INTERFACIAL EVALUATION AND SELF-SENSING OF SINGLE-CARBON FIBER/ CARBON NANOTUBE (CNT)-PHENOL GRADIENT NANOCOMPOSITES USING ELECTRO-MICROMECHANICAL AND WETTABILITY TESTS

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Introduction

Nowadays, fiber reinforced polymers (FRPs) have become the most important materials in the field of lightweight constructions [1]. Carbon nanotube (CNT) is an intriguing material that has attracted much attention from both scientists and engineers. It has high heat resistance and excellent dimensional stability, accordingly phenols are produced as wastes in a variety of industries, such as aerospace industry, transportation industry, insulation materials [2]. Strong and durable interfacial adhesion can efficiently transfer the stress from the matrix to the fiber, which may provide the outstanding mechanical properties of the composites.
In this work, the interfacial properties of carbon fiber reinforced CNT-phenol nanocomposites were evaluated using micromechanical test combined with wettability test, and measured the electrical properties of CNT-phenol nanocomposites using two-point and four-point methods. In addition, the hydrophobicity of CNT-phenol nanocomposites was investigated by both dynamic and static contact angle tests [3].

Experimental

Materials

Carbon fiber (T700S, Korea and Toray Inc., Japan) was used as reinforcing fiber. Multi-wall carbon nanotube (CNT, IlJin Nantech Co., Korea) was used as reinforcing and self-sensing materials. Phenol (Cellobond J2027L, Borden Chemical, Inc.) based on phenolic resole resin was used as matrix and hardner (Cellobond Phencat 382, Borden Chemical, Inc.) based on partial phosphate ester catalyst was used as curing agent. Acetone (Dae Jung Chemical, Co.) was used for dispersion of CNT.

Fabrication of CNT-phenol nanocomposites

CNT was dispersed in acetone solvents by sonication for 2 hours. The phenol resin was then poured into the CNT solution. Next sonication of the CNT and phenol mixture was performed for an additional 12 hours in an enclosed beaker. The phenol solution, with the embedded CNT was then dispersed in a sealed beaker for 6 hours. Next the CNT dispersive solvent in the phenol solution was removed by evaporation under sonication at 35 ℃ for 3 days. The residual solvent was eliminated in a vacuum oven at 50 ℃ for an additional 3 days. Concentration of CNT-phenol nanocomposites was 0.3 vol%.

Interfacial shear strength (IFSS) measurement

The interfacial shear strength between carbon fiber and CNT-phenol nanocomposites was measured by microdroplet pull-out test. Microdroplets of CNT-phenol nanocomposites were formed on each fiber using a tip pin and fiber. Microdroplets of CNT-phenol nanocomposites were put into oven at 60 ºC for 2 hours for curing.

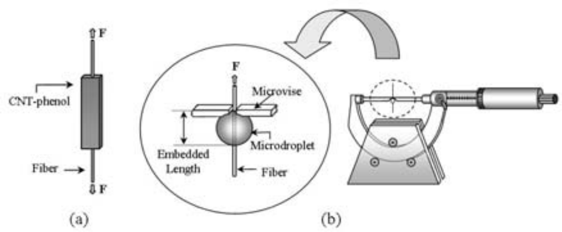

Fig.1 Schematic diagram of: (a) apparent modulus test; and (b) microdroplet pull-out test

Figure 1 shows the test process of microdroplet pull-out test. One of major advantages of microdroplet technique is that the value of forces at the debonding moment can be measured. The microdroplet specimen was fixed by the microvice using a specially-designed micrometer. The IFSS was calculated from the measured pullout force, F which can be calculated using the following equation,

$$\tau = \frac{F}{\pi D_f L} \tag{1}$$

Where D_f and L are fiber diameter and fiber embedded length in the matrix, respectively.

Results and Discussion

Electrical properties of CNT-phenol nanocomposites

Figure 2 shows the result of electrical measurement using two-point and four-point probe methods. Figure 2(a) shows the electrical resistance values which measured by two methods. From the linear fit of resistance against CNT gap length, $2R_c$ is obtained which is the intercept. Figure 2(b) shows the result of the electrical resistivity values measured using above two methods. The electrical resistivity that is calculated using four-point probe method data are similar, whereas the results of two probe method data exhibit errors. It is because the contact resistance dominates the overall resistance in the calculation process.

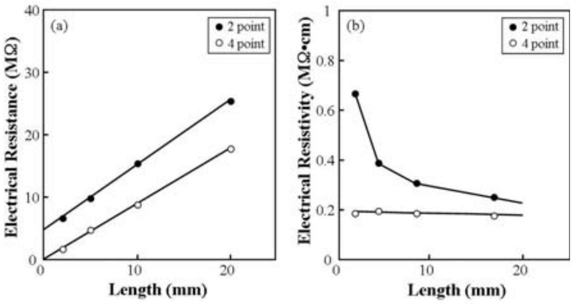

Fig. 2 Electrical resistance and resistivity

Apparent modulus and IFSS

Figure 3 shows stress-strain curves and apparent modulus of bare carbon fiber and carbon fiber embedded phenol/CNT-phenol nanocomposites. The reinforcing effect was measured indirectly by apparent modulus, which is the modulus of single carbon fiber embedded in the matrix. As expected, apparent modulus of carbon fiber embedded matrixes were higher than bare carbon fiber, and CNT-phenol nanocomposites exhibited a higher apparent modulus than neat phenol due to the better stress-transferring and reinforcement effects of CNT-phenol nanocomposite. The CNT-phenol matrix is more rigid than neat phenol.

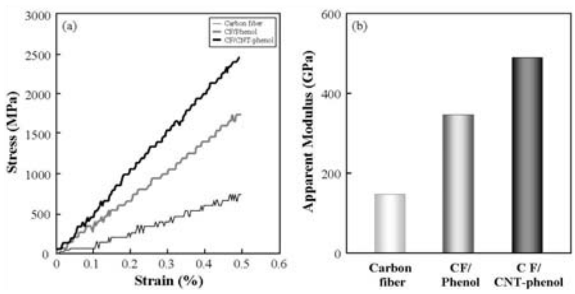

Fig. 3 Stress-strain curves and apparent modulus

Contact angle and wettability

Figure 4 shows the static contact angle of water droplet on neat phenol and CNT-phenol nanocomposites plate. CNT-phenol nanocomposites exhibits hydrophobic property and the static contact angle was about 95°. Comparing with the CNT-phenol nanocomposites, the static contact angle of neat phenol was much lower, measured value was just 68° with same size water droplet. It means that there were different surface energies based on the CNT microstructure. This enhancement in static contact angle was contributed to the combined effects of CNT microstructure on the surface of CNT-phenol nanocomposites, thus leading to the hydrophobicity of the CNT-phenol composites.

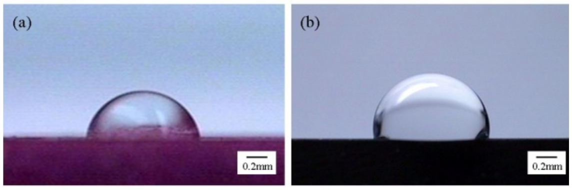

Fig. 4 Static contact angles measurement

Conclusion

Electro-micromechanical test combined with wettability test were investigated to obtain the interfacial properties of carbon fiber reinforced CNT-phenol nanocomposites and their hydrophobicity. Contact resistance of CNT-phenol nanocomposites was obtained using gradient specimen with two and four-point methods. Carbon fiber reinforced CNT-phenol nanocomposites showed higher interfacial adhesion and apparent modulus than neat phenol. CNT microstructure caused hydrophobic property of CNT-phenol nanocomposites.

Acknowledgements

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