AIR PERMEABILITY OF BALSA CORE, AND ITS INFLUENCE ON DEFECT FORMATION IN RESIN INFUSED SANDWICH LAMINATES

Richard Cullen[1], Stephen Grove[1] and John Summerscales[1]*

[1] *MAterials and STructures (MAST) Research Group/Composites Engineering*
School of Engineering, University of Plymouth, Plymouth, PL4 8AA, United Kingdom.
*Corresponding author (J.Summerscales@plymouth.ac.uk)

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Introduction

Many large composite structures are manufactured using sandwich laminates to achieve high specific bending strength and stiffness. For wind turbine blades, the self-weight becomes increasingly important as blade size increases. Resin infusion of three-dimensional sandwich laminates can result in complex flow paths, and subsequent defect formation is difficult to predict. The core material used for sandwich construction and its interaction with liquid resins may also influence the formation of defects.

This paper considers the effect of cored sandwich laminate construction on the formation of defects. The primary focus is the characterisation of commonly used core materials and their interaction with liquid resin under high vacuum conditions. For balsa core, experiments indicate that the available pore space can act as a sink for trapped air, which can aid the reduction of defects when multiple flow fronts converge due to the complex flow paths in sandwich laminates.

Empirical data for air absorption and desorption rates in balsa core were obtained using a custom-designed experiment. Using these data, a theoretical model was developed that can indicate available pore space, which in turn informs optimum processing conditions, such as time under vacuum. The diffusion coefficients obtained for air absorption and desorption in balsa are very similar, and lie in the middle of published ranges for hard woods at around 2 x 10-7 m^2/s. The methodology developed represents actual behaviour of air absorption/desorption during resin infusion, whilst other techniques do not, merely measuring diffusion of air through a sample while not allowing for finite pore space. In consequence, infusion strategies can be planned more precisely because the core/resin interaction is better understood. Knit line defect formation could be predicted with greater accuracy with suitably modified flow-modelling programs.

Experimental methodology

Experiments were conducted using unsealed Baltek AL600 end-grain balsa samples (40 x 40 x 30 mm). Thirty samples were dried for 48 h at 103°C as per ISO 3130. After storage in a holding desiccator, they were weighed and the density calculated. The samples were then exposed to ambient conditions (20°C, 42% RH) for 48 h and then re-dried for four days. Similar experiments were conducted on three larger (60 x 60 x 25 mm) samples for moisture absorption over 40 h.

The 30 samples were wrapped in infusion mesh and immersed/weighted in 8 L of water in a vacuum pot. The chamber was evacuated to 80 mbar absolute for 100 h (lower absolute pressure caused the water to boil). The samples were then dried of excess surface water, weighed, then re-dried.

Resin penetration experiments were conducted using a proprietary epoxy resin. End grain balsa can absorb or release air during resin infusion. The rate at which this occurs may be critical in composite manufacturing, especially if the timescale is longer than that of the commercial process. A two-chamber apparatus was developed with a 1.5 L sample (six cylindrical pieces) sensibly filling one chamber connected to a 2.5 L reservoir. SDX 15D4 pressure sensors were used in both chambers and a Digitron 2085P digital pressure gauge on the vacuum line. Diffusion coefficients were determined based on a modification of the Carslaw and Jaeger [1] classical solution for heat transfer.

Comparative tests were run with impermeable acrylic sheet or balsa core to examine the effect of core porosity on the presence of knit lines in a 150 mm square model laminate. The experimental rig produced four separate glycerol flow fronts from holes near the corners of the core, with flow converging to the centre of the plate.

Subsequent infusion experiments were conducted with EBX936 non-crimp glass fabric and the proprietary epoxy resin. Five core materials were used: (i) unsealed 130 kg/m^3 Baltex AL600 balsa (ii) sealed 150 kg/m^3 Baltex AL600T balsa, (iii) Fagerdala 150 kg/m^3 PET foam, (iv) 60 kg/m^3 Airex T90.60 PVC foam, and (v) 1180 kg/m^3 Perspex poly(methylmethacrylate) (PMMA) solid as a non-permeable reference panel. A square grid of 3 mm flow holes were drilled through the core with either 25mm or 40 mm spacing. A high flow distribution medium was used to ensure that flow through the laminate thickness would be virtually simultaneous for all samples.

An experimental apparatus built to establish absorption/desorption rates in/from core materials [2]. An initial series of experiments were conducted to establish any equipment leak rate (measured over 7 days), baseline absorption/desorption levels, and absorption/desorption dependencies on core material volume. Absorption and desorption runs were conducted using tightly fitting discs of unsealed AL600 end grain balsa from a single panel.

Results

The initial average density of the small samples was 119 kg/m^3 and average moisture uptake was 6.7% by weight. The sample masses after re-drying were marginally lower (within the boundaries of experimental error) than after initial drying. The average moisture uptake for the three larger samples was 7.4% by weight (Fig. 1). The rate of moisture absorption was quite rapid, with 50% of the final level reached in the first 100 minutes of the experiment.

In the infusion experiments, the spacing of the flow holes made little difference to the fill times. Knit lines were present where fibre tows did not fully wet-out leaving partially impregnated fabric where residual gases are compressed preventing resin from fully filling the region of convergence (Fig. 6). The unsealed balsa produced notionally defect free panels, while the PET and acrylic cores had poor laminate quality. When balsa is used as the core, as the air is compressed by the advancing flow front it can be absorbed by the core material with consequent elimination of the defects.

In considering balsa as a resin sink, small differences between absorption and desorption behaviour can be explained by the different ambient pressures at experiment start (~10 mbar), and the fact that balsa is a variable natural material making it susceptible to ambient condition fluctuations. 'Apparent' diffusion is comprised of two components of resistance to diffusion: external surface resistance and internal resistance.

Resin flow was modelled using PAM-RTM or Liquid Injection Moulding Simulation (LIMS) finite element software. PAM-RTM was unable to deal with two-phase flow, which limits the effectiveness of the simulation, as air drawn into a porous core was not simulated. Using LIMS, with an absolute pressure within the mould cavity defined for a simulation, the prediction of lock-off was sensitive to the mesh density used. This model was capable of simultaneously modelling multi-scale (macro- and micro-) flow but proved to be complex.

More complete information can be found in the doctoral thesis [2] and a paper at ICCM-21 [3].

Conclusions

The fabric architecture can have a significant effect on resin flow in a monolithic laminate, and the consequent formation of voids. This potential for void-related defect formation is greatly increased due to the complex 3D flow in a cored laminate, particularly when using un-sealed end-grain balsa where the sap channels provide increased through-thickness flow channels. The chosen infusion strategy and materials selection are both vital considerations in reducing the formation of voids.

Experiments have been conducted to provide data on the pore space in core materials, the absorption/desorption rate of air, and a diffusion coefficient for end-grain balsa wood. This knowledge has been utilised to show that evacuated partially permeable core materials in resin infused panels can permit manufacture of panels with reduced or eliminated knit line defects.

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