LESSONS FROM IN-SITU X-RAY CT AND HIGH-RESOLUTION μ-CT IMAGING OF LIQUID TRANSPORT IN TIMBER FOR BIOCOMPOSITE MANUFACTURE

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Biocomposites are (once again) capturing our imagination with their potential applications: engineered timbers, such as glu-lam and lamintaged veneer lumber, are being used for the construction high-rise buildings [1], and plant fibre biocomposites have become go-to material solutions for automotive interior components [2]. The efficient impregnation of timber and natural fibre reinforcements with fluids, such as preservative chemicals and polymer matrices, is necessary to produce biocomposites with robust performance. However, modelling and characterisation of these biocomposites has remained a challenge [2-5].

Darcy's law describes fluid flow in porous media by their permeability, the driving pressure gradient, and the viscosity of the fluid. The use of a single permeability parameter has shown to be inaccurate in representing the fluid flow in wood [6, 7] and plant fibre composites [2-5]. Pore space within timber is typically around 70% (for softwoods), and between 50-70% for natural fibre preforms. Being naturally hierarchical, heterogeneous materials, there is substantial variation in cell/fibre geometry and pore space distribution. Moreover, as fibres have luminal porosities and as the valve-like bordered pits on cell walls provide the primary path for fluid exchange through the wood (i.e. between cells), the effects of interfacial tension and capillary pressure need to be considered. Swelling of cell walls and constriction of lumens upon absorption and during flow of polar liquids present further challenges for modelling. Simple modified models (to account for say, swelling of cell walls and constriction of lumen) are in current use, but these models lack a sound physical basis, and the match between predictions and experimental data is often poor (often >25% error) [2-5].

We present a model based on increasingly refined geometric parameters that accurately predicts the time-dependent ingress of a liquid in softwood timber thereby addressing a long-standing scientific challenge. Parametrisation of the timber pore space was informed by micro-scale cell morphometry data from high-resolution μ-CT scans of the timber. Model predictions of timber impregnation with choloform are found to be within 3% of experimental data at all times, when the statistical variability of the timber pore space is input in the model (Figure 1). Furthermore, scaling the data highlights that the limiting factor is the drag associated with flow through the bordered pits.

We then use X-ray CT to image Sitka spruce at mm-resolution both in the absence and presence of fluid flow (Figure 2). Detailed measurements of saturations obtained for two different fluids (water, ethyl acetate) show enhanced transport in the least porous regions of the timber, occurring at the interface of late- and early-wood. 3D-reconstruction of the flow alongside spontaneous imbibition experiments offer novel, visual insights, which agree with the mathematical model developed. The flow measurements allow the physics of liquid transport in timber to be understood and modelled at an unprecedented scale. The combination of multi-scale imagining techniques and the developed model are relevant to the advancement of biocomposites.

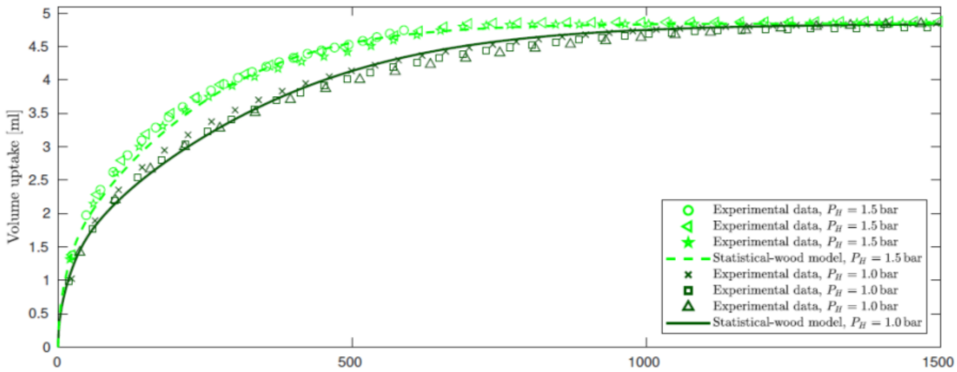

Figure 1: *Data from six independent experiments at two different imposed pressures. The predictions of the statistical-wood model at these are marked by the solid dark-green and dashed light-green curves, respectively.*

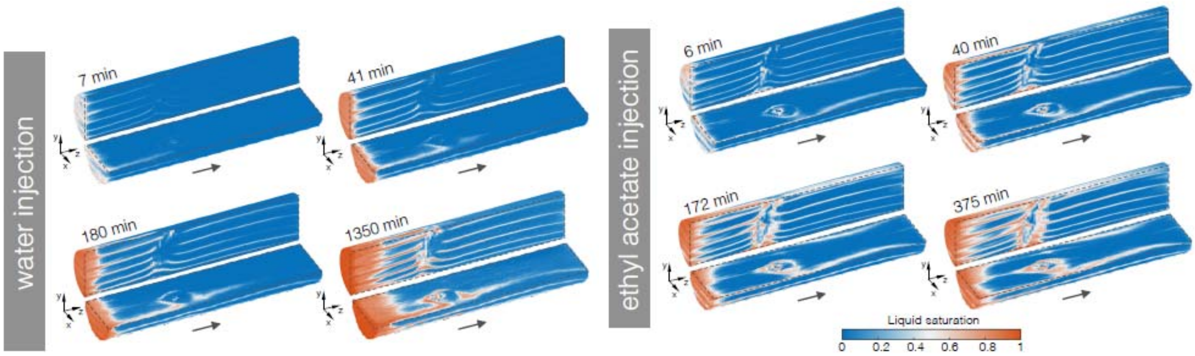

Figure 2: *3D-reconstruction of the timber sample in terms of liquid saturation at different times based on X-ray CT imaging. Voxel size: (0.5×0.5×2)mm^3.*

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