Challenges in determination of cohesive laws from R-curves of unidirectional composites experiencing delamination damage

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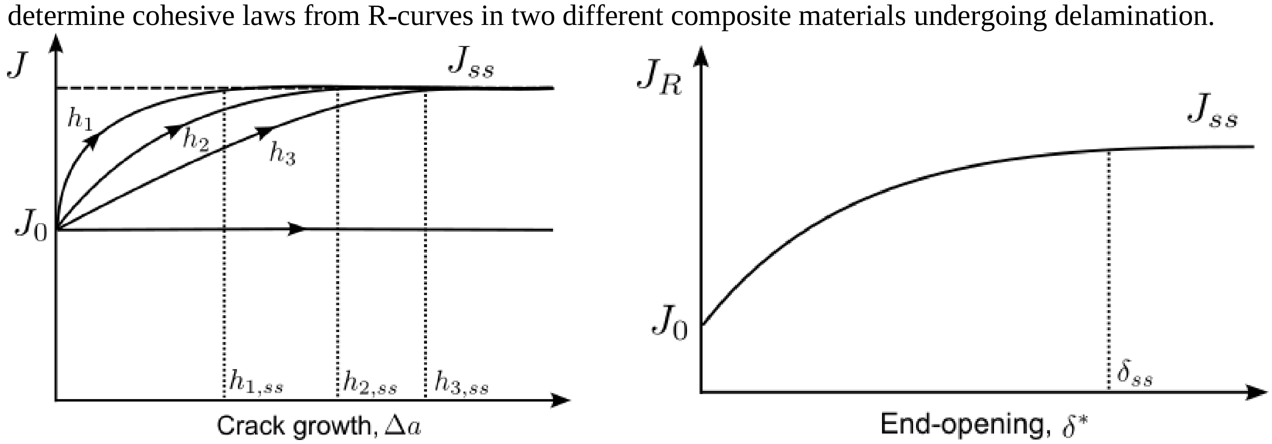
Keywords: Fibre composites, Delamination, Fracture resistance, R-curve behavior

ABSTRACT

With the growing size of wind turbine rotor blades, it is unrealistic to expect composite laminates used in a rotor blade structure to be free from defects. Instead, it would be appropriate to accept that damages will form in these laminates either from manufacturing defects and then try to limit or allow damage growth in a stable manner or arrest. Fortunately, most fibre composite materials are damage tolerant and can exhibit increased fracture resistance under stable damage growth.

Delamination is one of the critical damage types seen in composite structures which is often associated with loss in stiffness and overall load-carrying capability and can eventually lead to structural failure [1]. The delamination crack growth may be characterized by the material fracture resistance, known as R-curve [2], which is a graph showing the J-integral as a function of the crack growth, as shown in Figure 1. The fracture resistance is the value of the J-integral when the crack grows, defined by J_0 for crack-tip initiation and J_{ss} for steady-state crack growth. The R-curve as such has been shown not to be a material property but depend on specimen size [2]. Instead, it has been shown that the J integral as a function of end-opening and cohesive laws (traction as a function of separation are independent of specimen size). The present work aims to determine cohesive laws from R-curves in two different composite materials undergoing delamination.



(a) (b)

Figure 1: A schematic illustration of 'R-curve' behavior in fibre composite materials exhibiting fibre bridging. a) J integral plotted against crack extension and with specimen thickness dependence and b) J integral plotted against end-opening (independent of thickness).

In the present study, an experimental campaign was carried out to extract cohesive laws for two different unidirectional composites: i) Material A and ii) Material B. Both these materials have common UD fabric but different resins: vinylester and flexible resin (with very high elongation) respectively. Test laminates with pre-inserted slip foil were made by vacuum infusion. Specimens of dimensions 500 mm x 24 mm were cut form each laminate plate and bonded with high strength steel beams of thickness 2 mm on both sides. Prior to bonding of steel beams, surface of the laminate was grinded slightly (removing about 0.5 mm) so that the surface was plane, and fibres were exposed making stronger adhesion with the steel beams. Static Double Cantilever Beam (DCB) tests loaded by pure bending moments were performed on the two specimen series under displacement control. Digital Image Correlation was used to measure crack end opening displacements. Further, two acoustic emission sensors were mounted on DCB specimens to record delamination damage growth activities. Two cameras were used to record the DCB test, one camera positioned near to crack tip for extracting end openings and the other having large field of view to capture specimen curvature.

Figure 2 shows the Mode I R-curve behavior for Material A (shown in purple color) and Material B (shown in light blue color). The fracture energy for crack tip initiation (J_0) in case of Material B was significantly much higher than the Material A. Further, the steady-state fracture energy (J_{ss}) also found to be approximately two and half times more than that of the Material A. Based on these R-curves, cohesive laws were determined for both the material systems.

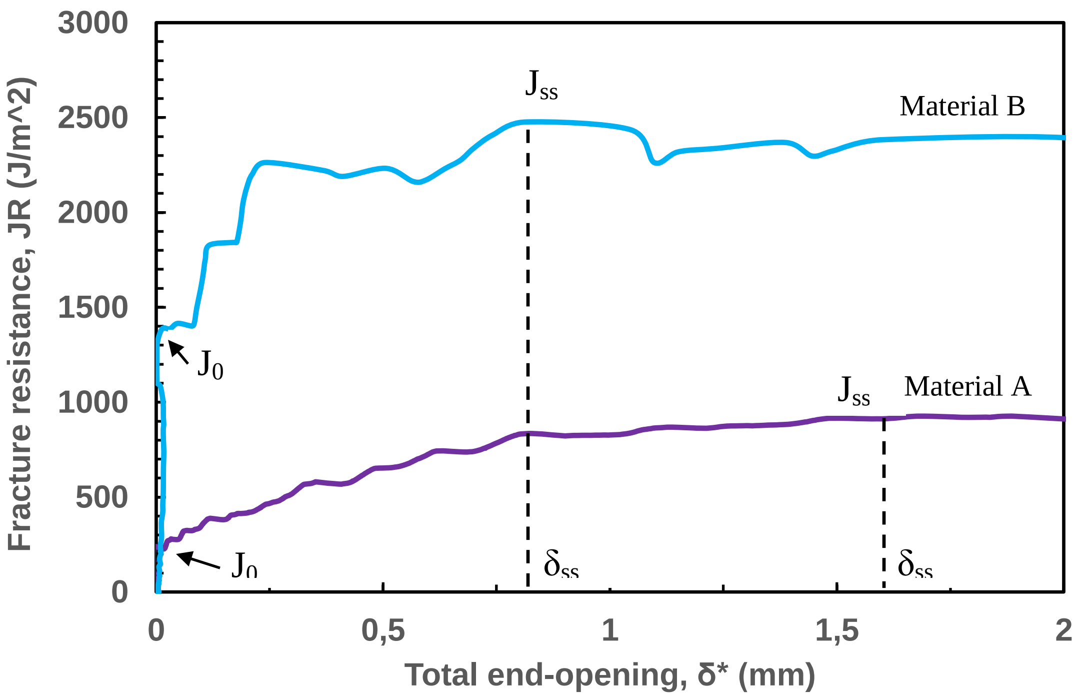


Figure 2. A comparison of Mode I delamination crack growth (R-curve behavior) in two different unidirectional composite materials.

References

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