PhD Thesis offer
Absorption of mechanical energy by natural materials for impact protection

- A guide to the next generation of architected materials -

Louise Le Barbenchon and Jérémie Girardot, Institut de Mécanique et d'Ingénierie (I2M)

1 - BACKGROUND

Modern engineering challenges—ranging from crashworthiness in automotive design to impact protection in aerospace applications—demand materials and structures that combine lightweight characteristics with high energy absorption. Natural materials, like the density gradients observed in cortical bone, plant stem and bamboo, offer excellent inspiration for designing engineered materials. Advances in additive manufacturing and design tools enable the fabrication of complex lattice structures with spatially varying properties, paving the way for efficient and robust bio-inspired designs.

2 - PROJECT DESCRIPTION

This PhD project builds on observational and quantitative analysis of the Citrus Maxima peel (see Fig. 1) [1]. As demonstrated in recent literature—and notably in our previous work—, the link between the intricate lattice architecture of the Citrus Maxima peel and its mechanical behaviour under high strain rates lacks of understanding [2-4]. Thanks to additive manufacturing processes—notably 3D printing—and design tools [5], we propose developing a new methodology into these natural structures to better understand the structure/mechanical relationship and enable innovative bio-inspired design for mechanical energy absorption applications.

This strategy leverages the variability in the relative densities of the structure to better absorb and dissipate mechanical energy, offering a more efficient solution than homogeneous cellular materials. Demonstrating this advancement opens up new perspectives in strategic fields such as aeronautics, automotive, and civil engineering construction, where weight reduction and improved mechanical strength and energy absorption are major challenges.

3 - OBJECTIVES AND CONTEXT

The primary objectives of this project are:

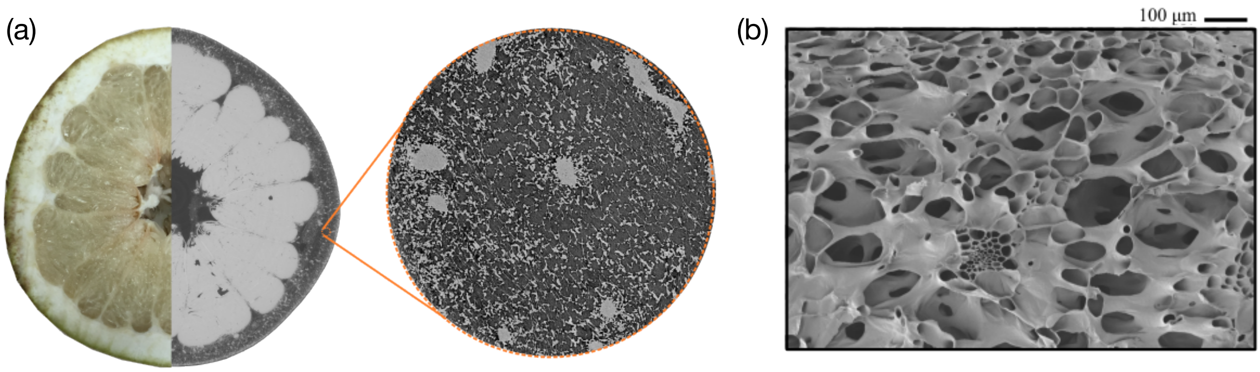

Fig.1 - Citrus Maxima peel. (a) Tomography acquisitions (b) cryo-SEM observations

- <u>Design and Simulation:</u> Develop computational models of density-graded lattice structures inspired by the Citrus Maxima peel. Use finite element analysis (FEA) or discrete element modeling (DEM) to predict and optimize their energy absorption performance.
- <u>Fabrication:</u> Utilize the additive manufacturing techniques (e.g., Fused filament fabrication, stereo lithography or SLS) to fabricate prototypes of the optimized designs.

- Experimental Validation: Conduct quasi-static and dynamic mechanical tests to evaluate the energy absorption, deformation characteristics, and failure modes of the fabricated lattice structures.
- Optimization and Guidelines: Analyse test results to refine the lattice geometry and grading parameters, and develop design guidelines for future applications.

This project proposes a comprehensive approach to developing bio-inspired density-graded cellular structures with enhanced energy absorption capabilities. By integrating computational modeling, advanced manufacturing, and rigorous experimental testing, the research aims to bridge the gap between natural design principles and engineered applications. The outcomes of this work are expected to contribute significantly to the development of lightweight, high-performance materials for critical safety applications.

4 - SUPERVISION

The PhD work will be supervised by both Dr Louise Le Barbenchon (CR CNRS, I2M laboratory, https://louiselebarbenchon.wixsite.com/cnrs-researcher) and Dr Jérémie Girardot (CR ENSAM, I2M laboratory) with regular meetings (about once a week).

Host laboratory : Institute of Mechanics and Mechanical Engineering, Bordeaux, France, https://www.i2m.u-bordeaux.fr/

This research project will benefit from collaborations with academic partners: LaBRI Laboratory at Bordeaux (Fabien Baldacci) and Portela Research Group, MIT at Boston (Carlos Portela)

5 - APPLICATION

To apply, send a CV and a letter of motivation to Louise Le Barbenchon at the following email address: Louise.le_barbenchon@ensam.eu

6 - REFERENCES

[1] Fischer et al., Pummelos as Concept Generators for Biomimetically Inspired Low Weight Structures with Excellent Damping Properties, Advanced Engineering Materials, 2010. DOI: 10.1002/adem.201080065
[2]Le Barbenchon, Influence of the loading regime on the uniaxial compressive behaviour of density graded Citrus Maxima peel, Materials Letters, 2023. DOI: 10.1016/j.matlet.2023.135079
[3] Thielen et al., Structure-function relationship of the foam-like pomelo peel (Citrus maxima) - An inspiration for the development of biomimetic damping materials with high energy dissipation, Bioinspiration and Biomimetics, 2013. DOI: 10.1088/1748-3182/8/2/025001
[4] Thielen et al., Viscoelasticity and compaction behaviour of the foam-like pomelo (Citrus maxima) peel, Journal of Material Science, 2013. DOI: https://doi.org/10.1007/s10853-013-7137-8
[5] Marchais et al., 3MAH/microgen: v1.1.0. DOI: 10.5281/zenodo.10880907