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Moisture-induced swelling of oil-painted linen canvas: experiments and modeling

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Oil-painted linen canvas is a well-used art support system, used for more than five centuries, where the capacity of the canvas and its wood frame to absorb water is not only an issue of dimensional stability and modified material properties, but also of durability and damage for the stiff oil paint. In effect, as water molecules are adsorbed into the hydrophilic matrix in the plant cell walls, the induced fluid-solid interaction forces result in a swelling of the cell walls. Moisture-induced internal stresses highly influence the hygro-mechanical behavior of linen and wood as observed at the macroscale. Further, the interaction of the composite polymeric material, that is the layer S2 of wood and linen cell walls, with water is known to rearrange the internal structure, make it moisture sensitive and influence its physical properties, as demonstrated by fundamental molecular dynamics investigations [1].

Such paintings may be exposed to daily or seasonal environmental variations in relative humidity, although most museums try to minimize such loads. The system of interest here is made of a linen canvas, a size layer, which is traditionally animal glue, a chalk-glue ground layer to flatten the substrate and an oil paint layer, incorporating diverse pigments. The canvas and the size used are hygroscopic, as the textile is made of flax fibers, which cell walls are a polymer-based (i.e. cellulose, hemicellulose and pectins) nanoporous material, while the glue is a protein-based material with subsequent loss of stiffness at high relative humidity. Both materials, and the wood frame, undergo significant swelling and shrinkage under moisture content variation. On the other hand, the oil layer is hydrophobic and dimensionally stable under varying moisture conditions, undergoing internal stress during movement of the base layer.

A multiscale experimental and modelling framework is developed to capture the phenomena of moisture transport, sorption and swelling. We present here the behavior of painted canvas samples undergoing changes in moisture content documented by laboratory X-ray tomography in order to better understand the coupled hygro-thermo-mechanical response of paintings as complex layered systems. The swelling of unrestrained small samples is captured, in terms at the yarn, textile and system scale. Accompanying this experiment, previous work has documented the sorption isotherms of the components of oil-painted canvas [2, 3]. With the moisture-induced swelling and the material properties documented adequately, a finite element model of the hygromechanical behavior of the layered system is then developed and used to identify risk associated with different environmental regimes.

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