INTERLAYER STRENGTH IMPROVEMENT WITH CNT DISPERSION IN WOVEN CFRP LAMINATES

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Introduction

Laminates of carbon fiber reinforced polymers (CFRP) are used in many high-strength-low-weight applications. CFRP laminates are produced by stacking and curing number of plies of prepregs together; the process that results in unreinforced inter-ply layer of matrix. Many researchers have embarked on using carbon nanotubes (CNT) for reinforcing the polymer matrix [1-2]. It is, however, challenging to engineer the contact surface using CNTs of a readily available prepreg because of their optimized resin content and the tackiness making it difficult to accomplish uniform CNT distribution and dispersion. This paper presents a practical technique for CNT dispersion over woven CFRP prepreg and subsequent fabrication of laminates. It further covers the experimental findings on fracture toughness and bucking strength of CNT-engineered laminates. Analysis explaining the role of CNTs in possible load transfer mechanisms and mechanics leading to improved interface strength is discussed.

Experimental

Materials

Woven CFRP prepreg (12k filament count, 3x3 per inch plain weave; refer Fig. 1a) acquired from polymer technologies Pte Ltd Singapore, was used to prepare double cantilever beam (DCB), end notched flexure (ENF) and buckling specimen. Multi-walled carbon nanotubes (L-type MWCNTs, 5-15µm long, external dia. 40-60nm; refer Fig. 1b) procured from Nanostructured & Amorphous Materials, Inc., Houston (purity >95%) were used to engineer certain interlayer interfaces in various laminated specimens. A thin film of polytetrafluoroethylene (PTFE) was used to initialize a crack in DCB and ENF specimen.

Specimen manufacturing

The required amount of MWCNTs was first mixed with ethanol. The mix was sonicated for an hour using a water bath sonicator and spread immediately on a flat-laid, Teflon coated (0.2mm thick) cloth (by Airtech International, Inc., CA 92647, USA).

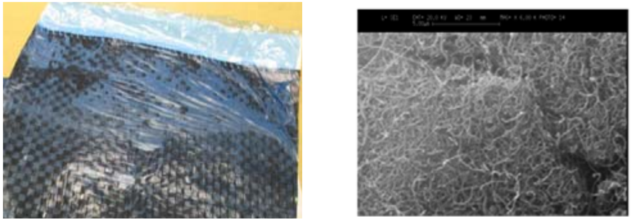

Fig.1(a) Woven CFRP prepreg. Fig.1(b) SEM of dry CNT.

The CNT-laden cloth was then placed in a fume-hood until the entire solvent volatized leaving behind a dry, well-spread layer of MWCNT. An already cut layer of CFRP prepreg was then placed over the MWCNT layer and a light roller was applied. Due to the roll and the tacky prepreg surface, most of the MWCNTs transferred from the Teflon cloth to the prepreg. Two pieces were cut out of this CNT-engineered prepreg and placed with the CNT-laden surfaces facing each other to form a 2-layer laminate having a cross-section of a unit cell in its final form as seen in Fig. 2.

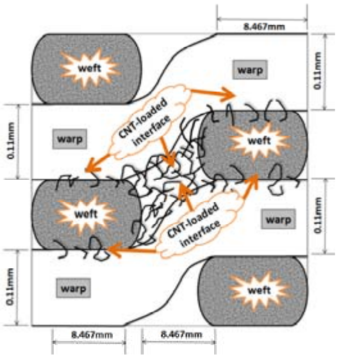

Fig.2. A face of unit cell.

Fig. 3 Specimens for curing.

With these 2 layers at the centre, 12-14 ply, [0/90] laminates were built by laying normal prepreg plies symmetrically on either side; refer Fig. 3. The lay-ups were then cured under the prescribed cure cycle.

Results and Discussion

Fig. 4 shows the graphs of the buckling test results for the laminates with and without CNT-engineered (1 g/m^2) mid layer. A uniform 10-15% increase in buckling load was observed. This can only be attributed to a rise in flexural rigidity of the laminate.

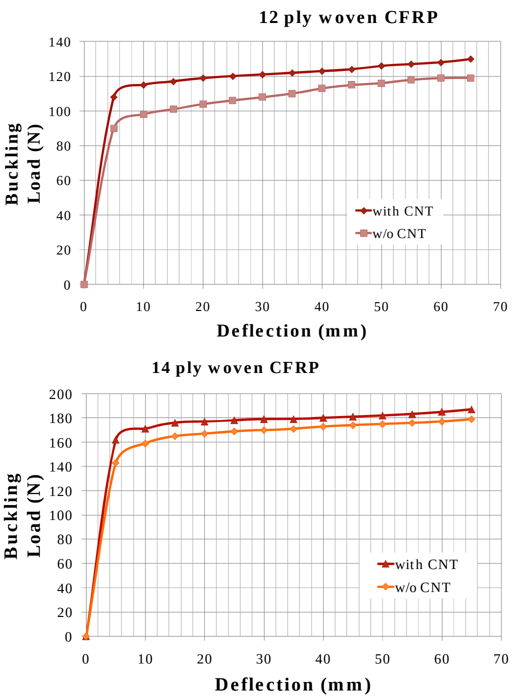

Fig. 4 Buckling behaviour of woven CFRP laminates.

Buckling load (per unit width) for a laminate can be calculated using [3] -

In eq. (1), except E and ν, other parameters will change little due to the effect of CNTs. The product of ν values leads to a small number and can be ignored. Thus, apparently E_{11} is the only parameter that has brought about the change in the buckling load capacity. For a CNT-laden CFRP laminate, effective Young's modulus, , can be estimated as:

OR

The may be calculated using the improved shear modulus with the randomly distributed CNTs as:

(4)

The of MWCNTs due to their random distribution can be taken as (+)/2. The proportionality between various properties as in [4] is –

=, and Also known are [4] and . For 1 g/m^2 CNTs, 3.25E-3 at 1400kg/m^3 density. Substituting values in eq (4) . Also, . Subsequent use of eq (3) will lead to . When tested, GPa for [0/90] lay-up giving . When substituted in eq (1), the P_{cr} increase will also be about 14% for a 2-ply laminate with CNT-engineered interface. In addition, MWCNTs are flexible and their tortuous geometry adds to the shear resistance, which in turn, also enhances the buckling strength.

In earlier mode I and mode II studies [5], changes in fracture toughness values (with the given content of MWCNT) were observed; see Table 1.

Table 1 Mode I & II behaviour of woven CFRP laminates [5]

CNTs	0.0 g/m^2	1.32g/m^2	2.25g/m^2	3.62g/m^2
G_I (DCB)	G_{I0} kJ/m^2 = 0.76 ±0.03	1.09*G_{I0} (±0.11)	1.04*G_{I0} (±0.11)	0.78*G_{I0} (±0.21)
G_{II} (ENF)	G_{II0} kJ/m^2 = 1.7 ±0.08	1.78*G_{II0} (±0.11)	1.75*G_{I0} (±0.11)	1.52*G_{I0} (±0.11)

As such, any improvements in E will lead to better G_I and G_{II}. It may be, however, seen that 1.32 g/m^2 CNT content provided optimum results whereas higher % of CNTs caused lesser impact. It may be noted that CNTs cause fibre-bridging in woven composites [5] provided CNTs are able to lock into the fibres from the adjacent layers and have enough adhesive coating to form a reasonably strong bond with those fibres. This phenomenon appeared weak with 2.25 g/m^2 CNTs. With more CNTs (3.62 g/m^2), the interface became thick and lacked enough adhesive. The likely cohesive failure of that layer caused the drop in G_I. However, the layer was able to offer enough shear resistance due to entangled CNTs and hence led to better G_{II} values.

Conclusion

MWCNTs, when added at the inter-ply interface in a right proportion, showed enhancement in buckling and fracture strengths of woven CFRP laminates due to improved Young's moduli, tortuous geometry, entanglement and bridging to the reinforcement fibres.

Acknowledgment

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References

[1] Z. Fan, M. H. Santare, S. G. Advani, Composites Part A: Applied Science and Manufacturing, 39 (2008) 540-554.

[2] T. Yokozeki, Y. Iwahori, S. Ishiwata, Composites Part A: Applied Science and Manufacturing, 38 (2007) 917-924.

[3] C.W. Yap, G.B. Chai, Composite Structures, 80 (2007) 307-319.

[4] Tan P., Tong L., Sun X., Composite Structures, 84 (2008) 1–10.

[5] Joshi S.C., Dikshit V., ICMAT(Sym I), 2009, Singapore.