechanical performances / Lightweight / Cycle time

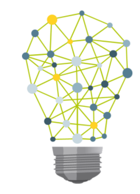
- Material designing

Optimisation of the materials choice and distribution / Economic optimisation

Methodology

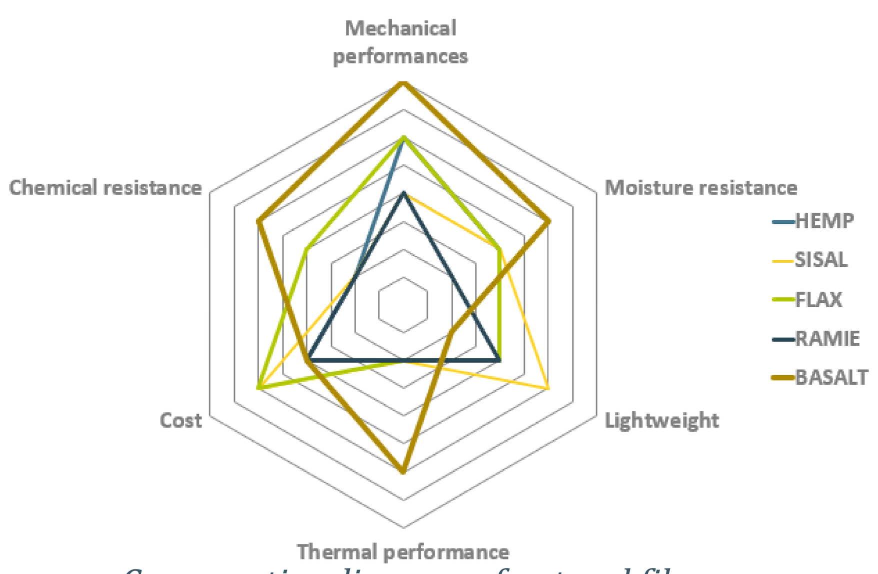
Materials choice → Composite fabrication → Experimental study → Numerical study



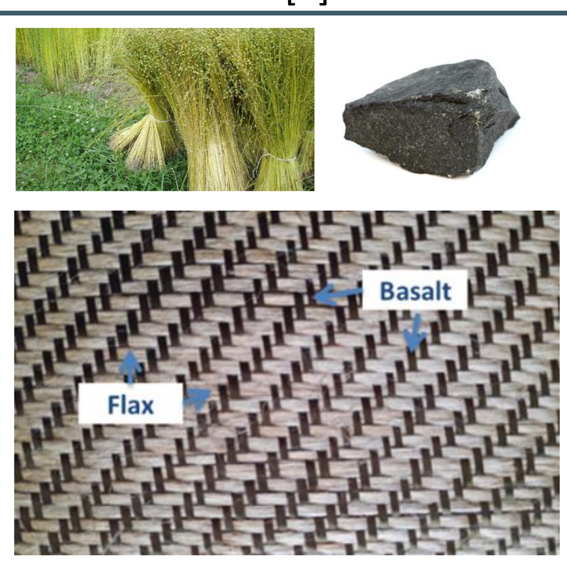


Material choice

- The choice of these materials is linked to the final properties required for the semi-structural parts.
- A selection of natural and mineral fibres was made based on studies of bio-composite materials [4],[5].
- Selection : flax and basalt as fibre reinforcement and a PA11 matrix from Arkema [5].



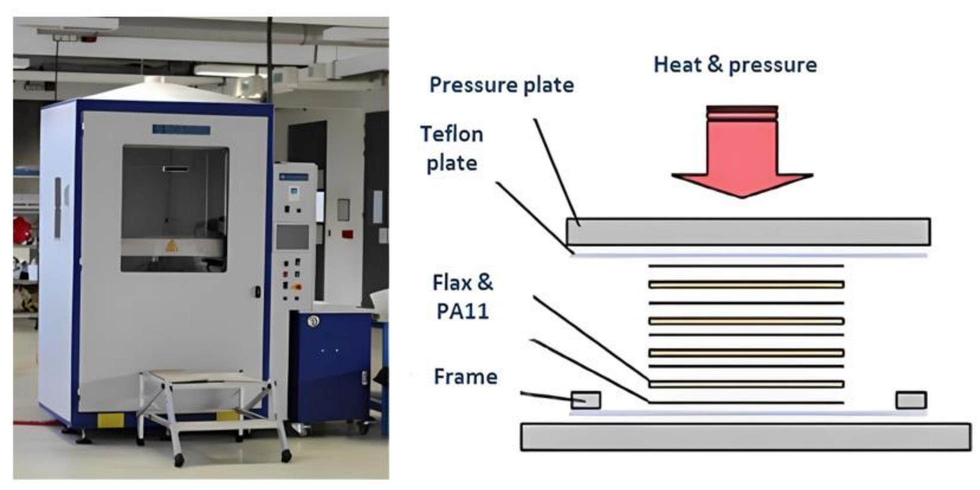
Comparative diagram of natural fibres



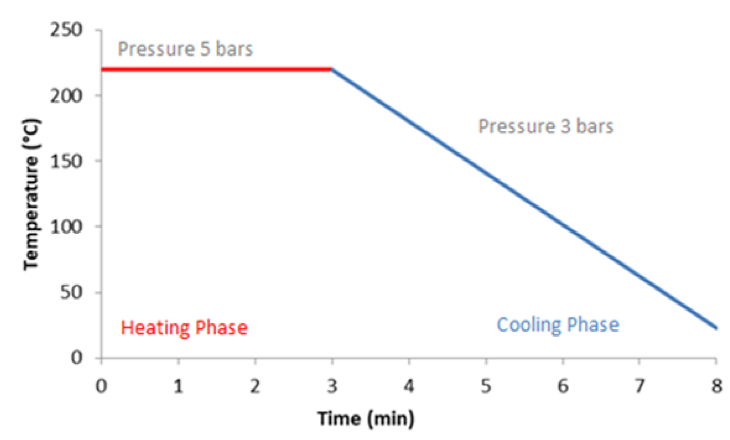
Hybrid5050/PA11 fabric Twill2X2

Composite fabrication

- The thermo-compression process : short cycle time compatible with automotive production.
- The temperature: 220°C for 3 minutes for the heating phase / 23°C for 5 minutes for the cooling phase.
- The material is kept under a pressure of 5 bars during heating and 3 bars during cooling.



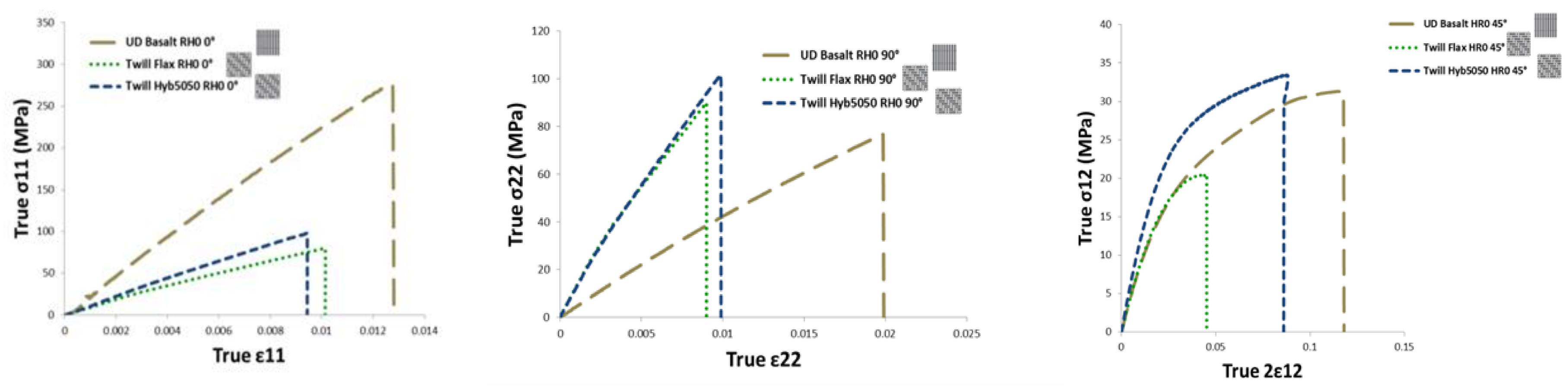
Hydraulic press SCAMEX



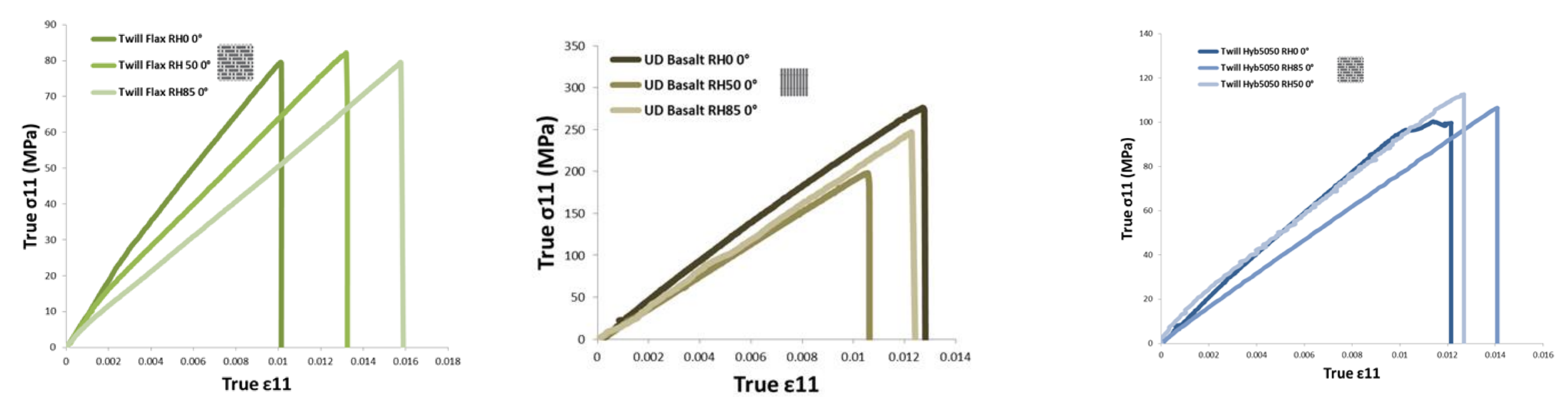
Thermo-compression cycle

Experimental study

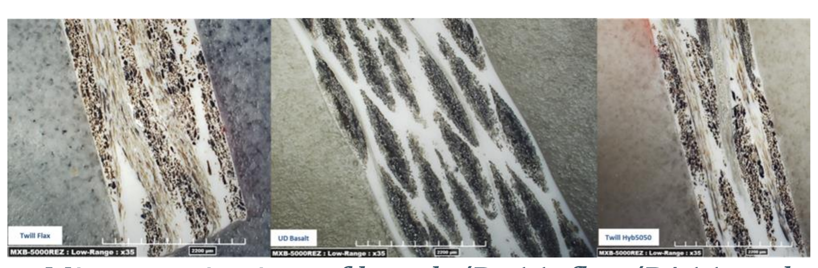
- Identify the mechanical characteristics of the composite's flax/PA11, basalt/PA11 and hybrid50/50.
- Understand the evolution of their mechanical behavior for the humidity ranges RH0, RH50 and RH85.
- Understand the impact of the hybridization on the mechanical behavior of the hybrid5050/PA11 material.



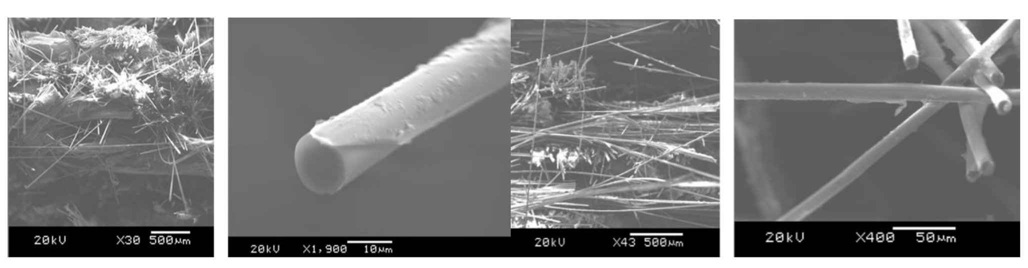
σ true= f (ε true) for the flax/PA11, Hyb5050/PA11 & basalt/PA11 composites for RH0 and 0°,45° and 90° at 23°C



σ true= f (ε true) for the tensile tessof flax/PA11, hyb5050/PA11 & basalt/PA11 0° for RH0 RH50 &RH85 at 23°C



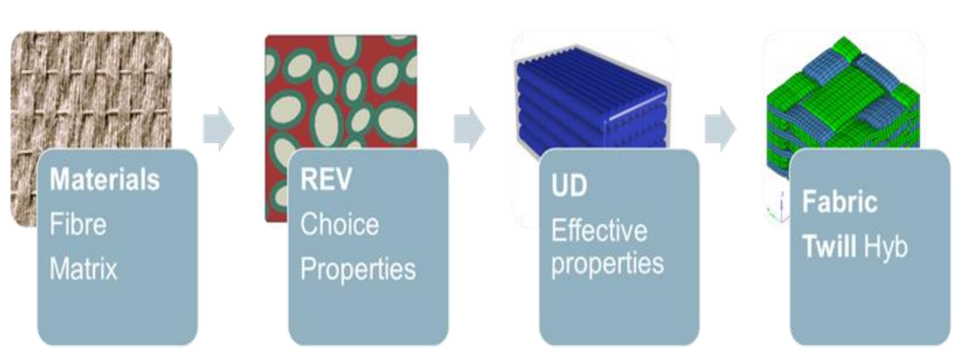
Microscopic view of basalt/Pa11, flax/PA11 and hybrid5050/PA11



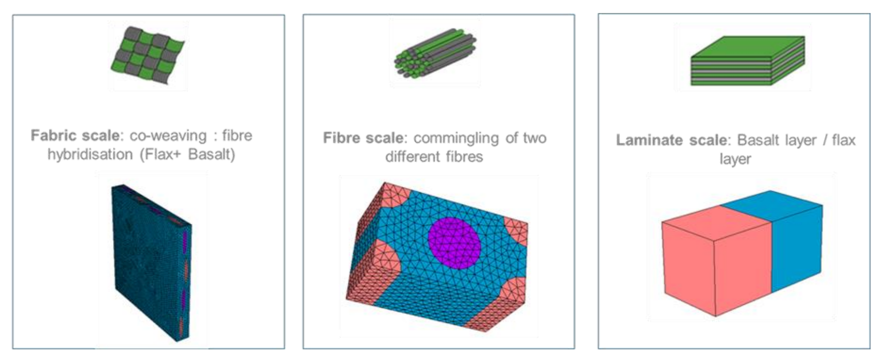
SEM view of flax/PA11 and Basalt/PA11 composites after 0° quasi-static tensile tests

Numerical study

- Determine the effective properties at the macroscopic scale of the material from a Representative Elemental Volume (REV) that depends on the scale of hybridization and for RH0, RH50 and RH85
- Compare three scales of hybridization: the laminate scale, the layer and the fiber scale



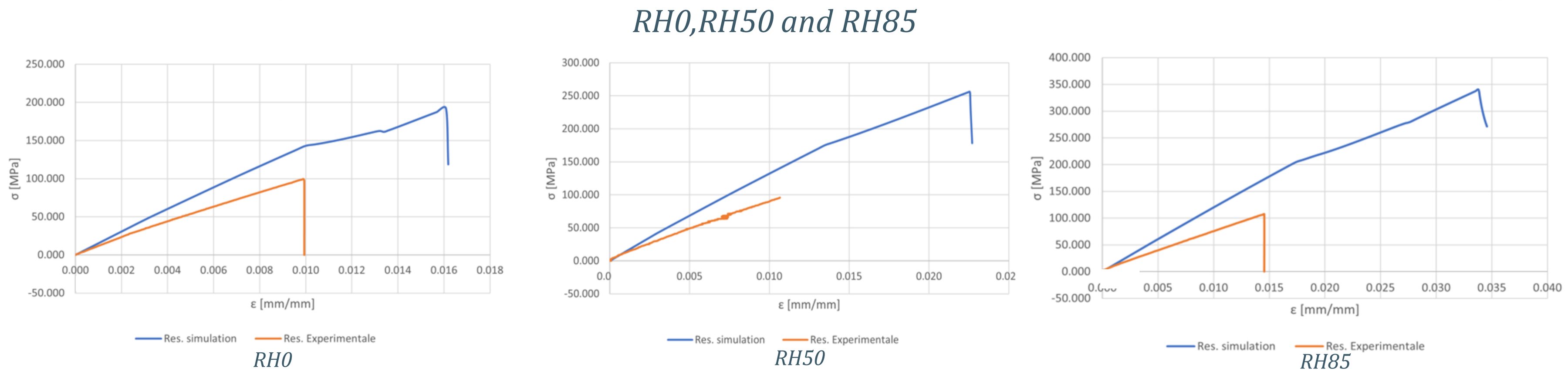
Multi-scale Homogenization protocol for the hybrid composite



REV developed on Hypermesh for the different scales of hybridization

Composite Materials	Relative Humidity	E11(MPa)	E22(MPa)	G12(MPa)
Flax/PA11	HR0	9970	9970	1090
	HR50	9270	9250	923
	HR85	8550	8554	817
Basalt/PA11	HR0	27700	2330	1040
	HR50	24900	1800	804
	HR85	24800	1570	702
Hybride5050/PA11	HR0	15000	15000	1090
	HR50	14100	14100	893
	HR85	13400	13400	782
Hybride3070/PA11	HR0	13900	13900	1080
	HR50	13000	13000	889
	HR85	12700	12184	778

Comparative table of numerical mechanical properties of Flax/PA11, basalt/PA11, hyb5050/PA11 composites for RH0,RH50 and RH85



Comparison of experimental and numerical results for the hybride5050/PA11 at RH0, RH50 & RH85

Conclusion

The use of basalt fibers with flax fibers improves the mechanical performance of the hybrid composite compared to the flax/PA11 and reduces its density by increasing the potential mass gain compared to the basalt/PA11 composite. The multiscale numerical homogenization is used to determine the effective properties of the studied materials and to compare the three scales of hybridization: the laminate scale, the layer scale and the fibre scale, and helps us to make the appropriate choice of hybridization.

Acknowledgements

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