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Manufacturing of pultruded rod based hierarchical composite structural members

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ABSTRACT

Inspired by natural composites such as bamboo (Figure 1) or bone, the NextCOMP programme [1] seeks to improve compressive performance through a novel, hierarchical approach to advanced composites. Features designed to improve compressive performance are introduced at multiple length scales. Novel fibres and resins are under development, along with new approaches at the ply level. These hierarchical composites present different manufacturing challenges than traditional fibre-reinforced composites.

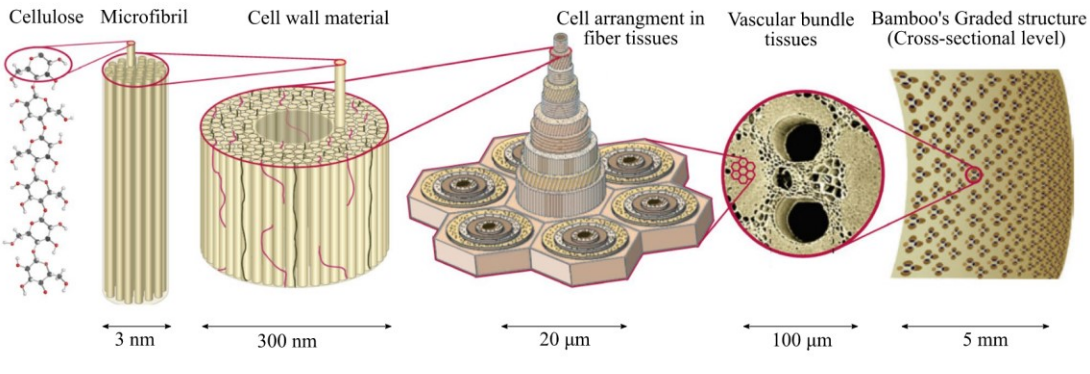

Figure 1. Illustration of hierarchical structure of bamboo. Reproduced from [2]

This work focuses on hierarchical composites based around pultruded carbon fibre-epoxy rods. In order to deliver the desired compressive properties, these must be manufactured with good rod alignment and minimal porosity. The pultruded rods [3] are a carbon fibre-epoxy system of 0.8 mm diameter (Figure 2). The rods are flexible.

Cylindrical struts were chosen as a trial of the hierarchical composite concept. These consist of carbon-fibre epoxy pultruded rods of circular cross-section, combined with a second resin. Use of two resin systems, one within the rods and another surrounding them, allows more options to tailor the properties to improve compressive performance.

Cylindrical struts were manufactured by vacuum infusion, using a resin which is liquid at room temperature, in contrast to previous work with a heated resin [4]. Initial trials used a rigid, transparent borosilicate tube as the tool. The tube, internally coated in release agent and packed with rods, was suspended vertically with the inlet at the base and outlet at the top of the tube. Prime 27 resin [5] with Prime slow hardener [6] was measured according to the manufacturer's guidelines, mixed and de-gassed for 30 min prior to infusion. The speed of the infusion was controlled using clamps on the inlet tube. Following infusion the strut was cured in an oven at 80 °C for 4 h.

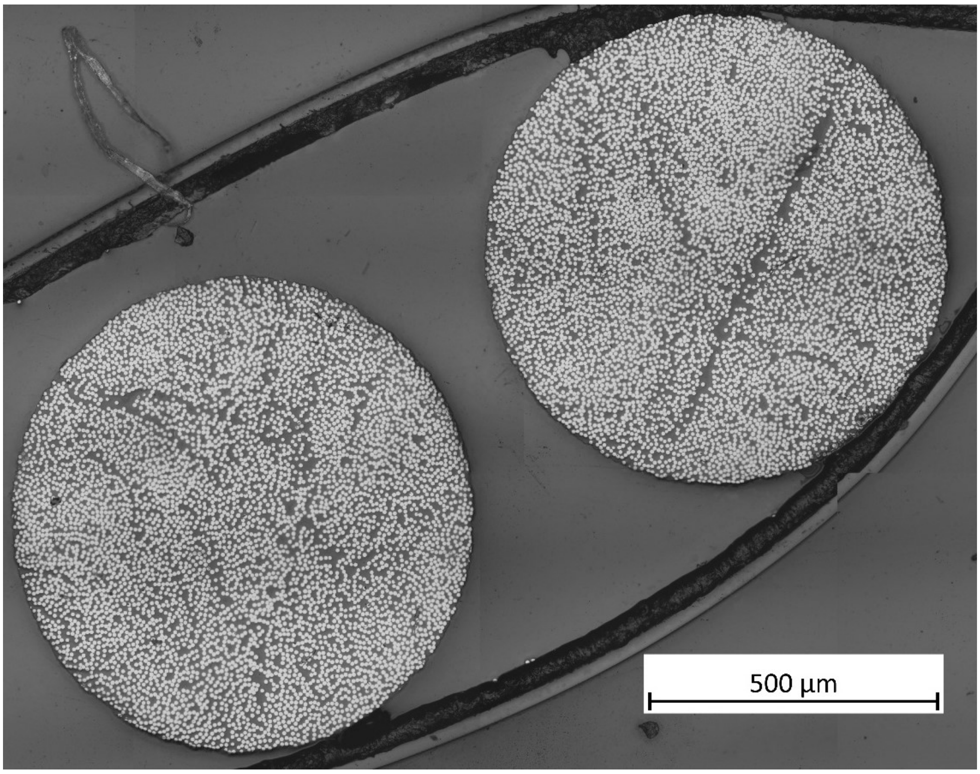

Figure 2. Cross-section of two pultruded rods taken using Zeiss microscope 20x lens.

During infusion racetracking between the rods and tube was clearly visible.

Cured struts were sectioned and inspected by microscopy and X-ray CT. While the rods were packed tightly during setup, movement during infusion and cure was sufficient to result in non-uniform rod density. Voids were present throughout including some large voids between tightly packed rods thought to be due to internal racetracking (Figure 3).

The method was therefore modified to use flexible tubing as the tool. The flexible tubing was wrapped in a vacuum bag which provided radial pressure. Again, the tube was held vertically and the same infusion and cure procedure performed as previously.

The flexible tool method delivered a marked improvement in rod density and significant reduction in porosity (Figure 3), including a complete lack of the large resin free zones between rods characteristic of racetracking at the outer edge.

Porosity analysis of X-ray CT reconstructions was carried out by two methods - the VG Studio porosity analysis tool using the largest feasible region of interest, and an in-house algorithm analysing slices from the same CT scan, manually verified using ImageJ.

The rigid tool strut with the lowest porosity (Figure 3) had a void fraction of 2.2 ± 1.1% according to the in-house algorithm, which agrees with the VG studio figure of 2.16%. The flexible tool strut with the highest porosity had a void fraction of 0.6 ± 0.1% according to the in-house algorithm, again in agreement with the VG studio figure of 0.51%. This shows a reduction in porosity of 76%.

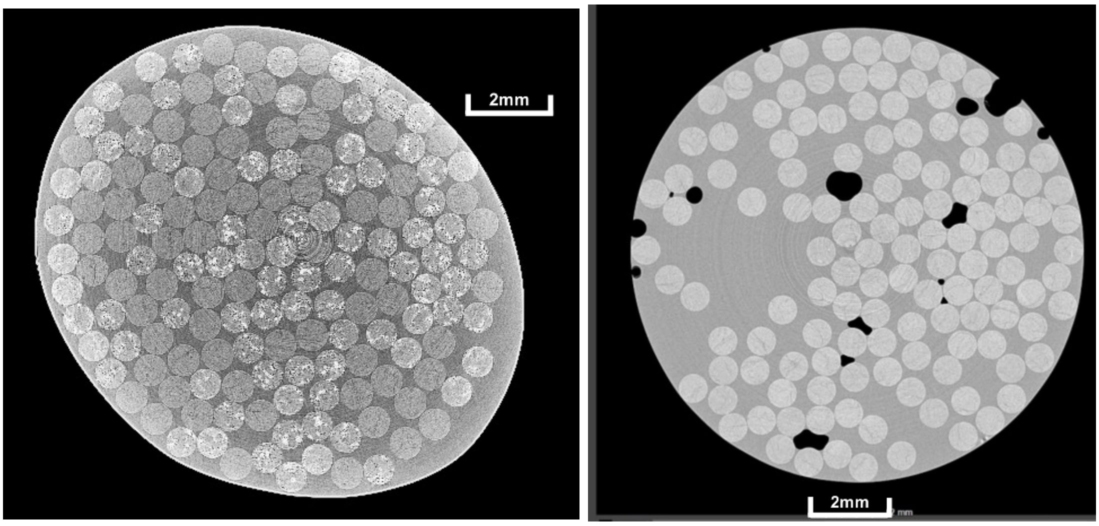

Figure 3. Cross section slices of X-ray CT reconstructions of rigid tool strut (left) and flexible tool strut (right).

However, the flexibility of the tool results in a strut cross section which is not cylindrical (Figure 3). It is feasible to make a larger strut than required and machine it to shape. Tooling of intermediate flexibility is under investigation.

The next stage of the work is to incorporate overbraided pultruded rods. The overbraids are intended to constrain kink band formation at the rod level, which should improve performance under compression. These struts will then be tested under compression.

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