Joint ELytMaX[1] PhD subject 2023-2026

PhD's title: Understanding long term ageing mechanisms of fiber dense media in superinsulation materials: coupled mechanical and thermal characterization and modelling

Start of the PhD thesis: October 2023

PhD's candidate profile and skills sought
Master 2 degree or Engineer degree in Mechanics of Materials, Physics, Materials Science, Mechanical Engineering, Numerical Mechanics

Deadline for applications: mid-July 2023

PhD's Keywords
Superinsulation materials, Fiber Networks, Ageing, X-ray microtomography, In situ mechanical experiments, Creep, Advanced experiment, Thermal conductivity

Summary of the PhD's subject
Energy efficiency in buildings is one of the significant challenges that need to be addressed for reducing their impact on climate and meeting the emission targets as agreed in the Paris agreement. In the EU, buildings approximately consume 40% of energy and are responsible for 36% of CO2 emissions. Insulating the building envelope is key to achieving savings on building space heat energy and reducing carbon emissions (Brunner and Simmler 2008, Karami et al. 2015).

In addition, in the domestic, refrigerators accounted for a very large amount of residential electric energy consumption (up to 20%) in some countries and taking a larger view on the cold chain shows that the potentials energy saving equals 10 000 GWh/y or 665 Mt eq. CO_2 worldwide (Gao 2018).

For buildings, cold chain chambers and refrigerators, medical transportation systems, vacuum insulation panels (VIP) offer a unique way of reducing the transmission losses of with minimal insulation thicknesses so that it is possible for buildings to save valuable living space area or allow for proper thermal insulation of slender constructions, whereas it is possible to enhance the useful volume of the compartments of refrigerators without changing their external dimensions (Verma and Singh 2019, Kan et al., 2022,).

VIP's exhibit thermal conductivity down to 1-2 mW m^{-1} K^{-1} that are five times lower than that of the best polyurethane foams (20-29 mW m^{-1} K^{-1}) used for domestic appliances or eight times lower thermal conductivity than conventional thermal insulation materials (glass wool) used in the building domains.

At a first glance VIP's consist of a sealing envelope 400x400 mm^2 (Figure 1a) with a thickness of approx. 100 µm in the form of a polymer-metal multilayer, e.g. a polyethylene (PET) layer coated with aluminum assembled with a low-density polyethylene (LDPE) layer by an adhesive (Planes et al. 2011).

[1] https://www.elyt-lab.com/en/content/elytmax-umi-3757

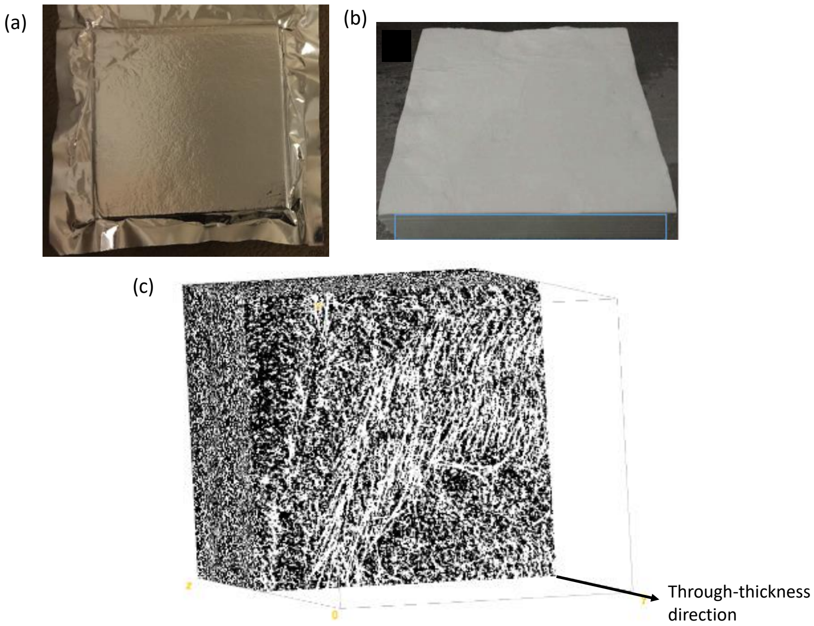

Figure 1. (a) Top view of a VIP with its envelope (In-plane dimensions 400x400 mm^2. (b) View of the corresponding fibrous core material inside the envelope under vacuum. Adapted from Chen et al., Energy, 2015. (c) 3D image of a fibrous core material of a VIP (30-µm resolution, in-plane dimensions 2x2 mm^2).

VIPS' also consist of a highly porous bearing core material that is usually made of an anisotropic network of glass fibers (Figure 1). Natural fibers (Kan et al., 2023) are emerging materials in this domain as well as polymer-based fibers. These new fibers are scrutinized because they offer the possibility to adapt the VIP's concept to e.g. food packaging applications that require a shorter life-time than in the traditional domains of VIP's for a lower cost and an expected better environmental impact. Moreover local material use is envisioned, as pyrogenic silica and glass fibers industries are not common, and rely on the same mineral.

The bearing core fibrous materials, assemblies of fiber stacks (Figure 1c), are subjected to various coupled thermo-mechanical loadings during their manufacturing and their use. During manufacturing, the sealing envelope exerts compressive loading on the fibrous material because of the vacuum (< 0.1 mbar) that is applied to lower the thermal conductivity of VIP's, which results in an initial compressive stress state applied on the fibrous network. During their use, VIP's are also subjected to varying environmental conditions (varying temperature and relative humidity conditions). Varying temperature conditions can induce cycling loading conditions on VIP's which is known to induce in fibrous materials a structural evolution (Ghafour et al., 2021). Varying relative humidity conditions can result in dry gas and moisture permeation through the polymer-metal envelope and the absorption of water in the core materials of VIP's.

These mechanisms can affect the overall thermal conductivity of the VIP's that depends on residual gas conductivity, fibrous material conductivity, envelope conductivity and result in their aging, i.e. a progressive increase in their thermal conductivity.

To enhance and tailor the lifespan or to recycle VIP's, it is thus crucial to better understand the aforementioned mechanisms and their effects on the structural evolution of VIP's, the mechanical properties of the core and envelope materials, and their resulting thermal conductivity (Chal et al. 2021). This is all the more important for emerging core materials made of hygroscopic and viscoelastic biosourced or polymer fibers. This requires a multiscale approach and coupled characterization and simulation.

Research program

- Choice of VIP's materials with aged and non-aged core materials (glass, biosourced fibres) obtained with different manufacturing techniques. Elaboration of multi-scale sample for characterization.
- Characterization of the mechanical and barrier properties of the envelope materials of the various types of VIP's.
- Characterization of the sorption-desorption behavior of VIP's and phenomenological modelling.
- Lab-scale cyclic mechanical tests coupled with DIC measurements techniques in controlled varying environmental conditions (T and r.h.) on sealed and non-sealed fibrous core materials.
- Characterization of thermal and radiative properties of the various types of non-deformed and deformed VIP's in controlled varying environmental conditions (T and r.h.) on sealed and non-sealed fibrous core materials using dedicated measuring devices (Kobari et al. 2015).
- In situ mechanical cyclic compression tests using X-ray microtomography imaging in controlled varying environmental conditions (T and r.h. and pressure) on sealed and non-sealed fibrous core materials. The recent DTHE investment enables multiscale analysis from the panel size down to a few tens of microns, i.e. the fibre and fibre-fibre scale.
- Multiscale characterization of the deformation mechanisms of the core fibrous materials at the fibre and fibre-fibre contact scale, of the microstructure characteristics (porosity, pore size, pore connectivity, fibre length, orientation and curvature, specific surface area, number of fiber-fiber contacts, area of contacts). Tests performed at ESRF or with similar equipment.
- Numerical simulation of the thermal properties using 3D images of deformed real fibrous core materials and numerically generated fibrous networks and comparison with experiments.

The experimental and numerical data will be used to enhance the current modelling approaches of the thermo-hygromechanical properties of non-aged and aged VIP's. They will also enable to propose original strategies to improve the durability and to recycle these materials as well as to expand their use for other applications.

Organization of the PhD work and locations

- 18 months at LaMCoS laboratory on the site of INSA Lyon located at Oyonnax[2] (located between Lyon and Geneva),
- 6 months at Tohoku University in Japan,
- 12 months at MATEIS laboratory on the LyonTech-La Doua campus

Research entities

CNRS-Université de Lyon-Tohoku University, International Joint Unit, UMI 3757 ELytMaX. ELyTMaX is an International Joint Unit (UMI) launched by CNRS (France), Université de Lyon (France) and Tohoku University (Japan).

Co-direction Team

[2] https://www.insa-lyon.fr/en/node/112

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[3] http://lamcos.insa-lyon.fr/?L=1
[4] http://www.ifs.tohoku.ac.jp/LyC/jpn/index.html
[5] https://mateis.insa-lyon.fr/