LOW-OBSERVABLE RADOMES COMPOSED OF ARAMID/EPOXY COMPOSITE SANDWICH STRUCTURES AND FREQUENCY SELECTIVE SURFACE

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1 Introduction

Radar antennas are indispensable for improving the performance of weapon systems such as aircrafts, warships and missiles. The radome (radar + dome) is a protective cover of radar antennas as shown in Fig. 1. In order to shield radar antennas, the radome should be not only mechanically strong but transparent at the operational frequency range of the radar antenna [1].

The radomes are generally composed of materials that have high mechanical properties with low level of dielectric constants in order to shield the radar antennas from the external load and environmental conditions and to minimize the loss of EM (electromagnetic) wave which is transmitted to the radar antennas through the radome.

In this work, a composite sandwich radome structure including the stealth technology for a low-observable radome has been fabricated. For the face material of the low-observable radome, aramid fiber polymeric composite material has been selected. Both surfaces of the radome are supported with a core material of PMI (Polymethacrylimide) foam, which incorporates a FSS (Frequency Selective Surface).

The EM wave transmission characteristics of the low-observable radomes were simulated and measured with respect to the composite face thickness. Also the mechanical properties of the low-observable radome were measured.

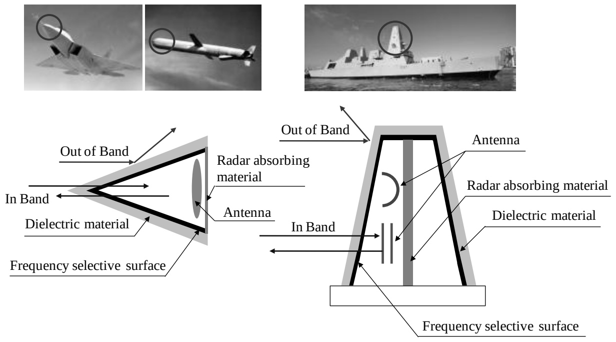

Fig.1. Schematic diagrams of radar and radome systems.

2 Fabrication

The low-observable radomes were fabricated as sandwich structures with composite faces, foam core and FSS as shown in Fig. 2. For the face materials, plain weave aramid fabric (1000 denier Heracron, Kolon, Korea) was used as reinforcement and epoxy resin (RS1212, Hankuk fiber, Korea) was used as matrix. As the core material, PMI foam (WF110, Degussa, Germany) was selected. The FSS was composed of copper foil of 20 µm thickness and polyimide film of 4 µm thickness. All the components were assembled by adhesive bonding with the epoxy adhesive (Araldite®, USA) at 80°C for 2 hours under 0.1 MPa pressure.

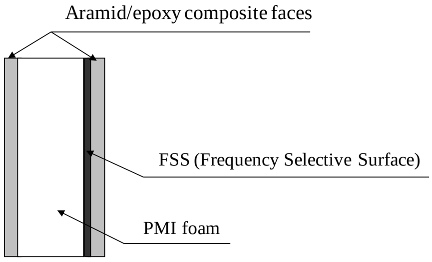

Fig. 2. Schematic diagram of sandwich structures of the low-observable radome.

3 EM wave transmission characteristics

The FRs (Functional requirements) of the low-observable radome for the EM wave transmission characteristics are selected as follows.

FR_1: Have a resonance in the X-band frequency range (8.2 ~ 12.4 GHz).
FR_2: Have more than 80% of the maximum transmission rate.
FR_3: Have less than 1 GHz bandwidth for over 80% of transmission rate.

3.1 EM properties of the face and core material

The dielectric constants of the face materials were measured by the free space measurement system (HVS Technologies, Pennsylvania, USA) as shown in Fig. 3 [2]. The dielectric constant and loss tangent of the aramid/epoxy composite were 3.742 and 0.018, respectively at the central frequency of 10 GHz of X-band range as shown in Fig. 4. The dielectric constant, ε_r of the aramid/epoxy composites was closer to that of free space (ε_r = 1) than that of plain weave fabric E-glass/epoxy composite (ε_r = 4.686, loss tangent = 0.015) [3]. The measured dielectric constant and loss tangent of the PMI foam (WF110, ρ = 110 kg/m^3) were 1.183 and 0.018, respectively at 10 GHz as shown in Fig. 4.

Fig. 3. Photograph of the free space measurement system.

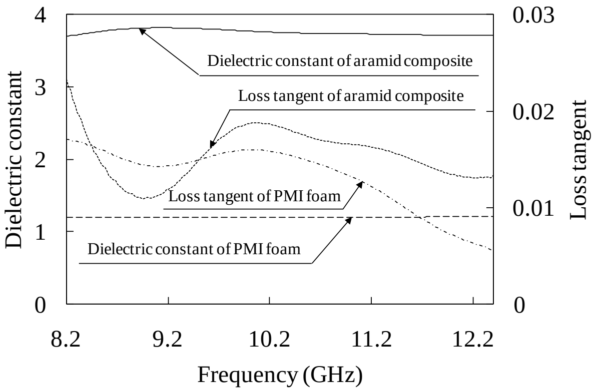

Fig. 4. EM properties of the aramid/epoxy composite and PMI foam.

3.2 Simulation

The analysis model of low-observable radome for the 3-dimensional electromagnetic simulation by CST Microwave Studio® (CST Gmbh, Germany) is shown in Fig. 5. The model has 116440 hexahedral meshes with the same boundary conditions as the free space measurement.

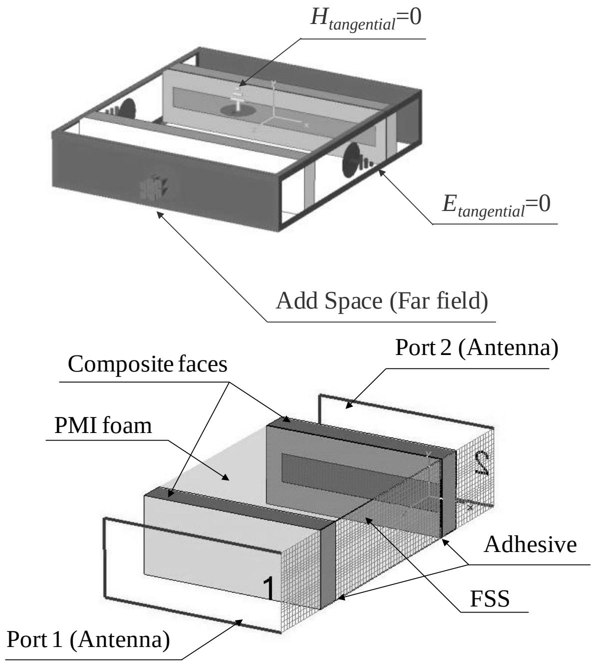

Fig. 5. The boundary conditions and the 3-dimenstional electromagnetic analysis model of the low-observable radome.

3.3 Measurement

The EM wave transmission spectral profiles of the low-observable radome were measured by the free space measurement system. The thicknesses of aramid/epoxy composite faces were fabricated as 0.24, 0.49, 0.74, 0.94, 1.15, 1.39 mm. The step change of composite face thickness was due to a ply thickness of prepreg.

The spectral profiles of the radome with respect to the thickness of aramid/epoxy composite faces are shown in Fig. 6. The transmission loss, L_{tr} was the logarithmic scale of ratio of transmitted EM wave to incident EM wave which is expressed as follows [4].

$$L_{tr} = 10\,Log\left|\frac{E_t}{E_i}\right|^2 \text{ (dB)} \tag{1}$$

The transmission rate was then calculated from Equation (1) as follows.

$$\left|\frac{E_t}{E_i}\right|^2 = 10^{L_{tr}/10} \times 100\,(\%) \tag{2}$$

When the thickness of aramid/epoxy composite face was increased, the resonance frequency shifted to the lower frequency, both the maximum transmission rate and bandwidth for over 80% of transmission rate decreased as shown in Table 1. When the thickness of aramid/epoxy composite face was 1.15 mm, all the functional requirements of the low-observable radome were satisfied.

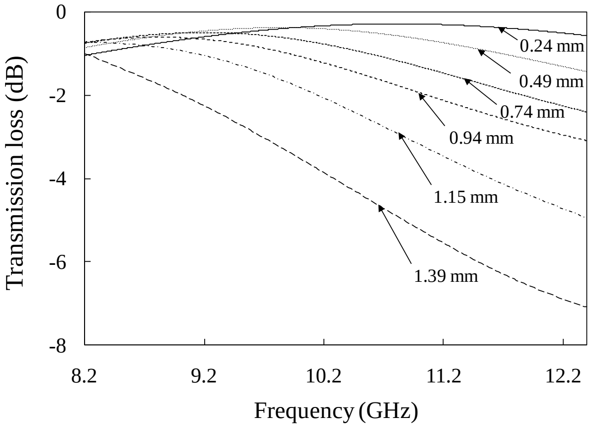

Fig. 6. EM wave transmission spectral profiles of the low-observable radome with respect to the thickness of the aramid/epoxy composite faces.

Table 1 Simulated and measured EM wave transmission characteristics of the low-observable radome with respect to the thickness of aramid/epoxy composite faces.

Thickness (mm)	0.24	0.49	0.74	0.94	1.15	1.39
Resonance frequency (GHz)						
Simulated	11.1	10.1	9.5	9.5	8.9	-
Measured	10.8	9.8	9.2	8.8	8.6	-
Maximum transmission rate (%)						
Simulated	93	91	89	86	81	79
Measured	94	92	89	87	83	79
Bandwidth for over 80 % of transmission rate						
Simulated	3.7	3.5	2.5	1.8	0.4	-
Measured	4.1	3.5	2.4	1.8	0.9	-

4 Mechanical properties

The flexural strength of the low-observable radome was measured with the 3-point bending test according to ASTM D790-03 as shown in Fig. 7 and the critical stress σ_{cr} at the failure was calculated by the following equation [5].

$$\sigma_{cr} = \frac{3PL}{2wt^2} \tag{3}$$

where, P is the external load at the fracture and t, w and L are the thickness, width and span, respectively.

Figure 8 shows the load-displacement curves obtained from the 3-point bending test for the face thickness of the aramid/epoxy composite face of 1.15 mm, which satisfied the EM wave transmission characteristics,

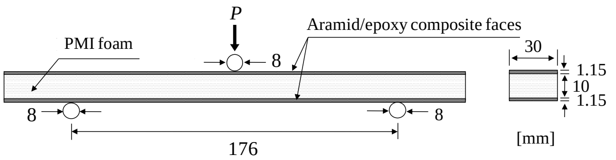

Fig. 7. Specimen of the low-observable radome composed with aramid/epoxy composite faces and foam core for 3-point bending test.

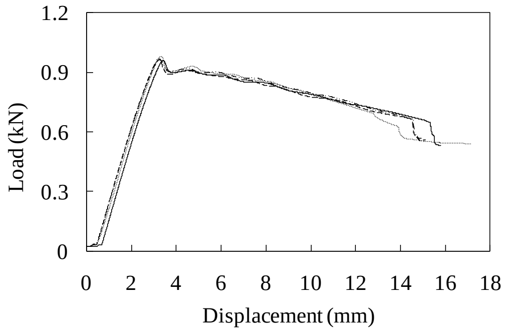

Fig. 8. Load-displacement curves of the low-observable radome specimens.

The flexural strength of the conventional low-observable radome with E-glass/epoxy composite faces was 45.6 MPa [3], while the flexural strength of the low-observable radome with aramid/epoxy composite faces was 56.3 MPa, which was 23.5% higher than the conventional radome structures.

The total densities of the radome sandwich structures were calculated as follows.

$$Total\ density = \frac{M_C + M_f + M_{FSS} + M_{adh}}{V_t}\ (\mathrm{kg/m^3}) \qquad (4)$$

where, M_C, M_f, M_{FSS} and M_{adh} are the masses of composite face, foam core, FSS and adhesive layer, respectively and V_t is the total volume of sandwich structure. The calculated specific flexural strength of the aramid/epoxy composite sandwich structure (total density: 350 kg/m^3) was 56.2% higher than that of conventional E-glass/epoxy composite sandwich structure (total density: 442 kg/m^3) as shown in Fig. 9.

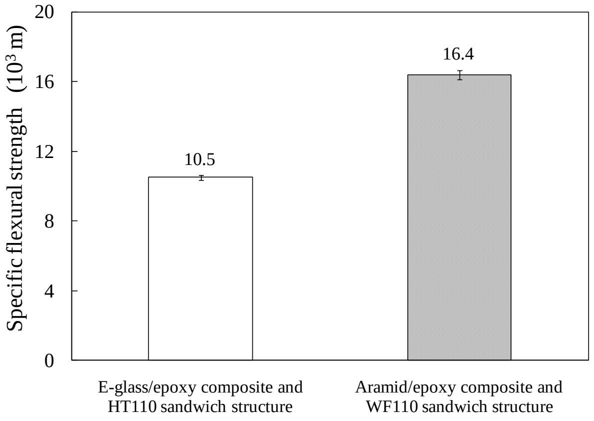

Fig. 9. Specific flexural strengths of E-glass/epoxy composite face and aramid/epoxy composite face low-observable radome.

5 Conclusion

The sandwich radome structures for the low-observable radome were fabricated with aramid plain weave fabric/epoxy composite, PMI foam and FSS (Frequency Selective Surface), which were bonded with epoxy adhesive.

The dielectric constant and loss tangent of the aramid/epoxy composite measured by the free space measurement method were 3.742 and 0.018, respectively, which were closer to the dielectric characteristics of free space than those of E-glass/epoxy composite which were 4.686 and 0.015, respectively.

The 3-dimensional EM wave simulation software was used to design the radome structure and its EM wave properties were verified by the free space measurement. When the thickness of the aramid/epoxy composite face was 1.15 mm, all the functional requirements of the low-observable radome were satisfied with the resonance frequency of 8.6 GHz. The maximum transmission rate was 83% with the bandwidth of 0.9 GHz for over 80% transmission rate.

The flexural strength and specific flexural strength of the aramid/epoxy sandwich structure were 56.3 MPa and 16.4 x 10^3 m, which were 23.5% and 56.2% higher than those of conventional E-glass/epoxy composite sandwich structure.

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