11th International Conference on Composites Testing and Model Identification
J. Costa, J. Renart and N. Blanco (Editors)
Girona, 2023

DETERMINING FRACTURE PROPERTIES FOR PREDICTING DAMAGE PROPAGATION FROM NOTCHES IN COMPOSITE STRUCTURES

Michael R. Wisnom[1], Xiaoyang Sun[1] and Xiaodong Xu[2]

[1]Bristol Composites Institute, University of Bristol, BS8 1TR, UK.
Email: M.Wisnom@bristol.ac.uk, web page: www.bristol.ac.uk/composites

[2] University of the West of England, Coldharbour Lane, Bristol BS16 1QY, UK.
Email: Xiaodong.Xu@uwe.ac.uk

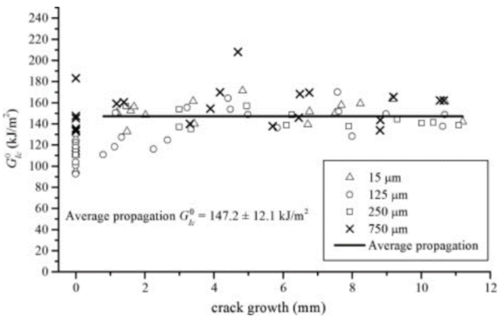
Keywords: Fracture mechanics, Translaminar fracture toughness, R-curve

ABSTRACT

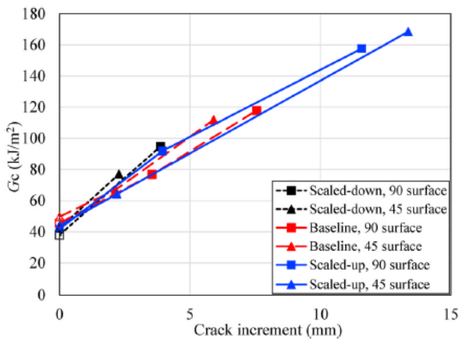
Although composites exhibit distributed damage rather than sharp cracks, linear elastic fracture mechanics can be a useful tool for predicting failure from notches [1]. To do so requires the value of translaminar fracture toughness, and this paper considers the question of whether fracture toughness is a material property, and how it should be measured.

Some authors refer to the fracture toughness of unidirectional material, but if a unidirectional composite with a sharp notch is tested, it will split, and it is not possible to obtain propagation of fibre failure from the notch tip. Although fracture toughness can be back-calculated from laminate tests, splitting also occurs at notches in laminates and the amount of splitting and associated fracture toughness depends strongly on the layup and whether plies are blocked together [2]. Translaminar toughness decreases with reducing ply thickness, associated with smaller damage zones with reduced pull-out lengths [3]. Absolute laminate thickness can also affect fracture toughness [4]. Fracture toughness therefore must be considered as a laminate property.

The next question is whether a single value of fracture toughness can be used, or whether it is necessary to consider R-curves. Some results show approximately constant toughness, whereas others show substantial increases with crack propagation, Figure 1.



a) Cross-ply [5]



b) Quasi-isotropic [6]

Figure 1: Different R-curves for IM7/8552 laminates

Again this behaviour depends on the layup, with cross-ply laminates showing a much smaller damage zone, associated with less of a resistance curve. Quasi-isotropic specimens can have large damage zones, with extensive delamination, as shown for example by X-ray CT in Figure 2. R-curves also depend on the ply thickness. Quasi-isotropic carbon/epoxy laminates with plies only 0.03mm thick show a flatter R-curve as well as much lower values of toughness.

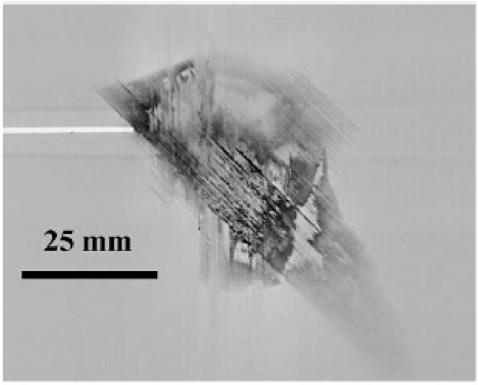


Figure 2: Large damage zone at notch [6]

A key question is how to measure the R-curve. The results in Figure 1b were obtained with over-height compact tension specimens, which reduce one of the potential problems of premature compressive failure. It is important that the specimen is sufficiently large to allow sufficient crack propagation to reach the expected plateau value of constant fracture toughness. Standard sized specimens 106x208mm were used, together with ones with halved and doubled dimensions. Even the scaled-up 212x416mm specimens were not large enough to deduce the full R-curve, and there are challenges with potential buckling. Also care needs to be taken in interpreting the results as later points on the R-curve may be invalid due to insufficient remaining size of the ligament compared with the damage zone size, invalidating the data reduction. Better test methods are needed to overcome these limitations.

Another issue is the definition of crack length. More consistent results are obtained when the process zone is included to define an effective crack length. If the nominal crack length is taken when deriving fracture toughness, the value will tend to be too low, which may give overconservative results when predicting notched failure. However if the effective crack length is used, and the specimen is sufficiently large to establish the crack resistance behaviour, satisfactory predictions of failure may be obtained based on linear elastic fracture mechanics [1].

REFERENCES

[1] Xu, X., Takeda, S.I., Aoki, Y., Hallett, S.R., Wisnom, M.R. *Predicting notched tensile strength of full-scale composite structures from small coupons using fracture mechanics,* Composite Structures, **180**, 2017, p. 386-394. https://doi.org/10.1016/j.compstruct.2017.08.026

[2] Li X., Hallett, S.R,, Wisnom, M.R., Zobeiry, N., Vaziri, R., Poursartip, A. *Experimental study of damage propagation in overheight Compact Tension tests,* Composites Part A, **40**, 2009, p. 1891–1899. https://doi.org/10.1016/j.compositesa.2009.08.017

[3] Teixeira, R.F., Pinho, S.T., Robinson, P. *Thickness-dependence of the translaminar fracture toughness: Experimental study using thin-ply composites,* Composites Part A, **90**, 2016, p. 33–44. https://doi.org/10.1016/j.compositesa.2016.05.031

[4] Xu, X., Paul, A., Wisnom, M.R. *Thickness effect on Mode I trans-laminar fracture toughness of quasi-isotropic carbon/epoxy laminates*, Composite Structures, **210**, 2019, p. 145-151. https://doi.org/10.1016/j.compstruct.2018.11.045

[5] Laffan, M.J., Pinho, S.T., Robinson, P., McMillan, A.J. *Translaminar fracture toughness: The critical notch tip radius of 0° plies in CFRP,* Composites Science and Technology **72**, 2011, p. 97-102. https://doi.org/10.1016/j.compscitech.2011.10.006

[6] Xu, X,, Sun, X., Wisnom, M.R. *Initial R-curves for trans-laminar fracture of quasi-isotropic carbon/epoxy laminates from specimens with increasing size,* Composites Science and Technology, **216**, 2021, 109077. https://doi.org/10.1016/j.compscitech.2021.109077