SCALE EFFECTS IN THE POST-CRACKING BEHAVIOUR OF CNT-EPOXY COMPOSITES: PREDICTING CRACK JUMPS AND DUCTILE-TO-BRITTLE TRANSITIONS

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Abstract
The scale effects on the global structural response of fibre-reinforced brittle-matrix specimens subjected to bending are discussed in the framework of Fracture Mechanics by means of the Updated Bridged Crack Model (UBCM). This analytical model assumes the composite as a bi-phase material, in which both the brittle matrix and the reinforcing fibres contribute to the global toughness [1-3]. In particular, the bridging mechanism of the reinforcing layers can be described by an appropriate cohesive softening constitutive law, which takes into account the progressive slippage of the fibre inside the matrix [4,5]. In addition, the discontinuous phenomena, i.e., crack jumps (snap-back) and snap-through instabilities, which experimentally characterize the post-cracking behaviour of the composite, can be captured in a quantitative way [1]. Furthermore, UBCM predicts different post-cracking regimes depending on two dimensionless numbers: the *reinforcement brittleness number*, N_P, which is related to the fibre volume fraction, V_f, and the *pull-out brittleness number*, N_w, which is related to the fibre embedment length, w_c. N_P turns out to govern the stability of the fracturing process, whereas N_w is able to describe the softening tail of the non-smooth post-cracking evolution [4]. Both these dimensionless numbers depend on the beam depth, h, which, keeping the other variables to be constant, drives a ductile-to-brittle transition in the post-cracking regime of the composite. The critical value of the reinforcement brittleness number, N_{PC}, allows to predict the minimum (critical) specimen size, h_{min}, which, analogously to the minimum fibre volume fraction, $V_{f,min}$, is required to achieve a stable post-cracking response. Finally, UBCM simulations of non-smooth crack evolutions are compared to experimental results reported in the scientific literature [6], in which carbon nanotube-epoxy specimens are tested in bending (Figs. 1,2).

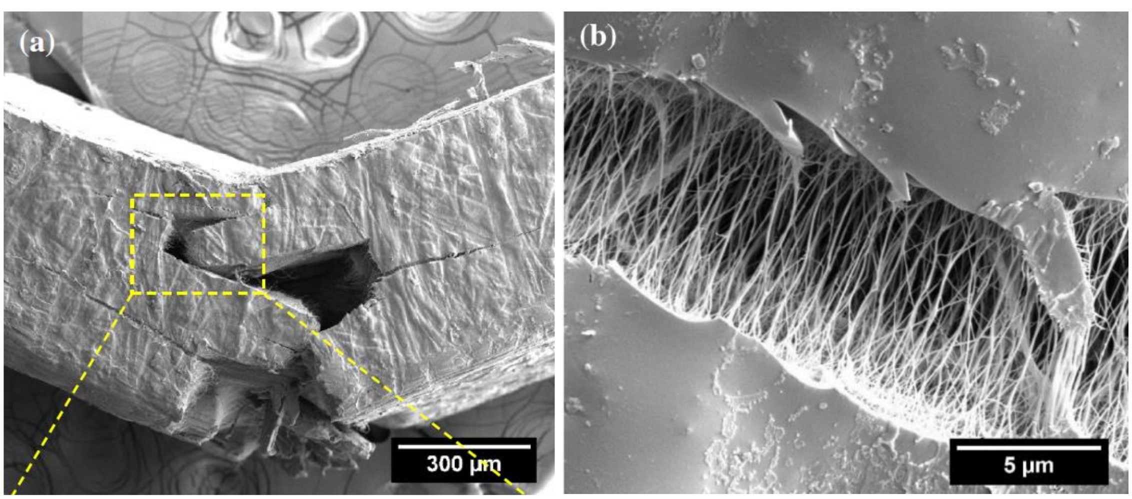

Figure 1. Failure of CNT-epoxy in bending (a); Pull-out nanotube bundles bridging the crack before failure (b) [6].

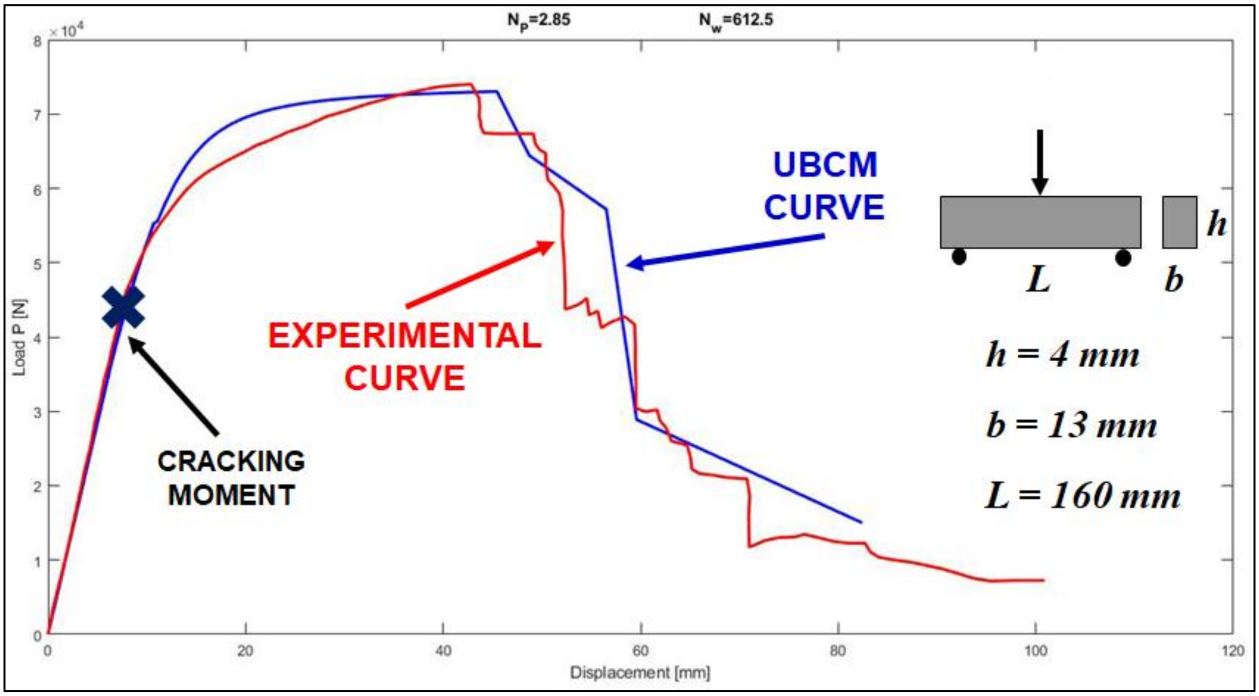

Figure 2. UBCM modelling of the non-smooth post-cracking evolution of a CNT-epoxy specimen in bending.

References

[1] A. Carpinteri, F. Accornero, "The Bridged Crack model with multiple fibers: Local instabilities, scale effects, plastic shake-down, and hysteresis", *Theoretical and Applied Fracture Mechanics*, 2019, 104:102351.

[2] A. Carpinteri, F. Accornero, "Residual crack opening in fiber-reinforced structural elements subjected to cyclic loading", *Strength, Fracture and Complexity*, 2020, 12(2-4):63-74.

[3] F. Accornero, A. Rubino, A. Carpinteri, "Ductile-to-brittle transition in fibre-reinforced concrete beams: Scale and fibre volume fraction effects", *Material Design & Processing Communication*, 2020, 2(6):e127.

[4] F. Accornero, A. Rubino, A. Carpinteri, "Post-cracking regimes in the flexural behaviour of fibre-reinforced concrete beams", *International Journal of Solids and Structures*, 2022, 248:111637.

[5] F. Accornero, A. Rubino, A. Carpinteri, "Ultra-low cycle fatigue (ULCF) in fibre-reinforced concrete beams", *Theoretical and Applied Fracture Mechanics*, 2022, 120:103392.

[6] A. Mikhalchan, T. Gspann, A. Windle, "Aligned carbon nanotube-epoxy composites: The effect of nanotube organization on strength, stiffness, and toughness", *Journal of Materials Science*, 2016, 51(22):10005-10025.