FLEXIBLE/CNTS INTERPHASE FOR CFRP COMPOSITES

M. S. Aly-Hassan[1*], N. Yoshikawa[1], T. Koshino[1], A. Nakai[2], and H. Hamada[1]

[1] *Department of Advanced Fibro-Science, Graduate School of Science and Technology, Kyoto Institute of Technology, Matsugasaki, Sakyo-Ku, Kyoto 606-8585, Japan*
[2] *Department of Mechanical and Systems Engineering, Faculty of Engineering, Gifu University, Japan*
**hassan@kit.ac.jp*

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Abstract

In this research, an attempt was carried out to enhance the out-of-plane through-thickness mechanical properties of laminated carbon fibers reinforced polymer matrix (CFRP) composites. To improve the out-of-plane through-thickness impact properties of 2D CFRP composites, carbon nanotubes (CNTs) were grafted on the carbon fibers via flexible interphase without damages on the surface of carbon fibers as happens in other grafting processes such as Chemical Vapor Deposition (CVD) for CNT growth on carbon fibers. There are two issues for the present research. One is the optimal distribution and percentage of grafted CNTs via flexible interphase. The other is to establish simple and economical process that can be used for composite industry.

1 Introduction

Laminated FRP composite materials with tremendous in-plane mechanical properties fare weakly when out-of-plane through-thickness mechanical properties are essential. These poor out-of-plane mechanical properties often lead to interlaminar failures, such as delamination, in composites under various loading conditions. To tackle these significant challenges, three-dimensional (3D) composite architectures, e.g. 3D braided and through-thickness stitching architectures, were developed to alleviate the weakness in the transverse direction, but all of the efforts so far have only produced limited success [1] on the expense of the in-plane mechanical properties. As reported, these approaches have yielded some problems, such as lower in-plane strengths for the 3D braided fibers and shorter tensile fatigue life [2] and lower compression strengths for the stitched fiber laminates [3].

Therefore, new approach was revealed [4, 5] to the 3D composite challenge, without changing the 2D laminated design, on the basis of the concept of interlaminar carbon nanotube (CNTs) forests/grafts that would supply better multifunctional properties along the thickness direction. The grafted CNTs on the surface of micro-fiber fabric allow the fastening of adjacent plies in the 2D laminated composite. The suggested 3D composites with CNT forests/grafts have demonstrated significant improvements in the delamination resistance, damping, interlaminar fracture toughness, hardness, in-plane mechanical properties, thermoelastic behavior, and thermal and electrical conductivities making these structures truly multifunctional composites [6]. Due to the extraordinary properties of CNTs, their growth at the surface of carbon fibers is a promising approach to control the interfacial properties and achieving the enhanced bulk properties. However, the reactive conditions used to grow carbon nanotubes also have the potential to introduce defects that can degrade the mechanical properties of the carbon fiber substrate [6]. In addition, the process of the CNTs growth at the surface of carbon fiber is still expensive, slow, and unsuitable for large composite structures.

In this study, an attempt was carried out to improve the out-of-plane through-thickness impact properties of 2D CFRP composites, carbon nanotubes (CNTs) were grafted on the carbon fibers via flexible interphase without any damages on the surface of carbon fibers as happens in other grafting processes such as Chemical Vapor Deposition (CVD) for CNT growth on carbon fibers. There are two issues for the present research. One is the optimal distribution and percentage of grafted CNTs via flexible interphase. The other is to establish simple and economical process that can be used for composite industry.

2 Experimental Procedures

2.1 Composites Fabrication

First, plain woven fabrics using PAN-based carbon fibers (TC33_3K; Honlu Technology Co., Ltd.) were used to fabricate the laminated CFRP composites. These fabrics were dried in oven and then were soaked for 10 seconds in solution of 5 wt% flexible resin (PB3600; Daicel Chemical Industries Ltd.) and 95 wt% acetone to form flexible interface around the carbon fibers. The concentration of the flexible resin in the acetone solution was decided based on a previous research [Yoshikawa et al. 7]. The used carbon nanotubes (CNTs) in this study were vapor grown carbon fibers, or so called VGCF, that were obtained from Showa Denko KK, Japan with diameters of 100~150 nm and lengths of 10~20 μm. Different weight percentage of CNTs were dispersed in the above-mentioned mixture of flexible resin and acetone using mechanical stirring. This CNT/Flexible resin/acetone mixture was used to graft the micro-carbon fiber by flexible/CNTs interphase. After drying these fabrics in oven, epoxy resin (jER 828; Mitsubishi Chemical Corporation) and hardner (jERcure W; Mitsubishi Chemical Corporation) were used as matrix. The curing conditions was as follows; 7MPa Pressure, 100°C/2h and 175°C/4h for curing.

2.2 Drop Impact Testing

Impulse impact test was conducted with square specimens have dimensions 102×102 mm using Instron Dynatup 9250 HV vertical impact testing tower.

3 Results and Conclusion

The impact load-displacement curves for four kinds of CFRP composites; non treatment (no flexible interphase and no grafted CNTs on the surface of carbon fibers), 5wt% flexible interphase, 5wt% flexible interphase including 0.5wt% of grafted CNTs on the surface of carbon fibers and 5wt% flexible interphase including 1.0 wt% of grafted CNTs on the surface of carbon fibers, respectively were shown in Figure 1.

As shown in Figure 1 and as listed in Table 1, the surface treatment of the carbon fibers using the flexible resin has enhanced the impact properties of CFRP composites. However, significant improvements for the impact properties of CFRP composites were obtained by dispersing the only 0.5 wt% of CNTs though this flexible interphase. The composites kept the high load level with increasing CNTs to 1.0 wt%, whereas the total energy and energy after maximum load were increased, and in the other side the energy to maximum load was decreased. This impact enhancement can be explained from the fracture behavior shown in Figure 2 and 3.

References

[1] Tong L., Mouritz A.P. and Bannister M. *3D Fiber Reinforced Polymer Composites.* Elsevier Science, Oxford (2002).

[2] Mouritz A.P. Fracture and Tensile Fatigue Properties of Stitched Fiberglass Composites. *J. Mater. Des. Appl.*, **218**, pp. 87-93 (2004).
[3] Dexter H.B., Funk J.G. *Proceeding of 27th AIAA Structural Dynamics and Materials Conference* (San Antonio, TX) AIAA Paper 86-1020, American Institute of Aeronautics and Astronautics, New York, , pp. 700–709 (1986).
[4] Dresselhaus M.S., Dresselhaus G., Eklund P.C. *Science of Fullerenes and Carbon Nanotubes.* Academic Press, San Diego (1996).
[5] Baughman R.H., Zakhidov A.A., De Heer W.A. Carbon Nanotubes-the Route toward Applications. *Science*, **297**, pp. 787-792 (2002).
[6] Zhang Q. *Carbon Nanotubes on Carbon Fibers: Synthesis, Structures and Properties*. University of Dayton, PHD thesis (2010).
[7] Yoshikawa N., Nakai A., Mori M. *Mechanical Property of CFRP with Flexible Interphase*, Proceedings of the 36th Symposium on Composite Materials, pp. 53-54 (2011).

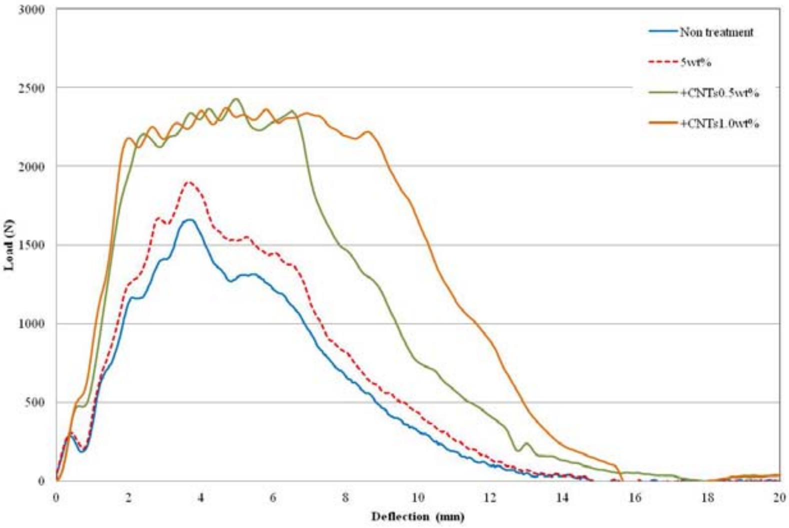

Figure 1. The impact load-displacement curves.

(a) Non treatment

(b) 5wt% flexible interphase

(c) 5wt% flexible interphase including 0.5wt% of grafted CNTs

(d) 5wt% flexible interphase including 1.0 wt% of grafted CNTs

Figure 2. Patterns and areas of damage after impact test.

(a) Non treatment

(b) 5wt% flexible interphase

(c) 5wt% flexible interphase including 0.5wt% of grafted CNTs

Figure 3. Micro observation of fracture behavior.

Flexble treatment	Energy to max load (J)	Energy after max load (J)	Total Energy (J)	Max Load (kN)
Non treatment	3.44	6.53	9.97	1.62
5wt%	3.81	7.72	11.5	1.90
5wt%(CNts0.5wt%)	8.27	12.37	20.6	2.38
5wt%(CNts1.0wt%)	7.32	15.74	23.1	2.41

Table 1. Summary of the impact results