MECHANICAL AND DIELECTRIC PROPERTIES OF E-GLASS FIBER / MWNTS DISPERSED EPOXY COMPOSITES

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Keywords : *carbon nanotube, electromagnetic absorbing material, complex permittivity*

1. Introduction

Absorption of electromagnetic pulses from radar has been an essential issue in the stealth technology. Radar stealth technology implies the technology that can make RCS (Radar Cross-Section) smaller by absorbing or scattering electromagnetic wave through radar absorbing materials (RAMs), radar absorbing structures (RAS) or stealth design and shaping[1]. Carbon black, ferrite, and magnetic particles have been investigated for stealth materials.

Carbon nanotubes (CNTs) have the potential for substitution of conventional conducting fillers due to their intrinsic characteristics such as high electric conductivity and low percolation threshold, and dielectric loss peculiarity.

Glass fiber reinforced multi-walled carbon nano tubes (MWNTs)-epoxy composite specimens were prepared for the study on their mechanical and dielectric characteristics. Tensile and flexural strength of the materials were measured in the various weight fractions of MWNTs. The dielectric properties were characterized by measuring complex permittivity and electromagnetic wave absorbing property through a free space measurement system in X-band (8.2~12.4 GHz). The relationship between complex permittivity and MWNT concentrations was considered in the constant degree of MWNT dispersion.

2. Preparation

MWNTs (Hanwha Nanotech Co., Ltd.) having outer diameter of 10~15 nm were introduced for preparing composite specimens. Figure 1 shows the transmission electron microscope (TEM) images of multi-walled carbon nanotubes (provided by Hanwha Nanotech Co., Ltd.). MWNTs were not treated at all, and their purity was more than 95%. Dimension of MWNTs is shown in Table 1.

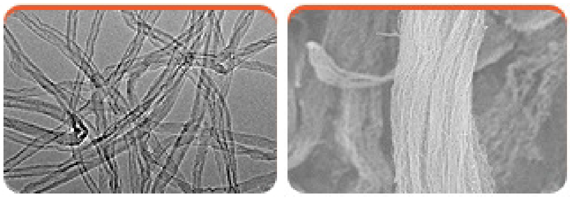

Figure 1. TEM images of MWNTs (provided by Hanwha Nanotech Co., Ltd.)

MWNTs were dispersed in acetone by using ultra-sonicator for 120 minutes. Figure 1 shows the transmission electron microscope (TEM) images of multi-walled carbon nanotubes (provided by Hanwha Nanotech Co., Ltd.). Pre-dispersed MWNTs were mixed with bisphenol-A type epoxy resin (Kukdo Chemical Co., Ltd.) in the ratio of 1, 2, and 3 weight percent, respectively and stirred for 5 hours under 60°C. MWNTs dispersed epoxy resin was pasted and coated on the surface of E-glass fibers (Hankuk Fiber Glass Co., Ltd.) by hand lay-up. E-galss fiber/MWNTs-epoxy prepregs were laminated and processed by vacuum infusion method. E-glass fibers were used for reinforcement of MWNT-epoxy composite specimens.

Table 1. Dimension of MWNTs

Diameter (nm)	Length (㎛)	Aspect ratio	Manufacturer
10 ~ 15	200	16,000	Hanwha Nanotech Co. Ltd.

The plate type specimens with dimension of 150 mm × 150 mm were prepared for the free space measurement. Table 1 shows the dimension of MWNTs.

3. Characterization and Results

3.1 Mechanical Properties

Tensile and flexural strength of the glass fiber reinforced MWNTs-epoxy composite materials were measured by using methodology of ASTM D 638 and ASTM D 790, respectively. Instron 8516 was used for the tests. Figure 2 shows the tensile strength of the specimens with different MWNTs ratio. As increased MWNTs concentrations in the ratio of 0, 1 and 2 weight percent, tensile strength seems to improve. This phenomenon can be estimated in proof of CNT roles as a load transferor in the matrix. But tensile strength in a case of 3 weight percent specimen started to be decreased in comparison with the rest concentrations. This result is largely caused by irregular distribution and partial aggregation of MWNTs in the materials.

Figure 3 shows the relationship between flexural strength of glass fiber/MWNTs dispersed epoxy composites and concentrations of MWNTs. As increased MWNTs concentrations from 0wt.% to 2wt.% , flexural strength of glass fiber/MWNTs dispersed epoxy composites was gradually declined. Flexural strength, however, was drastically deacreased when 3wt.% of MWNTs were dispersed in epoxy resin.

3.2 Dielectric Properties

Dielectric properties of glass fiber/MWNTs dispersed epoxy composite materials were investigated by measuring complex permittivity and electromagnetic wave absorptivity through the free space measurement system (HVS Technologies Co., Ltd.). It is composed of two spot-focusing horn lens antennas, a sample holder, a data acquisition system and a vector type network analyzer (Agilent Technologies, HP8510C). The network analyzer consists of a synthesized sweeper and a scattering parameter (s-parameter) test set. The s-parameter test set is linked to the spot-focusing lens antennas through precision coaxial cables and circular-to-rectangular waveguide adapters. Figure 4 is a schematic drawing of the free space measurement system.

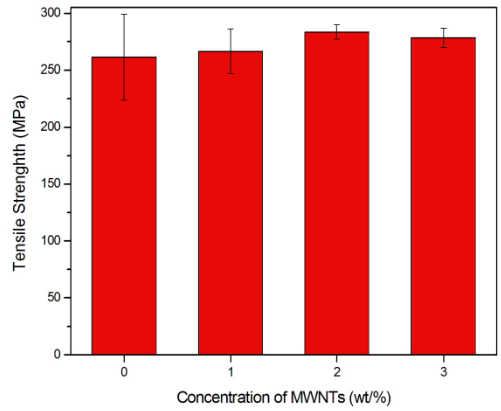

Figure 2. Tensile strength of glass fiber/MWNTs-epoxy composite

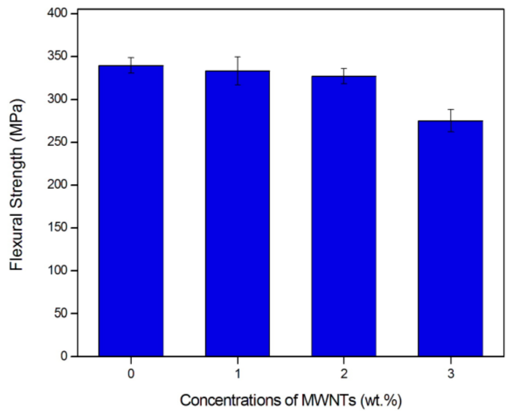

Figure 3. Flexural strength of glass fiber/MWNTs-epoxy composite

Complex permittivity can be expressed as follow ;

$$\varepsilon = \varepsilon' - j\varepsilon'' = \varepsilon'(1 - j\tan\delta)$$

ε' is the real part of complex permittivity, and ε'' means the imaginary part of complex permittivity. $\tan\delta$ is loss tangent which means the proportion of ε'' to ε'. It is related with lossy and attenuating property of materials[2].

Figure 5 shows the connection between complex permittivity of glass fiber/MWNTs dispersed epoxy and concentrations of MWNTs at 10 GHz. The concentrations of MWNTs increases, the complex permittivity and the loss tangent of glass fiber/MWNTs dispersed epoxy composites also linearly increase.

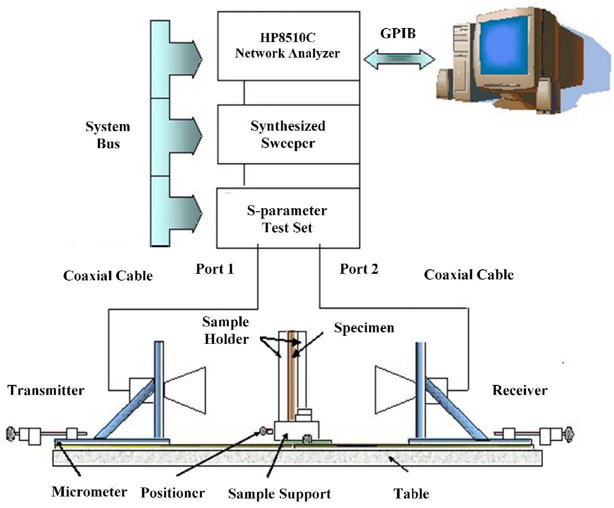

Figure 4. Schematic drawing of the free space measurement system

These results can be explained that lattice defects (vacancy, dislocation) inside the MWNTs function as electric dipoles with increase of MWNTs ratio. And electric loss occurs due to free electrons from π-conjugated structure of MWNTs. These are caused by improvement of polarizability in the material.

Real part of complex permittivity, ε′ of the composites can be described by the first-order linear equation from linear regression analysis.

$$\varepsilon' = 3.492x + 3.752$$
$$R^2 = 0.98936$$

,where x is concentration of MWNTs, and R^2 is coefficient of determination. As R^2 closes to 1, the plot closes to the perfect linear behavior.

Optimum concentration of MWNTs can be induced by using the first order linear equation. And suitable thickness of glass fiber/MWNTs dispersed epoxy composites as radar absorbing structures (RAS) can be estimated and calculated as follows :

$$t = \frac{1}{4}\frac{\lambda_0}{\sqrt{\varepsilon'}} = \frac{30}{4\sqrt{3.492x + 3.752}} \text{ mm}$$

,where λ_0 is wavelength of resonance frequency, ε’ is the real part of complex permittivity, and x is concentration of MWNTs. Figure 6 describes linear relationship between real part of complex permittivity and concentration of MWNTs. This is caused by improvement of polarizability in the material.

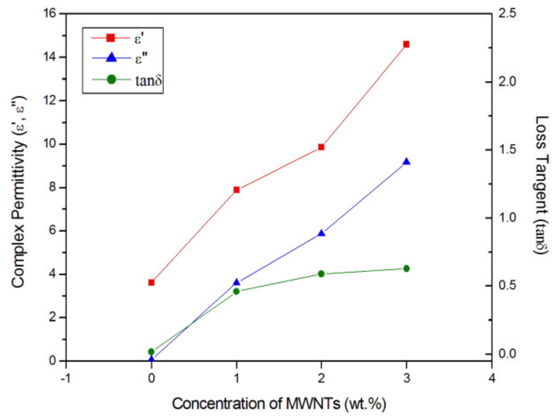

Figure 5. Complex permittivity of glass fiber/MWNTs dispersed epoxy composites with the different ratio of MWNTs at 10 GHz

Figure 7 shows frequency response characteristics of the specimen which contains MWNTs of 3 wt%. It is coincident with the “scaling dispersion law”[3].

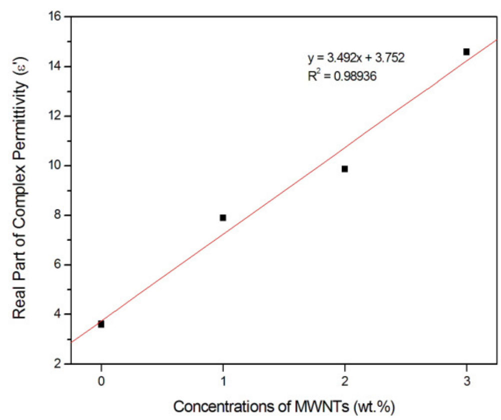

Figure 6. Linear relationship between real part of complex permittivity and the concentrations of MWNTs

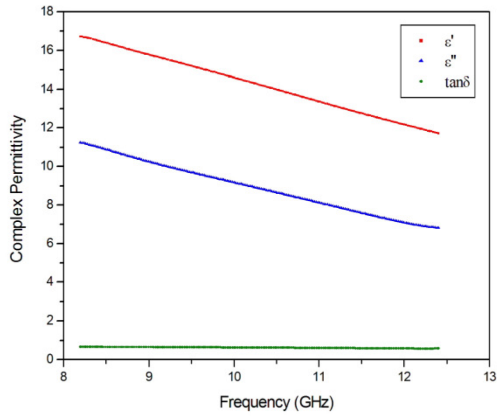

Figure 7. Frequency response characteristics of glass fiber / 3wt.% MWNTs dispersed epoxy composite

Absorptivity of electromagnetic wave was measured and characterized in X-band (8.2 ~ 12.4 GHz). The result of glass fiber/1wt.% MWNTs dispersed epoxy composite specimen is shown in figure 8. Resonance frequency was positioned near 10.6 GHz. And reflection loss was about -40 dB at the resonance frequency. It can be converted into absorptivity of 99.99 % against the vertical incident wave. Bandwidth that reflection loss satisfied below -10 dB was more than 3.44 GHz.

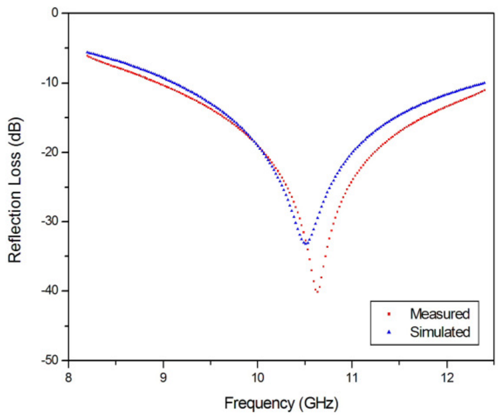

Figure 8. Electromagnetic wave absorptivity of glass fiber / 1wt.% MWNTs dispersed epoxy composite

Table 2 shows thickness, MWNTs concentration, resonance frequency, reflection loss, and -10dB bandwidth of the best composite specimen for RAS.

Table 2. Thickness, MWNTs concentration, resonance frequency, refelction loss, and -10dB bandwidth of the best composite specimen in the study

	Center frequency (at 10 GHz)
Thickness of the specimen [mm]	2.60
MWNTs concentration [wt.%]	1.0
Resonance frequency [GHz]	10.64
Reflection loss [dB]	-40.15
-10 dB bandwidth [GHz]	more than 3.44
Lower frequency below -10 dB [GHz]	8.96
Upper frequency below -10 dB [GHz]	more than 12.4

4. Summary

Mechanical and dielectric properties of glass fiber / MENTs dispersed epoxy composites were investigated in the different concentrations of MWNTs. MWNTs were dispersed in bisphenol A type epoxy resin for preparing fiber reinforced nanocomposites as radar absorbing structures.

Tensile and flexural strength of the composites were measured by using universal test machine. As increased MWNTs concentration, tensile strength was also increased. Flexural strength was, however, gradually declined as increased MWNTs concentration.

Dielectric characteristics of the composites were studied by measuring complex permittivity and reflection loss (loss of S_{11} parameter) in X-band. As increased MWNTs concentration, both real and imaginary parts of complex permittivity, and loss tangent were all increased. Absorption rate of electromagnetic wave was about 99.99% against the vertical incident wave. Resonance was occurred near 10.6 GHz. First order linear equations for optimal concentration and thickness of the composite were induced by using linear regression analysis.

References

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