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Effect of delamination on the electromagnetic wave absorbing performance of radar absorbing structures

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ABSTRACT

The purpose of this study is to understand a correlation between interlaminar delamination and radar absorbing performance of composite radar absorbing structures (RAS). Many researches have been conducted on composite RAS and composite delamination. No study, however, has dealt with the delamination effect on the radar absorbing performance of RAS so far. In this study, a multi-layer Dallenbach radar absorber with glass/epoxy and glass/epoxy-Multiwall Carbon Nanotubes (MWCNT) was designed. Based on the design, test specimens were fabricated and the 'split specimen' test method was introduced. This novel test method, for measuring the electromagnetic wave reflection and absorption, enabled quantitative analysis of the delamination effect by implementing delamination with various thicknesses and locations on the same specimen. The reflection loss of the specimen for normal incident EM waves in the X-band was measured. The measurement and analysis results verified that the changes in the thickness-wise location and thickness of the delamination altered the magnitude as well as the resonance frequency of the reflection loss.

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1. Introduction

Composite materials are widely used in many industrial aspects as well as in military applications due to their high specific modulus and high specific strength. Radar absorbing structures (RAS) are one of the applications that composite materials have shown their effectiveness, especially since the development of carbon nanotubes (CNTs) [1]. CNTs embedded in composite materials are associated with energy dissipation of incident electromagnetic (EM) waves due to its conductive properties. Recently, because of their good electrical properties, CNTs are also utilized in composite materials for EMI shields [2–4].

RAS works as an electromagnetic wave absorber as well as a load bearing structure [5–7]. A large number of researches have been conducted on the RAS, and many of them are on different types, shapes, and materials of the RAS. The Salisbury screen requires a thick substrate, and the Dallenbach layer contains additional lossy materials for absorbing electromagnetic (EM) waves at the resonance frequency [8,9]. A sandwich structured RAS with glass/epoxy and polyurethane has been proposed to improve the mechanical stiffness of RAS [10], and periodic patterns of resistive materials are employed for lightweight RAS [11].

On the other hand, due to the low interlaminar fracture toughness, a major weak point of composite materials is the occurrence of delamination. The delamination may be induced from 'low velocity impact' which can cause barely visible impact damage (BVID) during operations and services. Numerous researches have been conducted on BVID and delamination since they are major failure modes in composite materials and hard to be detected with visual inspection [12,13].

Despite the fact that so many researches have been conducted on radar absorbing structures and composite delamination, no research preceding this study has dealt with how delamination affects the EM wave absorbing performance of RAS.

In this study, the multi-layer Dallenbach radar absorber with glass/epoxy and glass/epoxy-MWCNT was designed to measure the delamination effect in the X-band (8.2–12.4 GHz). For the measurement of the delamination effect, the 'split specimens' were designed and fabricated, using the optimized design parameters. The reflection loss measurement test utilizing the 'split specimen' method was validated by excellent agreement between the analytical results and the experimental results.

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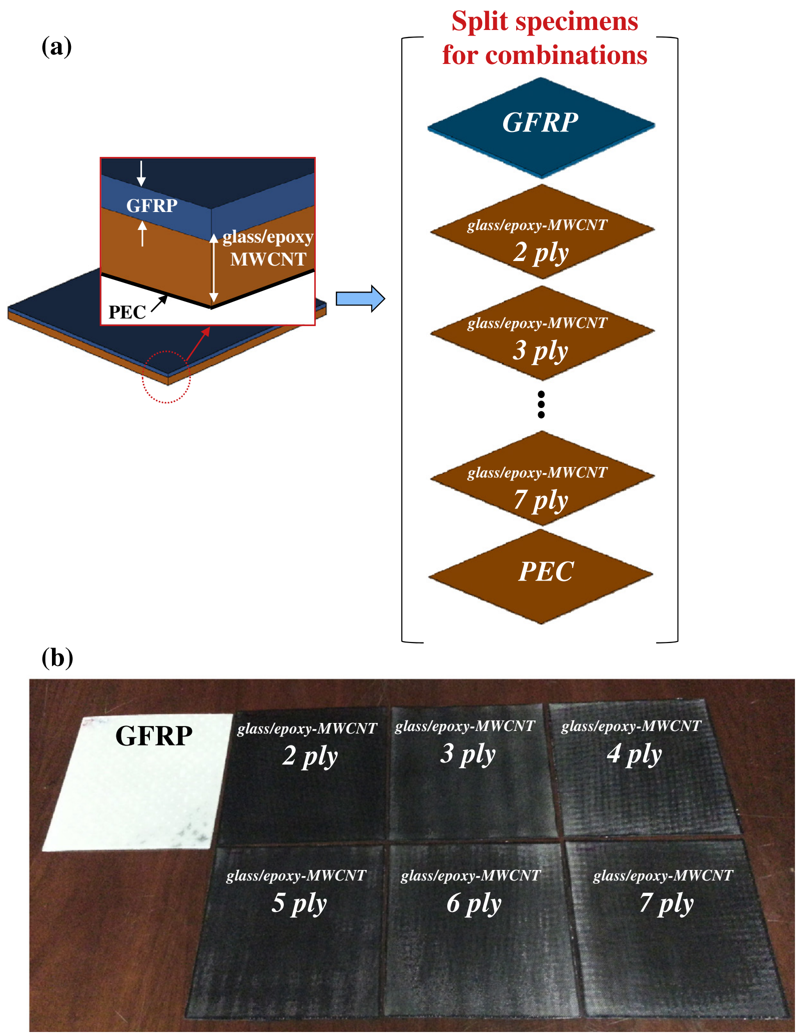

Fig. 1. Split layers for delamination effect measurement specimen and (b) fabricated GFRP and 2–7 plies glass/epoxy-MWCNT specimens (150 mm × 150 mm).

Table 1
Electrical properties of the specimens.

Specimen	ε'	ε''	Loss tangent	Thickness (mm)
GFRP	4.49	0.04	0.01	1.14
Glass/epoxy-MWCNT 2ply	8.63	4.77	0.55	0.26
Glass/epoxy-MWCNT 3ply	9.54	6.80	0.71	0.45
Glass/epoxy-MWCNT 4ply	9.48	6.87	0.72	0.58
Glass/epoxy-MWCNT 5ply	9.28	6.21	0.67	0.62
Glass/epoxy-MWCNT 6ply	10.06	6.30	0.63	0.74
Glass/epoxy-MWCNT 7ply	8.38	4.49	0.54	1.06

2. Design and fabrication of the specimen

2.1. Design of the delamination specimen

The design of RAS was conducted for the understanding of delamination effect on RAS. The Dallenbach absorber used in this study has a characteristic of minimizing the reflection of electromagnetic waves by absorbing the incident waves at the absorption layer and also by offsetting with $\lambda/4n$ out-of-phase reflected waves from the interfaces of the absorber, where λ is the wavelength and n is the refractive index. To increase design flexibility and reduce design sensitivity, the multilayer Dallenbach type was used. Since the multi-layer design has more design parameters (multiple thickness and permittivities) than the single-layer design, thus one parameter can be compensated with the other parameters [11]. The absorber in this study has two different layers with two different materials. The material for one layer is glass/epoxy (GFRP) and the other material for the other layer is glass/epoxy-MWCNT.

In designing the multi-layer Dallenbach absorber, the reflection theory of electromagnetic (EM) wave is applied. EM wave enters the absorber perpendicularly to the surface.

The general formula indicating the reflection loss of EM absorber [14] is

$$\Gamma_i = \frac{\rho_i + \Gamma_{i+1}\exp(-2j\delta_i)}{1 + \rho_i\Gamma_{i+1}\exp(-2j\delta_i)} \quad (1)$$

The reflection loss at the surface of absorber, Γ_i, is calculated from the combination of the Fresnel coefficient $\rho_i = (\eta_i - \eta_{i-1})/(\eta_i + \eta_{i-1})$ and the phase $\delta_i = (2\pi n_i d_i)/\lambda$, where the characteristic impedance of each layer is $\eta_i = \sqrt{\mu_i/\varepsilon_i}$, the refractive index of each layer $n_i = \sqrt{\varepsilon_i\mu_i}$, the thickness of each layer is d_i, and λ is the wavelength. The complex permittivity and permeability of the each layer are denoted by ε_i and μ_i, respectively [9,15]. Since dielectric lossy materials (glass/epoxy and glass/epoxy-MWCNT) were used in our study, the permittivities were only utilized in the designing the radar absorbing structure.

The equation of reflection loss at the surface of absorber was linked with a genetic algorithm to optimize the design parameter. The optimization code was written by using the derived equations,

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