Proposal: PhD student position within the Centre for Interdisciplinary Mathematics (CIM)

Project Title: Elasto-hydro-dynamic analysis of architectured materials: Miniatured materials with fluid-solid interaction

Project participants:

- PhD student (to be recruited)
- Main supervisor: Mahmoud **Mousavi**, Division of Applied Mechanics, Department of Materials Science and Engineering, Uppsala University, **Sweden**
- Co-supervisor: Murtazo **Nazarov**, Division of Scientific Computing, Department of Information Technology, Uppsala University, **Sweden**
- Co-supervisor: Arash **Yavari**, Geometric Solid Mechanics Group, School of Civil and Environmental Engineering, The Georgia Institute of Technology, **USA**

Project description:

Architectured materials (or metamaterials) are the state-of-the-art materials engineered for tailored functionalities. Two main paradigms exist when it comes to the **scale** of materials i.e., architecting in atomic scale or architecting in continuum scale. The focus in this project is the latter scale aiming for specific engineering applications [1].

The architectured materials are composed of a unit-cell, which is tessellated periodically in one dimension, two dimensions, or three dimensions. Considering the **base materials** used in the unit-cell, different classes of such materials have been analyzed and designed. On the one hand, solid architectured materials composed of deformable base materials and voids have been used for hydrogen storage [2] (see figure 1), mechanical loading [3], or thermal management. On the other hand, a combination of fluid phase with a rigid solid phase has been addressed in applications such as microfluidics [4] or liquid metal polymer composites [5]. However, many engineering applications would require the presence of **fluid and a deformable solid** in a unit-cell. At present time understanding of such mechanical systems is lacking. This project aims to fill this gap and will investigate the materials architectured with fluid and deformable solid phases performing an elasto-hydro-dynamic analysis.

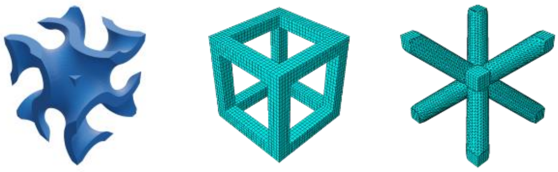

Figure (1a) TPMS, Cubic, and BCC unit cells

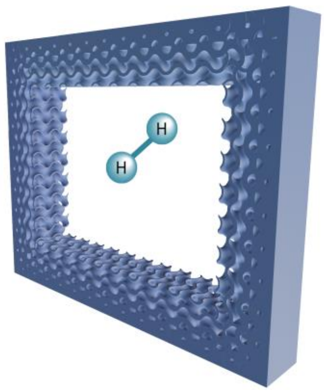

Figure (1b): Conceptual design of a prismatic meta-vessel composed of architectured material (TPMS).

Aiming for understanding the fluid-solid architectured materials and developing the tools to design them can benefit many industrial applications such as thermal management, hydrogen storage, microfluidics, among others.

An important step in analyzing and functionalizing these materials is understanding their dynamic properties. An efficient method to derive the dynamics of such materials are the **homogenization** techniques [6]. Elasto-hydro-dynamic homogenization is a challenging interdisciplinary research question here addressing both mathematics and mechanics. To tackle this challenge, in this project a PhD student will develop analytical and as well as computational methods for homogenizing the architectured materials under dynamic conditions. The work packages of the PhD project are envisioned to be the following:

- **WP1-**Elasto-hydro-dynamic analysis: fluid-solid interaction
- **WP2-**Homogenization of fluid-solid architectured materials: analytical and numerical approaches
- **WP3-**Tailoring the functionality with fluid-solid architectured materials

Project organization: involved actors and their roles

The host of the PhD student will be the research group led by Mahmoud Mousavi in the UU Division of Applied Mechanics addressing the "Mechanics of Architectured Materials". Currently this group includes two PhD students (one fully funded by Swedish Research Council, and one fully funded by industry, Hitachi Energy) as well as two master thesis students (co-supervised by companies, Northolt and Nitiu). Each of these projects aims for understanding and designing for a particular functionality using architectured materials, including mechanical properties, thermal conductivity, chemical degradation among others. The research group hosts activities from basic science (supported by Swedish Research Council) to applied engineering (supported by several companies) giving it an excellent potential for innovation and impactful research.

Main supervisor, Associate Prof. Mahmoud Mousavi, has extensive experience in solid mechanics and computational homogenization of solid architectured materials in quasi-static conditions. He is leading a project (2019-2023) funded by Swedish Research Council as well as industry PhD students (Hitachi Energy) and master students (Nitiu, Northvolt, among others) and his team has reported interesting contributions in this direction so far (e.g. [2-3]).

The co-supervisor from UU Department of Information Technology, Associate Prof. Murtazo Nazarov, has a solid background in numerical analysis of PDEs, and in particular, fluid mechanics [7]. His expertise will be very helpful in supervision and analyzing the fluid phase in the material.

The co-supervisor, Prof. Arash Yavari, from Georgia Institute of Technology has an extensive background in theoretical and computational solids mechanics, and in particular, in analyzing PDEs in mechanics and geometric solid mechanics [8-11], and his contributions to the analytical treatment for elasto-hydro-dynamic spatial-temporal homogenization of the PDEs of architectured materials would be essential for this project.

Project justification regarding interdisciplinarity

Mechanics abounds with **partial differential equations** (PDEs) while such PDEs differ for solid and fluid materials (the so-called Navier equations for solids, and Navier–Stokes equations for fluids). Moreover, due to tessellation of a periodic unit-cell in fluid-solid architectured materials, **homogenization** is an efficient tool for transforming the underlying heterogeneous multi-phase materials to an averaged homogeneous equivalent in our material library. Such material libraries are extremely interesting for **industry** in their ever-growing competition for optimizing their products, while importantly, a carefully designed fluid-solid architectured material system can possess improved **recyclability** in comparison to classical composite materials. The interdisciplinary nature of the project calls for an interdisciplinary team of applied and theoretical mechanicians, and mathematicians.

Project finance

The project main costs are the salary of the PhD student and the supervision costs. The salary of the PhD student will be supported 50% by CIM funding, and 50% by the Division of Applied Mechanics (through faculty compensation for two PhD students of Mahmoud Mousavi). The supervision cost is waived as the subject of this project has strategic significance for supervisors.

References:

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