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Development of Resin Modulus During Cure

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AIMS: To characterise the modulus of an epoxy resin during cure using a simple and repeatable test methodology

Background: Determining the relationship between degree of cure (α), temperature (T) and modulus (E) during cure is critical for process modelling and the determination of residual stresses and warpage that arise in composites from mismatches between the modulus of the resin and fibres, tooling etc. Whilst thermosetting materials such as epoxies behave viscoelastically, especially at low degrees of cure and high temperatures, they can be modelled as instantaneously elastic, reducing the amount of characterisation required and the computational requirements of the models generated. The instantaneous elastic modulus of the epoxy resin during cure is typically taken to be the storage modulus from isothermal bi-material beam dynamic mechanical analysis (DMA) experiments. However there are several limitations to the present experimental technique which are addressed in this work:

Experimental method

1. Perform dynamic DMA experiment on shim material

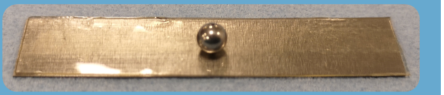

Figure 1: Steel shim with uncured resin film

2. Stick uncured resin film to steel shim to form bi-material beam
3. Clamp bi-material beam into 3PB DMA rig using a sacrificial ball bearing to prevent beam from curing onto the DMA machine

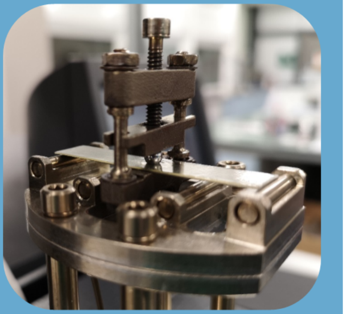

Figure 2: DMA 3PB bi-material beam experiment clamped in centre

4. Perform isothermal experiment to extract the effective stiffness
5. Calculate the epoxy modulus using beam theory

$$EI_{eff} = E_1 I_{1NA} + E_2 I_{2NA}$$

Current experimental limitations

1. Clamping at centre is not true 3PB
2. Current methods treat resin cross-section as rectangular, meaning that the calculated resin modulus requires normalisation to that from a cured sample
3. In reality the surface tension of the resin a parabola. Figure 3 shows the sensitivity of the resin modulus to resin distribution while keeping resin volume constant

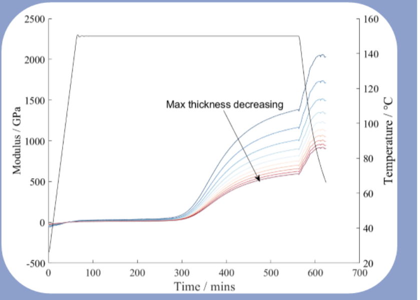

Figure 3: Resin distribution sensitivity study

Devised experimental solutions

1. Custom DMA rig that applies oscillation through disposable razor blade
2. Laser scan samples to get resin thickness

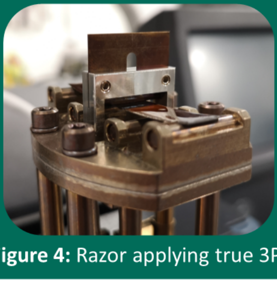

Figure 4: Razor applying true 3PB

Laser scanning DMA samples

Accurate and fast method of determining true resin distribution enabling a more accurate determination of epoxy modulus

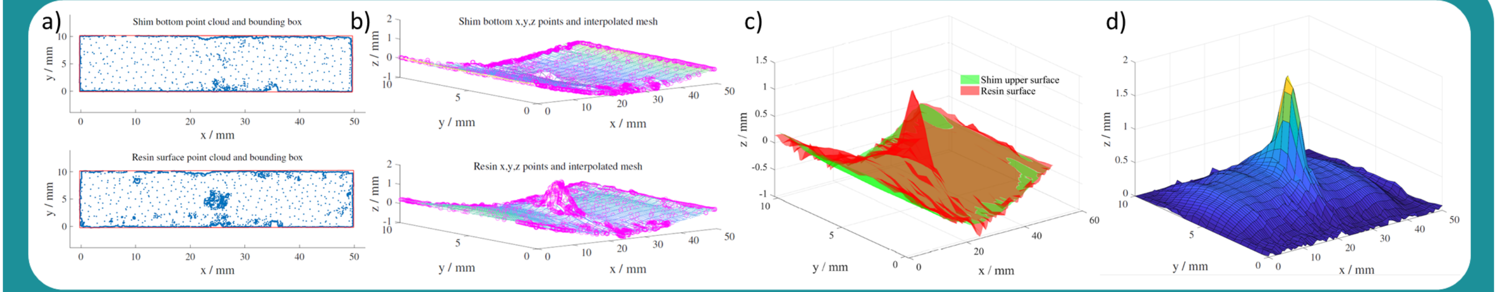

Figure 5: a) Apply bounding box to cloud points. b) Fit interpolated surface to top and bottom of beam. c) Add thickness of shim to bottom surface to find bottom of resin. d) Calculate distance between two surface to extract resin thickness.

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