SCALING-UP PRODUCTION OF CNT-COATED FIBRE REINFORCEMENT USING CONTINUOUS EPD FOR HIGH-PERFORMANCE AND MULTIFUNCTIONAL COMPOSITES

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Introduction

It is important within the composite community to improve out-of-plane performance of composites dominated by polymer matrix and properties of matrix-rich regions formed in the gaps between the interlaced fibre bundles. These properties are difficult to modify with traditional fibre reinforcement. Various nanoscale materials have been explored for such purpose, among which carbon nanotube (CNT) has been suggested as an ideal candidate because of its outstanding mechanical, electrical and thermal properties (1). Electrophoretic deposition (EPD) is considered as a cost-effective method to deposit CNTs onto substrates with mild working conditions, requiring relatively simple equipment and being amenable to scaling up (2,3). Due to the shortcoming of existing laboratory setup which corresponds to a non-continuous process, EPD has not been used at even a pilot plant scale for nano-coated fibre reinforcement. The current work presents the development of a prototype and method for continuous EPD process. Geometric defect of fibre reinforcement introduced during the deposition, which can shadow the reinforcing effect of CNT deposit, was discovered. Enhancement of composite properties by the CNT deposit was hence shown.

Mechanism of continuous EPD setup

The mechanism underpinned the continuous EPD setup is to make the fibre reinforcement as a movable electrode being fed through EPD bath at a certain speed so that every spot on the reinforcement can get deposition for defined time. In order to maintain the concentration consistence of the CNT in the EPD bath the viscosity of CNT suspensions prepared with different known concentrations is measured. Fitting the experimental data will lead to a model describing the variation of CNT concentration as a function of viscosity. When the viscosity of CNT suspension is measured during EPD process the concentration of the suspension can be deduced using the model. The amount of CNT suspension with tailored concentration to be added into the EPD bath can thus be calculated.

Materials, composite manufacturing and testing

A unidirectional carbon fibre fabric with a surface weight of 205 g/m^2 (Porcher composites) was used as the reinforcement. An epoxy system, Araldite® LY556/Aradur® 917/accelerator DY070 (Huntsman) with a mixing ratio of 100/90/0.5 (parts by weight) was used as matrix. Aquacyl™ AQ0302 (Nanocyl), a water suspension of 3 wt% of NC7000™ (an industrial MWCNT product without any chemical functionalization) was used for the EPD bath, which was diluted to 0.1 wt%, 0.025 wt% and 0.005 wt%, respectively, using deionized water, for treating the carbon fiber fabric.

In the continuous EPD process the strength of the electrical field was fixed at 10 V/cm. The fabric was fed through the bath at a constant speed of 50 mm/min leading to a deposition time of 3 min for every spot on the fabric. Additional batch of reference fabric was subjected to the same treatment procedure as CNT-treated fabrics through the EPD prototype but without addition of CNTs.

Unidirectional $[0]_{20}$ laminates were manufactured via RTM process with infusion and curing pressure of 3 bar, infusion temperature of 40°C and curing at 80°C for 16 h followed by post curing, free standing at 140°C for 4 h.

3-point bending (ASTM D790) and short beam shear (ASTM D2344) tests were carried out on reference composites with fabrics as received, composites with fabrics treated through EPD process but without CNTs, and composites with CNT-deposited fabrics.

Results

Figure 1 shows SEM images of randomly selected fabrics from continuous deposition with 0.1 wt% and 0.025 wt% CNT suspensions, respectively. The CNTs were deposited through the thickness of fabrics, not only onto the carbon fibres on the surface layer of the fabrics. CNTs were densely deposited by using 0.1 wt% suspension, almost covering the surface of carbon fibres like a blanket. Lower concentration led to the deposit relatively sparse and more uniform. The flexural properties of composites with CNT doped fabrics are lower than that of reference composite with fabric as received – the reduction of flexural modulus, strength and strain is around 9%, 17% and 10%, respectively; only ILSS values were comparable. Optical microscopic study revealed waviness and misalignment of significant amount of bundle in laminates with fabric treated through EPD process regardless of the addition of CNTs (Figure 2). Compared with the composite with fabrics treated through EPD process but without CNTs, properties of composite with doped fabrics using 0.005 wt% CNT suspension were improved – the flexural strength and strain was increased by 14% and 11%, respectively, while the flexural modulus was almost the same, and the ILSS was increased by 9%.

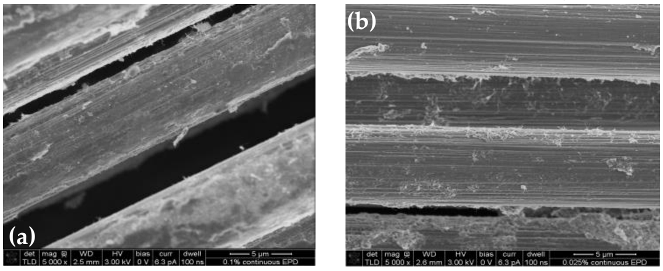

Figure 1: *SEM images of deposited carbon fabric by (a) 0.1 wt% and (b) 0.025 wt% CNT waterborne suspension via the continuous EPD prototype.*

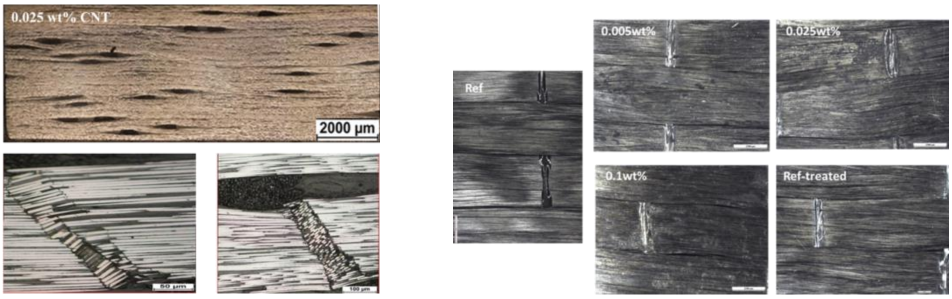

Figure 2: *Microstructure of the laminate with 0.025 wt% of CNT (upper left) showing bundle waviness and fiber microbuckling (bottom left) in specimens after 3P bending test. Waviness of bundles in the dry reinforcement (right): in reference, reference-treated and CNT-treated fabrics.*

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References

[1] Gojny, F.H., Wichmann, M.H.G., Fiedler, B., et al. Influence of nano-modification on the mechanical and electrical properties of conventional fibre-reinforced composites. *Composites: Part A: applied science and manufacturing*, 36: 1525-1535, 2005

[2] Bekyarova, E., Thostenson, E.T., Yu, A., et al. Multiscale carbon nanotube-carbon fiber reinforcement for advanced epoxy composites. *Langmuir*, 23: 3970-3974, 2007

[3] Fernberg, S.P., Joffe, R., Edgren, F. Carbon nanotube treated carbon fibre preforms for improved properties of aeronautical grade composites, in: *ECCM 15 – 15th European Conference on Composite Materials, Venice, Italy*, 24-28 June 2012