17th International Conference on
Flow Processes in Composites Materials (FPCM17)
Sheffield, United Kingdom, 30 June to 02 July 2026.

TITLE:Interfacial study of flax fiber moisture influence in liquid composite molding at controlled capillary number

AUTHOR(S): Jean-Baptiste Jouenne[1], Bernard Miranda Campos[3] and Joël Bréard[1]

AFFILIATION(S): [1]ABTE, UR 4651 Université de Caen Normandie, Bd Maréchal Juin, 14032 Caen, France

[3]Laboratoire CRISMAT, Normandie Université, ENSICAEN, UNICAEN, CNRS, 14050 Caen, France

ABSTRACT: (core theme : Liquid Composite Moulding (e.g. RTM, VARTM etc.,)

Flax fiber–reinforced composites remain at the forefront of research on the development of low–environmental-impact materials [1]. However, their processing remains challenging, mainly due to the hydrophilic nature of natural fibers. From an industrial perspective, composite manufacturers tend to dry the fibers; nevertheless, we believe that this step is not necessary and that controlling the moisture content is preferable in order to preserve the physicochemical integrity of the reinforcements. In this work, we propose to investigate the influence of the moisture content of natural fibers on the interfacial behavior of the resin during the impregnation of a porous medium. One of the most widely used processes for composite manufacturing is resin transfer molding, such as vacuum-assisted resin infusion (VARI) [2]. In this type of process, the resin is driven through the preform by the pressure difference between the inlet and the outlet of the mold. The main difficulty of this manufacturing method lies in the fact that the resin flow velocity is not constant along the part, leading to microstructural variations and defects in the mechanical properties. We have developed a low-tech process that enables the impregnation of a preform under controlled capillary number and constant flow rate. Using this approach, we investigated the influence of the moisture content of flax preforms on impregnation by measuring its impact on resin flow velocity, resin pressure variations within the preform, as well as on surface tension and dynamic contact angles.

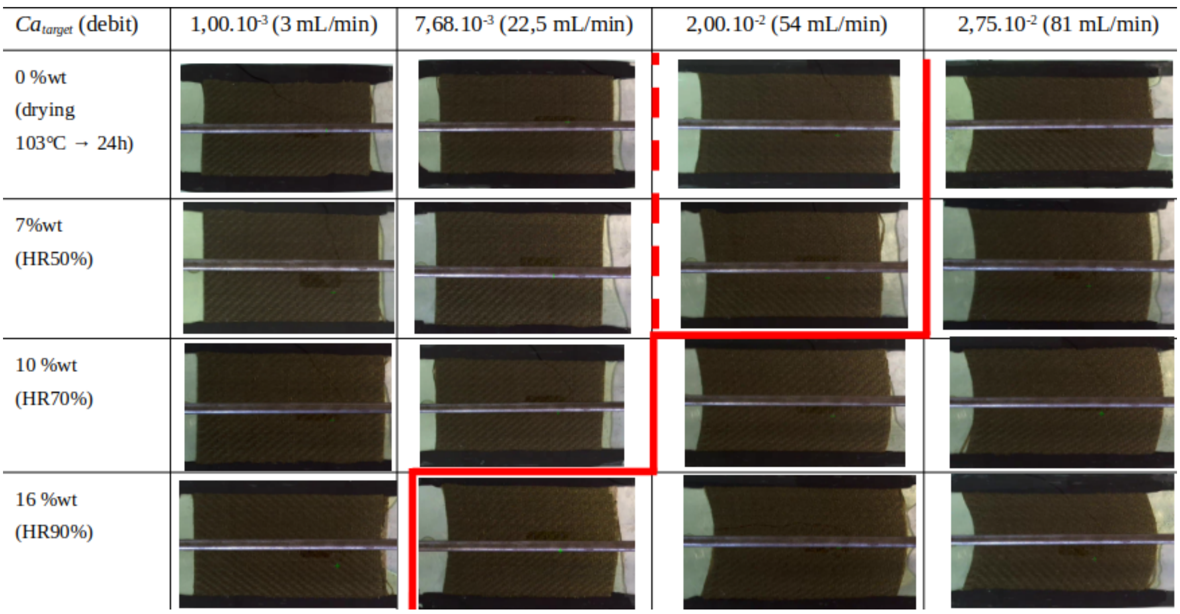

Figure 1: Processability window

The first results highlighted that slippage occurs in preforms with high moisture content, and that this phenomenon intensifies with increasing capillary number, i.e., at higher impregnation flow rates. Accordingly, the numerous impregnation experiments carried out at different capillary numbers and moisture contents made it possible to identify the existence of a processability window (to the left of the red line in Figure 1). From a physical standpoint, this preform slippage is due to its inability to withstand the pressure applied by the resin during impregnation. The preform is characterized by a limiting stress, related to

Terzaghi's work, known as the effective stress. This stress corresponds to the load that can actually be supported by the fibrous skeleton of the preform and represents a threshold that must not be exceeded before slippage occurs [3].

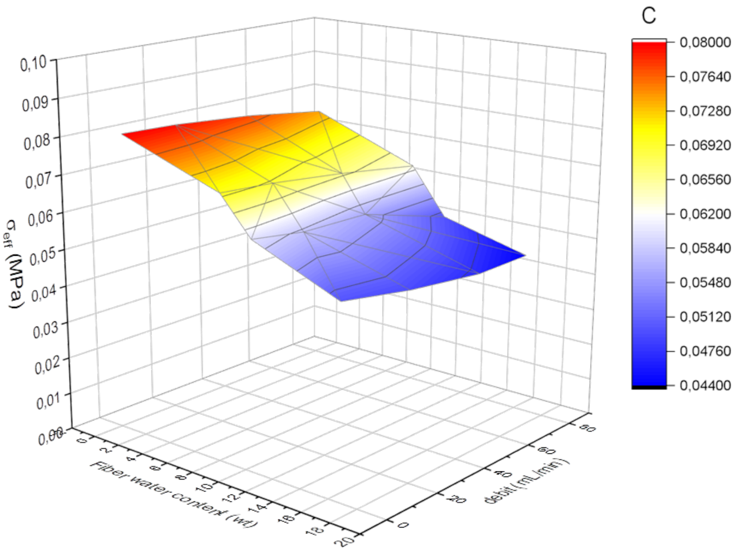

Figure 2: 3D representation of the calculation of effective stress as a function of preform moisture content and imposed resin flow rate

The conducted investigations enabled the determination of the effective stress of the preform for each "moisture content / capillary number (flow rate)" pair. This effective stress tends to decrease with increasing fiber moisture content. At high preform moisture contents, the fibers swell [4]. This swelling reduces the size of both micropores and macropores, thereby decreasing the permeability of the preform and leading to a reduction in effective stress. Increasing the imposed flow rate naturally increases the fluid pressure, which in turn reduces the effective stress. However, it can be noted that the moisture content of the preform has a greater impact than the increase in flow rate.

In parallel, DMA measurements were also performed on the manufactured laminates and highlight the interfacial properties obtained for each parameter pair (moisture content and Ca). The results demonstrate that drying the fibers prior to processing is not necessary and that composites with satisfactory final mechanical properties can be obtained with a controlled moisture content.

The use of this low-tech process could enable industries to rely more heavily on large-scale processes while reducing both economic and environmental costs. Moreover, it allows the investigation, under imposed flow conditions, of the physical phenomena occurring during the processing of natural fiber composites. As a perspective, this work will be extended by considering friction forces involved during impregnation, as well as the influence of natural fiber moisture content on polymer viscosity.

[1] C. Baley, A. Bourmaud, and P. Davies, "Eighty years of composites reinforced by flax fibres: A historical review," *Compos. Part Appl. Sci. Manuf.*, vol. 144, p. 106333, May 2021, doi: 10.1016/j.compositesa.2021.106333.
[2] A. Hindersmann, "Confusion about infusion: An overview of infusion processes," *Compos. Part Appl. Sci. Manuf.*, vol. 126, p. 105583, Nov. 2019, doi: 10.1016/j.compositesa.2019.105583.
[3] K. Terzaghi, *Theoretical Soil Mechanics*, John Wiley&Sons, Inc. 1943.
[4] W. Garat, N. Le Moigne, S. Corn, J. Beaugrand, and A. Bergeret, "Swelling of natural fibre bundles under hygro- and hydrothermal conditions: Determination of hydric expansion coefficients by automated laser scanning," *Compos. Part Appl. Sci. Manuf.*, vol. 131, p. 105803, Apr. 2020, doi: 10.1016/j.compositesa.2020.105803.