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Fabrication and design of multi-layered radar absorbing structures of MWNT-filled glass/epoxy plain-weave composites

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Abstract

The object of this study is to design radar absorbing structures (RAS) with load-bearing ability in the X-band. Glass/epoxy plain-weave composites of excellent specific stiffness and strength, containing multi-walled carbon nanotubes (MWNT) to induce dielectric loss, were fabricated. Observations of the microstructure and the permittivity of the composites confirmed that the fabrics are suitable for use as RASs. A genetic algorithm and a theory of the reflection/transmission of electromagnetic waves in a multi-layered RAS were applied to design an optimal RAS composed of MWNT-filled composites. The thickness per ply was observed to vary, depending on the number of plies and the MWNT contents. A fabrication process was proposed that considered the variation. The proposed process was in the fabrication of a designed RAS, and the theoretical and measured reflection losses of the RAS were found to be in good agreement.

Keywords: X-band frequency; Permittivity; Radar absorbing structure; Multi-walled carbon nanotube

1. Introduction

Radar cross section (RCS) reduction technology, which protects aircraft against radar detection, has become essential in contemporary warfare high-tech high-performance equipment. This technology is categorized into: shaping of aircrafts, radar absorbing materials (RAMs) and radar absorbing structures (RASs). The shaping is to design the external features of the aircraft to reduce the electromagnetic (EM) waves backscattered to the radar source direction. The RAM and RAS are developed to absorb the EM energy and thereby minimize reflected waves. In general, the shaping conflicts with the design to improve the aerodynamic performance. Therefore, the developments of RAM and RAS have become essential for RCS reduction.

In general, RAMs have been fabricated in the form of sheets that consist of insulating polymer, like rubber, and magnetic or dielectric loss materials, such as ferrite, permalloy, carbon black, and short carbon fiber. RAMs have the strong advantage of being easily applied to the surfaces of existing structures; however, RAMs increase structure weights and have poor mechanical and environment-resistant properties. Thus, RAMs cannot be used as load-bearing structures and they require constant maintenance and repair [1].

A RAS is composed of continuous fiber–reinforced composites and lossy materials which are mixed and dispersed into the matrix of the composites. The EM properties of these composites can be also tailored by controlling the content of the lossy materials. Therefore, RASs avoid the disadvantages of RAMs due to the high stiffness and strength of the composites involved and they are also able to have the same EM energy dissipating ability of RAMs. The characteristics of the composites to be stacked ply by ply facilitate multi-layered structures, which are necessary to broaden absorption bandwidth. On the other hand, each ply of the composite prepreg has a finite and discrete thickness, and its thickness per ply changes according to the

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number of plies and the content of the lossy materials involved. Therefore, achieving the precise thickness of a designed RAS is difficult.

For a lossy filler to be highly effective, it should have a high conductivity for shielding by reflection, a high aspect ratio for a conductive network, and a small size relative to the skin depth [2,3]. In this study, multi-walled carbon nanotube (MWNT) satisfying those requirements [4,5] was selected as a lossy filler. Moreover, the MWNT is expected to act as a mechanical reinforcement [5].

The absorption and reflection of a RAS depend on a number of variables, including frequency, incident angle, polarization, and the permittivity, permeability and thickness of each layer of the RAS. To address these variables and produce an optimal RAS, optimal design concept is necessary. In previous studies, Powell's method or a genetic algorithm (GA) has been used, and several objective functions have been proposed [6–9].

In this study, a program was coded to predict the reflection loss of a multi-layered RAS for normal incident EM waves in the X-band (8.2–12.4 GHz); the code was linked with a GA to design the RAS. A fabrication process of the RAS was proposed that considered the nonlinear measure of thickness per ply, depending on the number of plies and the content of MWNT. The practical applicability of the process was confirmed by the excellent agreement between the theoretical and measured reflection loss of a designed RAS.

2. Fabrication of MWNT-filled glass/epoxy plain-weave composites

2.1. Material and fabrication

The MWNTs used in this study, purchased from ILJIN nanotech Co. (South Korea), were synthesized via a chemical vapor deposition method with a carbon mass fraction of about 95%. The MWNTs were 10–25 nm in diameter and 10–50 μm in length. A transmission electron microscopy (TEM) image of the MWNTs is shown in Fig. 1.

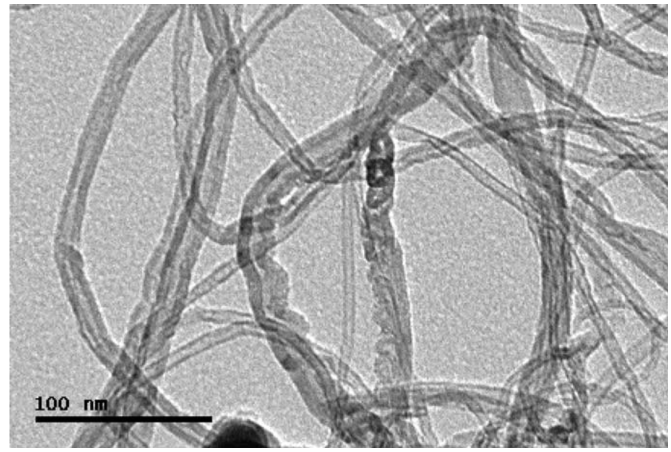

Fig. 1. TEM image of MWNT used.

Glass/epoxy plain-weave composites, K618, were supplied by Hankuk Fiber Co. (South Korea). First, the MWNTs were dispersed in epoxy matrix. The fabric composites were impregnated by the mixture of the matrix and the MWNTs. Then, The MWNT-filled fabric composites were dried for 5–7 min at 100 °C. Drying times increased with MWNT contents. As the viscosity of the premixture increased rapidly over the 3.0 weight percent (wt.%), it was difficult to maintain the uniformity of MWNTs in the matrix. The weight fraction of MWNTs to the total weight of the fabric, the epoxy system and the MWNTs is shown in Table 1. Specimens were cured and vacuum-bagged in an autoclave first for 30 min at 80 °C and then for 2 h at 130 °C. While the specimens were being cured, the pressure was stabilized at 3 atm.

2.2. Microstructure

The microstructure of the fabricated composites was captured by scanning electron microscopy (SEM). Figs. 2 and 3 show the SEM images of MWNT 1.0. Images of the matrix rich region and the interface between the glass

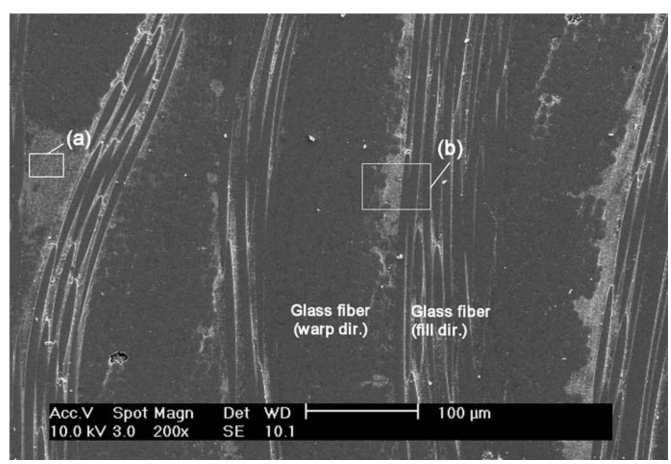

Fig. 2. SEM image of MWNT 1.0.

Table 1
Denotation of MWNT-filled glass/epoxy plain-weave composites

	Denotation							
	MWNT 0.0	MWNT 0.4	MWNT 0.7	MWNT 1.0	MWNT 1.3	MWNT 1.6	MWNT 3.0	MWNT 5.0
MWNT content (wt.%)	0.0	0.4	0.7	1.0	1.3	1.6	3.0	5.0