

Characterization of Compaction, Permeability, and Multi-Scale Swelling in Flax-based Hybrid Composites

Faron, D., Wiarso, F., Putchakayala, P., Sari, M., Steinhardt, M., Drechsler, K.

Hybrid composites combining natural fibers with synthetic fibers offer the potential to merge the superior damping, radio transparency, and low environmental impact of natural fiber-reinforced composites (NFRC) with the exceptional strength-to-weight ratio of carbon fiber-reinforced polymers (CFRP). This study investigates the processing characteristics of flax-based hybrid composites in liquid composite molding (LCM) processes, with a focus on compaction, permeability, and swelling behavior.

Compaction tests on pure flax, pure carbon, and 50/50 flax-carbon hybrid layups (8, 10, and 12 layers) revealed that flax requires peak pressures up to 40 bar to achieve 60% fiber volume content (FVC), substantially higher than carbon with peak pressures around 1 bar, due to its greater compaction resistance. Hybrid layups with alternating stack orders (flax-carbon vs. carbon-flax) exhibited intermediate pressure requirements, peaking at around 24 bar.

In-plane permeability measurements at different fiber volume contents (FVC) showed that pure flax reinforcements exhibit higher permeabilities at lower FVC compared to pure glass, resulting in faster flow fronts during infusion tests. Hybrid flax/glass layups displayed intermediate permeability values, underscoring the strong influence of compaction stiffness and out-of-plane flow effects induced by hybridization on in-plane permeability.

Multi-scale swelling experiments on flax composites quantified moisture-induced expansion across the fiber, roving, and laminate scales, revealing a consistent trend in the swelling factor. The swelling factor of a unidirectional (UD) layer was markedly lower—around 4%—compared to that of an individual fiber at 21%, indicating that bundling fibers into rovings and stitched layers constrains their expansion and thus reduces the overall swelling.

The empirical data on compaction, permeability, and swelling provides a foundation for a simulation-driven optimization of flax-based hybrid processing in aerospace structural applications, advancing sustainable composite manufacturing.