Accepted Manuscript

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PII: S0266-3538(17)31412-4

DOI: 10.1016/j.compscitech.2017.09.007

Reference: CSTE 6896

To appear in: *Composites Science and Technology*

Received Date: 12 June 2017

Revised Date: 6 September 2017

Accepted Date: 7 September 2017

Aligning carbon nanofibres in glass-fibre/epoxy composites to improve interlaminar toughness and crack-detection capability

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Abstract

An electric field is used to align carbon nanofibres (CNFs) in the matrix of a glass-fibre reinforced-polymer (GFRP) composite to simultaneously improve the (a) delamination toughness, (b) electrical conductivity and (c) damage-sensing capability. The CNFs are added to the epoxy resin prior to the manufacture of the GFRP composites. To align the CNFs, an alternating current (AC) electric field of 30 V/mm at 10 kHz is applied across the GFRP sheet throughout the matrix-curing process. The electromechanical force induced by the electric field, applied in the through-thickness direction of the composite sheet, rotates and aligns the CNFs in the direction of the applied electric field prior to the gelation of the epoxy matrix. After curing, the resultant aligned, 'chain-like', microstructure of the CNFs in the epoxy matrix significantly enhances both the interlaminar fracture toughness and the through-thickness electrical conductivity of the GFRP composite. Specifically, the addition of 0.7 vol% of randomly-orientated CNFs in the GFRP composite yielded an ~50% and 25% increase in the values of the mode I fracture toughness pertinent to the initiation, G_{Ici}, and steady-state growth, G_{Icss}, of delamination crack, respectively, compared to the control GFRP composite. The alignment of the CNFs, in the transverse direction to the direction of the crack growth, increases the mode I toughness values of G_{Ici} and G_{Icss} by ~100% and ~80%, respectively, compared to the control GFRP composite. These significant increases are attributable to multiple toughening mechanisms, including debonding of the CNFs from the matrix, void growth of the epoxy matrix, pull-out and rupture of the CNFs. Further the electric-field induced alignment of the CNFs, in the through-thickness direction, increases the out-of-plane electrical conductivity of the GFRP