REINFORCEMENT OF CARBON FIBER FABRIC/PHENOLIC RESIN COMPOSITES BY CNT OR CNF ADDITION

Shinn-Shyong Tzeng and Yu-Hon Lin

Department of Materials Engineering, Tatung University, Taipei 104, Taiwan

Introduction

The superior mechanical properties of carbon nanotubes (CNTs) and carbon nanofibers (CNFs) make them the ideal candidates for composite reinforcement. Although some experimental measurements indicated the enhancement of strength with the addition of CNTs into the polymer matrix [1-4], results without or with limited strength enhancement were also reported [3,4]. Two important issues concerning the applications of CNTs and CNFs in the composite reinforcement need to be overcome. The first is the uniform dispersion of these nano-reinforcing materials in the polymer matrix. The second is the effective stress transfer from the CNTs to the composite. For the effective stress transfer, the bonding between the reinforcement and the matrix should be strong, which make the surface properties of the CNTs and CNFs important.
Recently, incorporation of CNTs or CNFs in carbon fiber(CF)/polymer composites to form a hybrid multiscale composite was proposed and enhancements of mechanical behavior were reported [5-9]. In this study, both CNT and CNF were adopted to prepare the CNT or CNF/CF fabric/phenolic resin three-phase composites and the influence of CNTs and CNFs on the mechanical behavior of the composites was investigated.

Experimental

Sample preparation
Fig. 1 shows the SEM images of CNTs and CNFs used in this study. The CNFs, produced in our laboratory (40-60 nm), have a structure with internal conical cavities (insert in Fig. 1(a)) and the CNTs, 10-20 nm in diameter, have a tube structure (insert in Fig. 1(b)). For the fabrication of CNT or CNF/CF fabric/phenolic resin composites, the CNTs or CNFs dispersed phenolic resin solution was prepared first with the aid of ultrasonication. Then the CF fabrics were impregnated with the solution and the vacuum bag hot pressing technique was used to fabricate the composites.

Characterization
The mechanical properties and fracture behavior were studied using the three-point bending test according to ASTM D-790. The interlaminar shear strength of the composites was measured using the short-beam test according to ASTM D2344. The fracture surfaces of the composites after bending tests were observed using SEM.

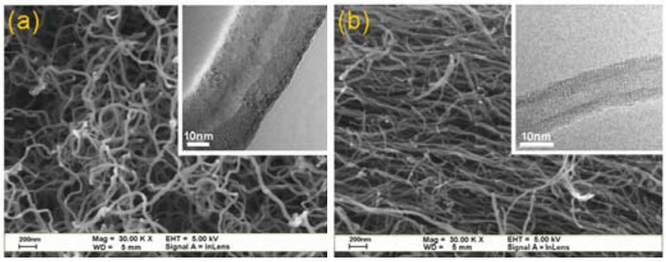

Fig. 1 SEM and TEM images of: (a) CNFs and (b) CNTs.

Results and Discussion

Fig. 2 shows the flexural strength of carbon fabrics reinforced phenolic resin composites with the addition of CNTs or CNFs of different amounts. The flexural strength was found to increase with increasing amount of CNT up to 0.5 wt%, where an increase of 24.4% was measured. However, a flexural strength even lower than that of the composites without CNT addition was obtained when the amount of CNT was over 0.5 wt%. Similar trend was also observed for the composites with the addition of CNFs. However, the maximum strength was lower than that of composites with CNT addition. The amount of CNF addition for the maximum strength was also lower (0.1 wt%) as compared with 0.5 wt% for the CNT addition.

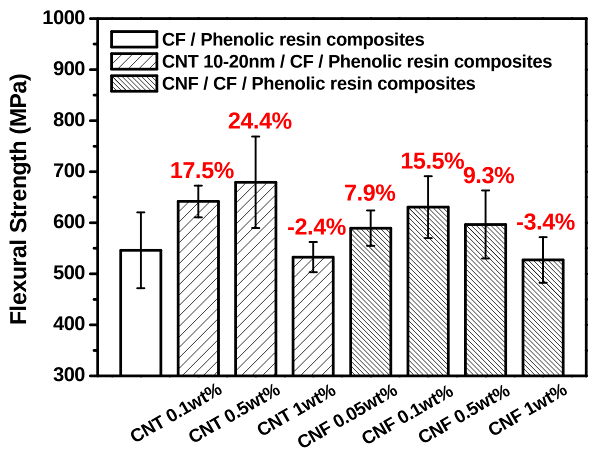

Fig. 2 Flexural strength of carbon fabrics reinforced phenolic resin composites with the addition of CNTs or CNFs of different amounts.

Fig. 3 shows the flexural modulus of carbon fabrics reinforced phenolic resin composites with the addition of CNTs or CNFs of different amounts. A best loading amount for the maximum modulus was also observed for both CNT and CNF. It is noted that the best loading for the maximum strength is the same as that for the maximum modulus. Although similar trends were found for the flexural strength and modulus, the moduli measured using the amount smaller than 1 wt% were all larger than that of the composites without CNT or CNF addition. However, the flexural strength could be lower than that of the composites without CNT or CNF addition when the addition was higher than the best amount.

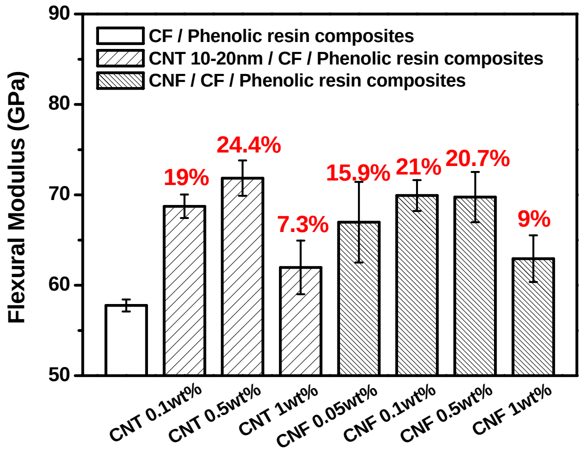

Fig. 3 Flexural modulus of carbon fabrics reinforced phenolic resin composites with the addition of CNTs or CNFs of different amounts.

It has been pointed out [5,8,9] that the introduction of nano-reinforcement, for examples nanofibers and CNTs, in the laminated composites could lead to the enhancement of interlaminar shear strength and interlaminar fracture resistance. Fig. 4 shows the measurement results of interlaminar shear strength using short-beam test. An increase of interlaminar shear strength was observed with the addition of CNTs or CNFs. Regardless of the larger scatter of the test data for the CNF addition, the average value of interlaminar shear strength for composites with CNT loading was larger than that with CNF addition, which is consistent with the results of flexural strength.

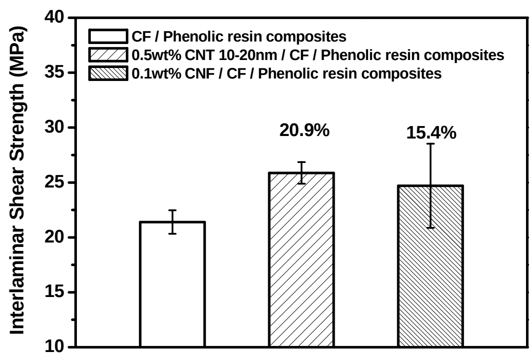

Fig. 4 Interlaminar shear strength of carbon fabrics reinforced phenolic resin composites with the addition of CNTs or CNFs of different amounts.

Conclusions

Introduction of CNTs or CNFs in the CF fabric/phenolic resin composites was found to increase the flexural strength and modulus of the composites. A best loading amount was observed for both CNT and CNF additions. However, the best loading amount was different for CNT and CNF additions. Better flexural properties were measured for composites with CNT loading as compared with those with addition of CNFs, which is consistent with the results of interlaminar shear strength measurements.

Acknowledgement

This work was supported by the National Science Council of Republic of China under the contract No. NSC95-2221-E-036-035-MY3.

References

1. Coleman, J.N., Cadek, M., Blake, R., Nicolosi, V., Ryan, K.P., Belton, C., Fonseca, A., Nagy, J.B., Gun’ko, Y.K. and Blau, W.J. High-performance nanotube-reinforced plastics: Understanding the mechanism of strength increase. *Advanced Functional Materials*, **14** (2004) 791-798.
2. Tai, N.-H., Yeh, M.-K. and Liu, J.-H. Enhancement of the mechanical properties of carbon nanotube/phenolic composites using a carbon nanotube network as the reinforcement. *Carbon*, **42** (2004) 2774-2777.
3. Coleman, J.N., Khan, U., Blau, W.J. and Gun’ko, Y.K. Small but strong: A review of the mechanical properties of carbon nanotube-polymer composites. *Carbon*, **44** (2006) 1624-1652.
4. Breuer, O. and Sundararaj, U. Big returns from small fibers: A review of polymer/carbon nanotube composites. *Polymer Composites*, **25** (2004) 630-645.
5. Dzenis, Y. Structural Nanocomposites. *Science*, **319** (2008) 419-420.
6. Mathur, R.B., Chatterjee, S. and Singh, B.P. Growth of carbon nanotubes on carbon fibre substrates to produce hybrid/phenolic composites with improved mechanical properties. *Comp. Sci. Technol.* **68** (2008) 1608-1615.
7. Iwahoria, Y., Ishiwata, S., Sumizawa, T. and Ishikawa, T. Mechanical properties improvements in two-phase and three-phase composites using carbon nano-fiber dispersed resin. *Composites Part A*, **36** (2005) 1430-1439.
8. Fan, Z., Santare, M.H. and Advani, S.G. Interlaminar shear strength of glass fiber reinforced epoxy composites enhanced with multi-walled carbon nanotubes. *Composites Part A*, **39** (2008) 540-544.
9. Bekyarova, E., Thostenson, E.T., Yu, A., Kim, H., Gao, J., Tang, J., Hahn, H.T., Chou, T.W., Itkis, M.E. and Haddon, R.C. Multiscale carbon nanotube-carbon fiber reinforcement for advanced epoxy Composites. *Langmuir*, **23** (2007) 3970-3974.