Teaching assistant
Léa Damiano
EPFL LPAC – MXH 147
lea.damiano@epfl.ch

TP D: LCM & PERMEABILITY

Location
MED 3 1119

Note: all relevant values are given in Table 1.
Optionally, read the annexes for further information on LCM and permeability.

Goals

In this TP, we will show why the concept of permeability plays an important role in impregnation for liquid composite molding processes (LCM), and how it can be measured. Using a simplified setup for RTM (Resin Transfer Molding), which is a particular case of LCM, we will discuss the links between the resin velocity v, the permeability K of reinforcements and the presence of defects in the resulting parts.

Our goal here is to measure the longitudinal permeability of a compressed stack of fabric. Since we are solely interested in impregnation, we will use silicon oil as a test liquid, which will not solidify in this experiment. The permeability will be assessed in two-phase *("unsaturated")* and in single-phase *("saturated")* flow configurations from a 2-steps experiment, following the guidelines in the annexes:

- Emulate and monitor the impregnation step in a RTM process
- Prepare the fabric and the experimental setup
- Record the evolution of the flow front position
- Measure the liquid flow rate when it is fully saturated
- Analyze the results and determine the 1D longitudinal permeability of the fabric
- Compare the permeability K_{unsat} measured in the *unsaturated* configuration (two-phase flow) and K_{sat} measured in the *saturated* configuration (single-phase flow).

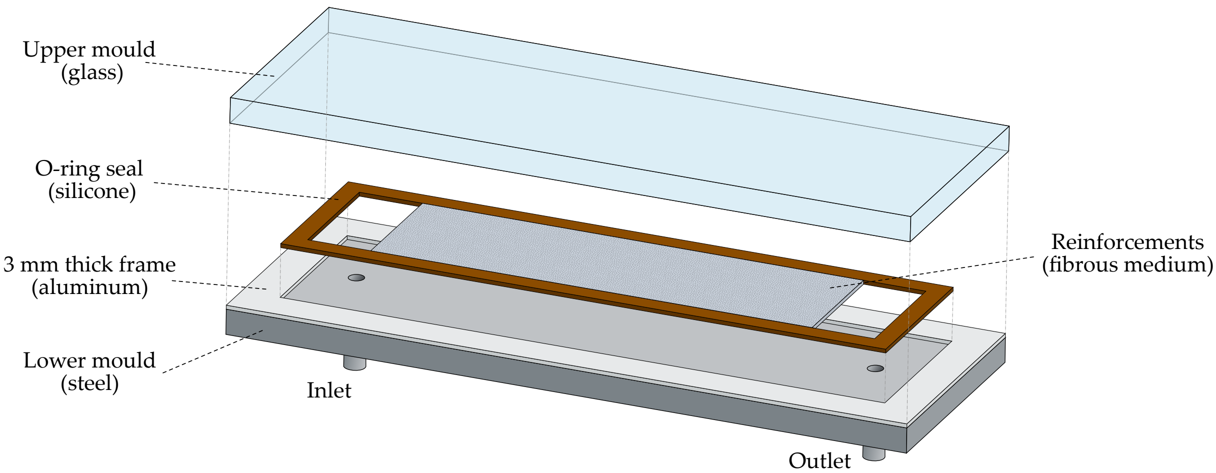

FIGURE 1: Schematic of the mould setup

Experimental procedure

Fabric and mould preparation

- Open and clean the mould. Make sure markings are still present.
- Calculate the number n of fabric layers needed to get $V_f = n\sigma/(\rho h) = (35\pm3)\,\%$ — with the thickness h of the mould frame and the fabric properties ρ, σ given in Table 1.
- Cut the fabric into n rectangles of $350\,\mathrm{mm}\times100^{+1}_{-0}$ mm.
  Check that they fit the mould perfectly: there should be no empty space on the sides.
- Weigh the fabric stack to determine the precise fiber volume fraction $V_f = m_f/V_{mold}$.
- Place the metallic frame , the silicon O-ring seal and the fabric according to Figure 1.
- Close the mould, **place the pins** and apply a pressure of ~ 3.5 bar to compress the fibers.
- Prepare the pressure pot (check that there is enough liquid left). With the valve closed, apply a pressure of approximately 700 mbar (70 kPa).
- Place the camera, set its focus on the fabric.
- Ensure that the mass and pressure acquisition program runs without errors.

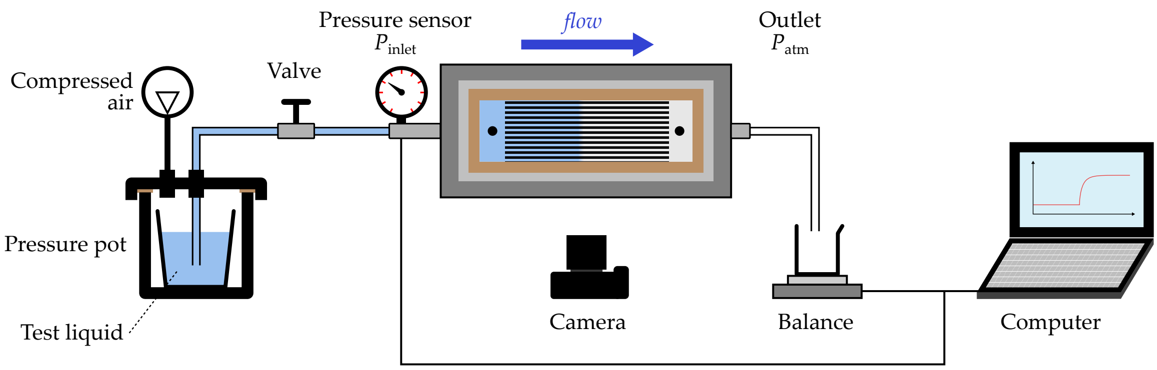

FIGURE 2: Schematic of the permeability measurement setup

Injection of the test fluid

- Start the video (camera).
- Start the pressure and mass acquisition (PC).
- Open the valve.
- Let the camera record the flow front position $x(t)$ during impregnation (unsaturated/two-phase flow) and then stop the video.
- Let the mass program record ~ 1 minute of outcoming fluid.

Data analysis

The experimental data produced during the TP include the video of the flow front, the recording of pressure $\Delta P(t)$, and the mass of liquid flowing out $m(t)$ recorded by the balance.

Unsaturated permeability

Analyze the experimental data (video and pressure datasheet) according to annex II (*"Experimental Procedures to Run Longitudinal Injections to Measure Unsaturated Permeability of LCM Reinforcements"*, paragraph 8.2):

- Plot the evolution of the square of the flow front position $x^2(t)$ and find its slope.
- Determine the average pressure difference ΔP between the outlet and the inlet.
- Deduce the permeability K_{unsat}

Saturated permeability

Calculate the permeability K_{sat} according to annex III (*"Permeability properties of reinforcements in composites"*, eq. 14.22):

- Plot $m(t)$ and its slope $\frac{\mathrm{d}m}{\mathrm{d}t}$. Deduce the average *volumetric* flow rate $Q = \frac{\mathrm{d}\mathcal{V}}{\mathrm{d}t}$.
- Calculate the corresponding permeability K_{sat}.

Report

Write a short report of the whole TP **(maximum 10 pages)** in French or in English. Make sure to report all measurements, significant figures and calculations. Plot the data when it is relevant, and pay attention to the plot layouts. The following items should be included in the report, following the order that suits you the best while remaining logical:

- *Short* general introduction on the context of LCM (principles, applications, issues, etc.).
- Context on permeability (why is it important for LCM, definition, equations, etc.).
  Exercise: deduce the theoretical liquid velocity $v(t)$ in unidirectional flow at constant applied pressure by integrating Darcy's law (Equation 1):

$$v = \frac{\mathrm{d}x}{\mathrm{d}t} = -\frac{K}{\eta(1 - V_f)} \frac{\Delta P}{x} \tag{1}$$

- Explain what was done in this TP: goal, motivation, methods, results, analysis.
  - Compare the theoretical flow front velocity $v(t)$ with your measurements.
  - Compare the two methods for measuring permeability.
  - Calculate the ratio $R = K_{\text{unsat}}/K_{\text{sat}}$ and discuss its value (why?).
- Write a short conclusion.

The main point of the report is to evaluate your ability to be concise and clear and to show that you understood the subject, the experiment and how they relate to each other.

Parameters & values

Some of the parameters needed in order to calculate K are summed up in Table 1. The areal density of fabrics σ (also known as gsm) might differ slightly in the experiments. The fabric used during the TP should be the flax fabric, but a glass mat could also be used depending on their availability.

h_{mould} [mm]	η [Pa · s]	ρ_{liq} [kg/m^3]	ρ_{glass} [kg/m^3]	σ_{glass} [g/m^2]	ρ_{flax} [kg/m^3]	σ_{flax} [g/m^2]
3	0.1	965	2600	500	1450	300

TABLE 1: Experimental parameters

With h_{mould} the thickness of the mould, η the silicone oil viscosity at 25°C, ρ the density and σ the areal density.