Finite element modelling of the coupled hygro-mechanical behaviour of flax fibre-reinforced composites

The problem of moisture ingress into natural fibre-reinforced polymer composites is of prime importance in several sectors like the automotive and marine industries [1]. Indeed, the presence of moisture in these materials can significantly affect their mechanical properties and may lead to a limitation of their use. Therefore, it is crucial to investigate and understand the diffusion kinetics within these composite materials when exposed to humid conditions to ensure their expansion and development. This is the reason why several works have been devoted to the ageing of natural fibre-reinforced composites over the last two decades. A large number of these contributions indicate that the fibre-matrix interface of this type of materials plays a major role in their long term durability. Indeed, water diffusion induces differential swelling of the natural fibre which is principally related to its hydrophilic character. Consequently, fibre swelling could develop internal stress at the fibre-matrix interface level and then causes damage and micro-cracking of the matrix that further accentuates water uptake.

The effect of external loading on the moisture penetration into natural fibre composites is also a relevant issue since it is difficult to imagine an application of natural fibre composite which is not subjected to static or even dynamic loading. For synthetic fibre-reinforced composites, it was shown that the general effect of such mechanical loading is to enhance the moisture-penetration mechanisms which produces higher moisture uptake and consequently, further decreases the durability of the material. As natural fibre-reinforced composites are more sensitive to moisture than the synthetic composites, the effect of mechanical loading in the presence of moisture is of prime importance and should be thoroughly investigated.

This doctoral thesis aims firstly at modelling the coupled hygro-mechanical behaviour of flax fibre-reinforced composites and secondly at developing finite element numerical tools to study the durability of applications using this type of composites. This work will be principally based on the experimental results by Chilali et al. [2,3]. In these latter papers, the authors investigated the effect of water ageing on the load-unload and tensile behaviours of flax fibre-reinforced composites aged in tap water until saturation. This doctoral thesis should be structured around the following key points:

➢ The first point concerns the development of a coupled hygro-mechanical model adapted to flax fibre-reinforced composites. This coupled model should predict the multi-scale mechanical states occurring during both the transient stage and the permanent regime of
the water diffusion process of flax fibre composites subjected to hygro-mechanical loads. This model should also regard the high difference between the hygroscopic coefficients of the flax fibre and the polymer resin which induces high stress concentrations at the fibre-matrix interface. Besides, the strong coupling between the moisture transport and the local stress state should also be considered.

➢ The second point concerns the development of 2D and 3D hygro-mechanical finite elements to conduct numerical simulations on applications using flax fibre-reinforced composites [4]. These applications are subjected to mechanical loading coupled with moisture ageing conditions. The developed finite elements present displacement and moisture content degrees of freedom and should integrate the coupled hygro-mechanical model developed in the first point. They should be implemented in the finite element code ABAQUS using the user element subroutine UEL. The development of these finite elements is mainly motivated by the lack of finite elements with coupled hygro-mechanical models in ABAQUS and more generally the well-known commercial finite element codes.


