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Experimental and numerical insights into the behaviour of CNT grafted on CF surface and defects in CNTs

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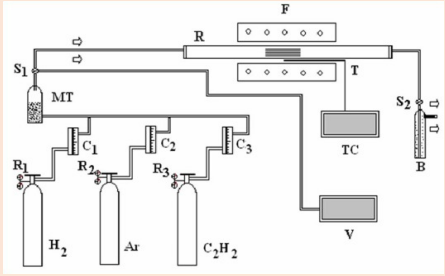
Abstract

The interfacial strength, vibrations attenuation and delamination resistance of Carbon Fibre Reinforced Polymer Composites (CFRPCs) can be significantly improved by introducing different nano-species (nanotube/nanorods/nanowalls/nanowires) on the Carbon Fiber (CF) surface. The present research work reports the grafting of carbon nanotubes (CNTs) on CF using a chemical vapour deposition method. Further, a numerical model is constituted for analysing the stresses at carbon nanotubes (CNT) grafted on CF, and also the interface of CF/CNT during tensile loading. A Finite Element (FE) numerical model analysing the variation of CF mechanical properties due to possible defects is also presented. The analysis of current data reveal a underutilization of strength for CNTs in CFRPCs. The numerical simulations, moreover, give evidence of failure near or at the interface. The results are thus compared and validated towards the experimental outcomes.

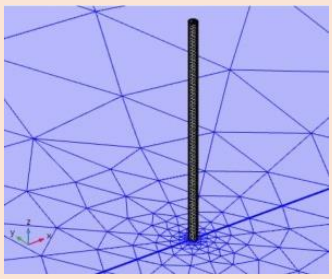
Introduction

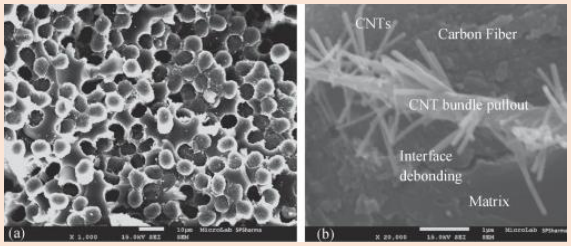
The excellent specific strength and stiffness, low thermal expansion, high modulus, high wear resistance, resistance to corrosion, and ability to withstand loads at high temperatures (as 3000 °C) in inert atmosphere make CF suitable for advanced engineering material used in aerospace, transportation, actuators, sensors, fuel cells, radar-absorbing material, wind turbine blades, electromagnetic interference shielding and expensive sporting goods. The higher density, thinner nanotubes having higher surface area are commonly preferred, but the length of nanotube resulting optimum properties is still unexplored [1]. A refined FE model is hence constituted for predicting the mechanical performance under tensile loading, while CNTs are grafted on the CF surface. Further, following [2], a FE model based on numerical homogenization technique is also constituted to determine how the introduction of glass powder on the CF surface can efficiently improve the mechanical performance of CFRPC.



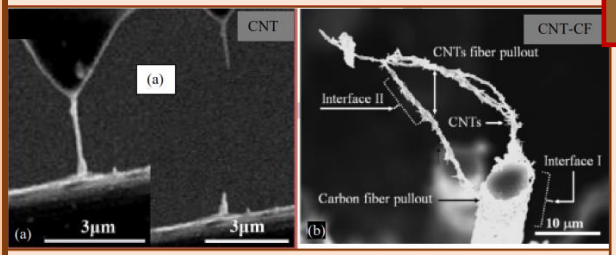
1. Schematic of CVD set up (KEY= F-Furness; R-reactor; T-thermocouple; S1, S2-cylinders; C1, C2, C3-Controllers; R1, R2, R3-regulators; V-vacuum chamber)

Materials & Methods

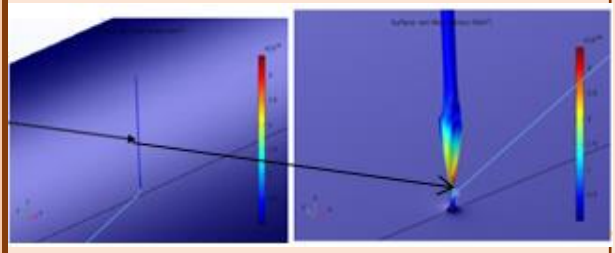




2. FESEM image of multi-scale hybrid composite: (a) low magnification image showing mainly fiber pull-out and fiber pull-out holes; and (b) high magnification image showing individual CNT pull-out and CNT bundle pull-out



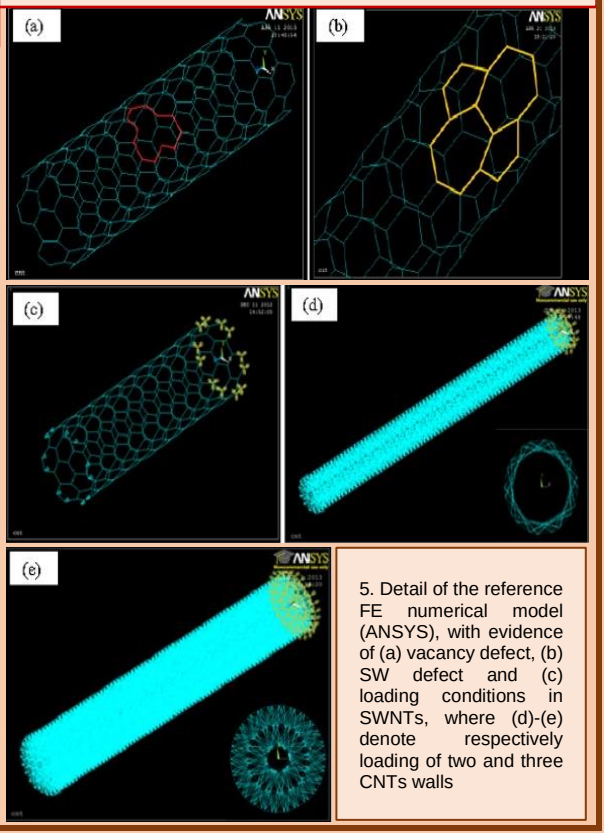
3. SEM image for the fracture detail of (a) CNT or (b) CFRPC having CNT/CF



4. Example of FE modelling results reflecting higher stress peaks at the CNC and CF interface

Results & Conclusions

The CNT grafting on CF surface by CVD method is presented in Fig. 1. Fig. 2 shows fiber pull-outs and their counterpart pull-out holes. In Fig. 3, the tensile test on CNT grafted on CF is shown. The tensile strength is found in around 5µN. The reference FE model (ANSYS) is thus constituted with boundary conditions that reproduce the experimental setup. Both Figs. 3-4 show the CNTs detachment from CF and fracture near the roots, with stress peaks at the CNT/CF interface. Fig. 5, finally, proves the effect of defects on CNTs. It is found that a given glass powder introduction at the CF surface can improve the fiber / matrix interface.



5. Detail of the reference FE numerical model (ANSYS), with evidence of (a) vacancy defect, (b) SW defect and (c) loading conditions in SWNTs, where (d)-(e) denote respectively loading of two and three CNTs walls

References

[1] Vedrtnam A, Sharma SP. (2019). Composite Part A, 125: 105509

[2] Vedrtnam A (2019). Composite Part B., 157: 305-321