Engineer intern in the **PIMM** laboratory at **ENSAM Paris**

Internship title: Experimental and numerical study of vacuum resin infusion process for composite manufacturing

Research fields: Mechanics, composite manufacturing process, process control, vacuum resin infusion, process modelling by finite elements

Context: Composite materials are involved for the fabrication of structural parts in different sectors such as aeronautical, aerospace, automobile, marine, or railway industry because of their better specific properties compared to metallic materials. For this reason, the company EHM (Efficient Hydrogen Motors) looks to design critical parts of the new generation of hydrogen motors in composites. However, the quality (*i.e.* fibre impregnation, resin cure degree) and performance (*i.e.* mechanical properties) of a composite part is directly related to the manufacturing process, which should be perfectly controlled (*e.g.* temperature, pression, resin flow) [1]. In addition, current sustainability restrictions make it necessary to think about energetic-efficient process. In this direction, Vacuum Resin Infusion (VRI) seems extremely well adapted. In particular, it allows to easily control the fibre/resin ratio and to reach large thickness ranges, depending of the application.

This project focuses on the VRI manufacturing process at its numerical simulation with the aim to link process input settings (flow rate, pressure, curing cycle) to the quality of microstructure (porosity, density, fibre rate) and the mechanical performance (engineering modulus and stress/strain rupture thresholds) of the manufactured structure [1-3]. For it, A VARI bench is currently available at laboratory, whose schema is shown in ***Fig. 1***.

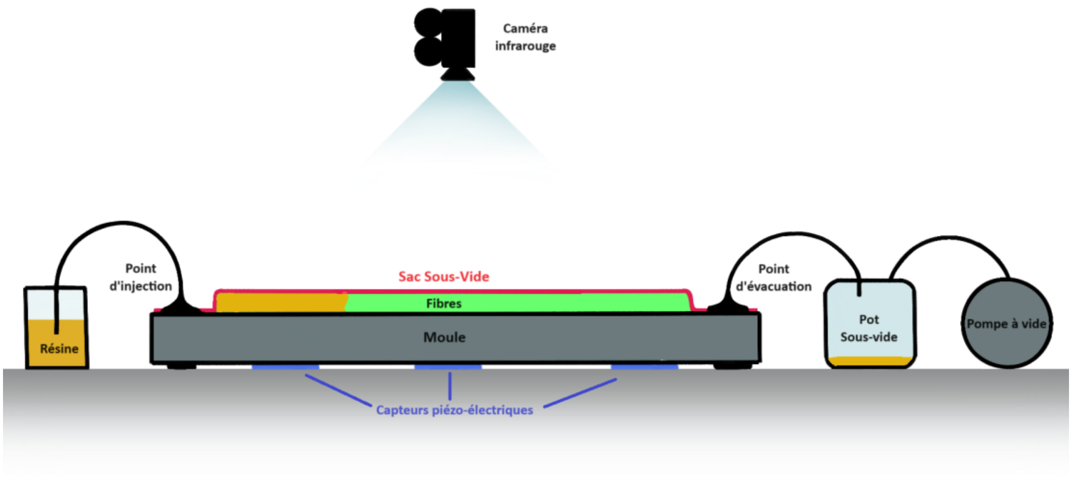

Fig. 1*. Schematic of experimental setup available at laboratory for monitoring of VRI process (adapted from [2])*

For reaching this goal, the candidate must carry out the following tasks:

- Manufacturing of composite samples made of continuous fibres embedded in a thermoset polymer matrix by the VRI manufacturing process. Classic carbon fibre woven and alternative biosourced woven (basalt fibre) are available.
- In situ control by multi-instrumentation: *(i)* optical tracking of the resin front during infusion and *(ii)* temperature evolution by thermal or piezoelectric sensors.
- Samples preparation for material characterisation testing at the microscopic (porosity, density, fibre rate) and macroscopic scales (engineering modulus and stress/strain rupture thresholds depending of the fibre orientation).
- Setting-up the numerical modelling of the main mechanisms involved during the process [4,5]: *(i)* resin flow and *(ii)* curing kinetics of resin whose reactivity law have already been identified.

For it, numerical approach based on finite element-modified control volume and volume of fluid are available at laboratory.

- Defining a link between manufacturing input parameters, composite microstructure and mechanical performance through a comparison between experimental and virtual testing.

The main experimental and numerical results of this internship will be used as "control data" for validating a monitoring methodology based on *in situ* acquired experimental data, which is currently ongoing in a PhD project. Firstly, the dialog between experimental and numerical data will help to identify optimal infusion and curing conditions. Secondly, numerical strategies to adjust the numerical bias will be discussed to go to the called digital twin. This data-based strategy will also allow EHM to improve the mechanical design of motor components made in composites.

References:

[1] Wang et al. Monitoring the resin infusion manufacturing process under industrial environment using distributed sensors. *J. Compos. Mater.*, SAGE Publications, 46(6), pp.691-706, 2012.
[2] Liu et al. Monitoring of resin flow front and degree of cure in vacuum-assisted resin infusion process using multifunctional piezoelectric sensor network. *Polym. Compos.*, 42(1), 2020.
[3] Faci et al. Monitoring in situ in real time of resin infusion for thermoset composite structures. *IOP Conf. Ser.: Mater. Sci. Eng.*, 254 142008, 2017.
[4] García et al. A fixed mesh numerical method for modelling the flow in liquid composites moulding processes using a volume of fluid technique. *Comput. Methods Appl. Mech. Eng.* 192, 877–893, 2003.
[5] Laurenzi et al. Advanced Composite Materials by Resin Transfer Molding for Aerospace Applications. In: Compos. Their Prop., InTech, 2012.

Candidate profile: The candidate could come from 2nd or 3nd year in Engineering program and/or 1st or 2nd year in Master 1/2 in material process and/or composite materials. The candidate comes from a background in engineering, mechanics and/or materials and must show a taste for manufacturing, experimental and numerical tools. Knowledge in the field of polymers and composite materials will be very appreciated.

Duration: 3 to 4 months / 5 to 6 months depending on candidate level

Place: PIMM laboratory (*Procédés et Ingénierie en Mécanique et Matériaux*), Paris (75013), France

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