THE DEVELOPMENT OF A MULTIFUNCTIONAL EMBEDDED COMPOSITE SMART SKIN ANTENNA STRUCTURE

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Abstract: This paper focuses on the research and development of the "Multi-functional Composite Embedded Smart-Skin Antenna (MECSSA) Structure" with load-bearing, shape maintaining and communication capabilities. MECSSA structure consists of top and bottom composite thin facesheet, honeycomb core, 4 by 8 micro-strip antenna arrays located among honeycomb core and some adhesive. Simulation and experiment methods were used to study the performance of MECSSA structure. Through the study we found that adhesive is the significant factor of affecting the electrical performance of MECSSA structure, especially for radio frequency (RF) and must take into account in the research. There may be two ways to avoid the influence of adhesive: compensation and separation. Three point bending test indicated that the strength of MECSSA structure meets design requirements.

Keywords: *smart skin antenna structure; composite sandwich; micro-strip array antenna*

1 Introduction

In the 1990s', the Northrop Grumman Corporation and Wright Laboratory developed high payoff technology called conformal loading antenna structure (CLAS), and successfully integrated a Smart Skin Antenna (SSA) for air-to-air and air-to-surface communication in the vertical tail of F/A-18, improving communication range, obtaining more symmetrical radiation pattern and reducing weight of the aircraft about 250 to 1,000 lbs. [1-3].

Scholars of Pohang University of Science and Technology of Republic of Korea have made great effort to study composite smart structures (CSS), and procured a series of favorable production[4].

Multi-functional composite embedded smart skin antenna structure (MECSSA) is a multi-functional composite sandwich structure with load-bearing, shape maintaining and microwave communication capabilities. A 4 by 8 micro-strip antenna array that was designed to work in the X-band had been successfully embedded in a honeycomb sandwich panel.

2 MECSSA structure design

2.1 MECSSA structure's configuration design

The design target of MECSSA structure and micro-strip antenna arrays is:

Resonant frequency (RF) of MECSSA structure is 9.6GHz; voltage standing wave ratio (VSWR) of RF is less than 1.5; the gain of antenna is greater than 12dB; relative bandwidth of bandwidth of voltage standing wave ratio below 2 is not less than 3%, about 300MHz; MECSSA structure could support 80KN/m in-plane tensile and compressive load and 20KN/m shear load respectively under the action of bending moment and torque moment.

MECSSA structure integrated micro-strip antenna arrays into composite sandwich structure. MECSSA structure consists of top and bottom composite thin facesheet, honeycomb core, micro-strip antenna arrays located among honeycomb core and adhesive, illustrated in Figure 1.

Because the thickness of adhesive is very thin, adhesive was neglected in the process of research.

2.2 The of materials MECSSA structure

Epoxy resin composites of medium temperature curing and low dielectric loss glass cloth (SW glass cloth/epoxy) and Nomexhoney comb were selected for facesheets and honeycomb core materials respectively; medium temperature curing adhesive (LWF-2) and PTFE of glass cloth reinforced upper and lower surface and coated thin Copper foil were used for adhesive and substrate of antenna materials respectively.

2.3 The size of MECSSA structure

The thickness of Honeycomb core of MECSSA structure was set as 25mm in accordance with the thickness of general aircraft skin. The length and width of flute is equal to that of substrate of antenna, while the depth of flute was determined by the thickness of substrate of antenna and the thickness of the honeycomb cover board.

In order to obtain high quality electrical performance, the thickness of honeycomb cover board must be integer times of $\lambda/2$. Considering the simulation result of the bandwidth, RF and gain of MECSSA structure, in this paper the thickness of honeycomb cover board was determined to be 15mm.

The thinner facesheet is, the better of its electrical performance. Commonly, the thickness of facesheet is less than $\lambda/20$ and dielectric constant of SW/epoxy resin composite is equal to 4.5. We have $\lambda = 14.73$ mm, the thickness of facesheet is less than 0.7 mm. But, thinner facesheet to withstand in-plane tensile and the compressive load is relatively small. In this paper the thickness of facesheet was taken compromise to 0.4 mm.

3 Simulation

Ansoft Designer was used to accomplish simulation of electrical performance.

3.1 Analysis of micro-strip antenna arrays

Micro-strip antenna arrays consists of 4 x 8 microstrip patch. Micro-strip antenna arrays adopted microstrip lines feeding mode. Micro-strip antenna arrays adopts microstrip lines feeding mode. The size of micro-strip antenna arrays is 190mm length 80mm width 1.5mm thickness. Figure 2 shows the sketch map of micro-strip antenna arrays (unit: mm).

Figures 3 and 4 show VSWR of micro-strip antenna arrays and radiation pattern of micro-strip antenna arrays at 9.6GHz respectively. The RF of micro-strip antenna arrays is 9.58GHz with bandwidth of 350MHz. The gain of antenna is 19.52 dB at 9.6 GHz with VSWR of 1.08. The simulation results indicated that micro-strip antenna arrays has good impedance characteristics and directivity in the band range of 9.41 to 9.76 GHz. The simulation results of micro-strip antenna arrays met the design index.

3.2 Analysis of MECSSA structure

Figures 5 and 6 show VSWR of MECSSA structure and radiation pattern of MECSSA structure at 9.6GHz respectively.

The RF of MECSSA structure is 9.55GHz with bandwidth of 320MHz. The gain of antenna is 19.52 dB at 9.6 GHz with VSWR of 1.15. The simulation results of MECSSA structure met the design index.

4 Experiment

4.1 Fabrication

A total of 12 micro-strip antenna arrays test specimens were manufactured with assign numbers 1# to 12#. Among them, specimens numbered with 1#, 2#, 8#, 9#, 10# and 11# are used for MECSSA structure electrical performance test, 3#, 4#, 5#, 6#, 7# and 12# for mechanical test. Figure 5 shows test specimens model and size of MECSSA structure.

To facilitate the access of feeding port, in the MECSSA structure, the length and width of electrical performance test specimens should be the same as that of substrate of antenna, as what shows in the dashed line part of Figure 7.

Specimens for electrical performance test and mechanical performance test of MECSSA structure are showed in the left and right of Figure 8 respectively.

4.2 Electrical performance test

Electrical performance had been tested in microwave darkroom, including testing VSWR using the vector network analyzer of micro-strip antenna arrays and MECSSA structure and testing radiation pattern using rotating antenna method of micro-strip antenna arrays and MECSSA structure.

4.2.1 micro-strip antenna arrays

Figure 9 shows test results versus simulation results of VSWR of micro-strip antenna arrays. The average RF of micro-strip antenna arrays is 9.64GHz with bandwidth of 435MHz. And both test and simulation results of RF met the design index, and the error was less than 0.5%.

Figure 10 shows test results versus simulation results of radiation pattern (E plane) of micro-strip antenna arrays at 9.6GHz. The average gain of micro-strip antenna arrays is 19.27dB.

According to the test results, the test results is consistent with simulation results, the electrical performance of micro-strip antenna arrays met design index.

4.2.2 MECSSA structure

Figure 11 shows test results versus simulation results of VSWR of MECSSA structure. The RF is 9.28GHz with bandwidth of 535MHz.

The test results of VSWR of MECSSA structure severely differed with the simulation results, the former for 9.28 GHz, the latter for 9.55 GHz, with 270MHz difference. Both of them were out of the range of RF of MECSSA structure, and could not meet the design index.

Figure 12 shows test results versus simulation results of radiation pattern (E plane) of MECSSA structure at RF. The average gain of MECSSA structure is 19.13dB.

Through the test, it was found that the test results disaccord with the simulation results. Especially the RF gravely deviated from 9.6GHz (the design RF).

As the facesheet of MECSSA structure and honeycomb core have attenuation effect on electromagnetic wave, the electric performance of MECSSA structure is decreased compared that of micro-strip antenna arrays. That is to say, the gain of MECSSA structure is lower than that of micro-strip antenna arrays, as is verified by the test results. However, the simulation results indicated that both the gain of MECSSA structure and micro-strip antenna arrays is 19.52dB, which suggested that some problems emerged during the MECSSA structure's simulation. It is possible that the problem arise due to the fact of adhesive neglecting in the MECSSA structure simulation. To verify the analysis result, the research had further simulation of the MECSSA structure, considering adhesive.

4.2.3 Validated simulation of electrical performance of MECSSA structure

The thickness of adhesive is 0.1mm, with dielectric constant of 3.14 and loss tangent of 0.0221.

Figures 13 and 14 show Validated simulation VSWR of MECSSA structure and radiation pattern of MECSSA structure at 9.27GHz respectively.

The RF of MECSSA structure is 9.27GHz with bandwidth of 250MHz and gain of 18.25 dB. The validated simulation results of RF of MECSSA structure accorded with the test results, but neither of them met the design indexes. The validated simulation results of MECSSA structure bandwidth is around 50% lower than test results, dissatisfied the design requirement. The simulation results gain of MECSSA structure is slightly lower than test results, but both them can meet the design index.

The validated simulation results showed that adhesive is the significant factor affecting the electrical performance of MECSSA structure and it must be taken into account in the process of study. Moreover, due to the influence of adhesive, RF of MECSSA structure gravely deviates from 9.6GHz (the design RF), resulting in MECSSA structure unable to work. Meanwhile, adhesive also weakened the gain of MECSSA structure.

4.3 MECSSA structure three point bending test

In three point bending test, all the specimens were prepared in accordance with GBT1456-2005 Standard that five specimens of size 250mm length 100mm width 26mm thickness were prepared. Three point bending tests were performed on instron1195 machine. Figure 15 shows lab ready state.

Figures 16 and 17 show the transverse dimensions of MECSSA structure and the load model of MECSSA structure. In figures 16 and 17, $h_0 = 25.2\text{mm}$ denotes the space between top facesheet and bottom facesheet, $h_c = 25\text{mm}$ denotes the thickness of core, t=0.4mm denotes the thickness of facesheet, b=100mm denotes the width of MECSSA structure, h=26mm denotes the thickness of MECSSA structure, l=200mm denotes the support span length.

The facesheet strength of MECSSA structure ($[\sigma_f]$) is equal to 510MPa, the shear strength of honeycomb core is equal to 1.91MPa, under the condition of considering correction factors, the shear allowable stress of MECSSA structure($[\tau_c]$) is equal to 1.34MPa. The design value of point load is determined as 4700N.

Table 1 shows date of the failure load and failure mode of MECSSA structure from three point bending test. Figure 18 shows the failure mode of MECSSA structure. The average of failure load is 5.58KN, which is higher than design load. Three point bending test indicated that the strength of MECSSA structure meets design target.

5 Conclusions

This paper completed the design, manufacture and test work of MECSSA structure, formed a set of research method of MECSSA structure.

Though the research we found that adhesive is the significant factor of affecting the electrical performance of MECSSA structure, especially for radio frequency and must take into account in the process of study. There may be two ways to avoid the influence of adhesive: compensation and separation.

Three point bending test indicates that the strength of MECSSA structure meets design requirements.

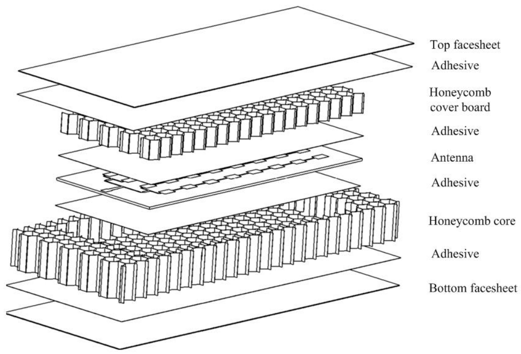

Figure 1 Configuration scheme of MECSSA structure

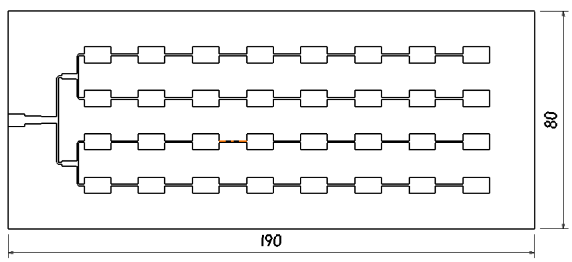

Figure 2 Sketch map of micro-strip antenna arrays

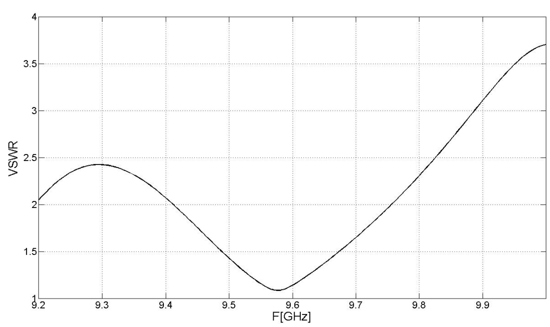

Figure 3 VSWR of micro-strip antenna arrays

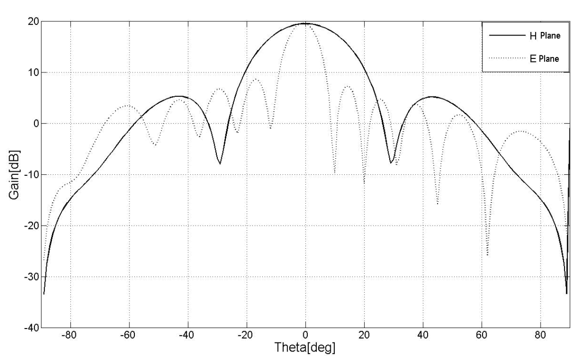

Figure 4 Radiation pattern of micro-strip antenna arrays at 9.6GHz

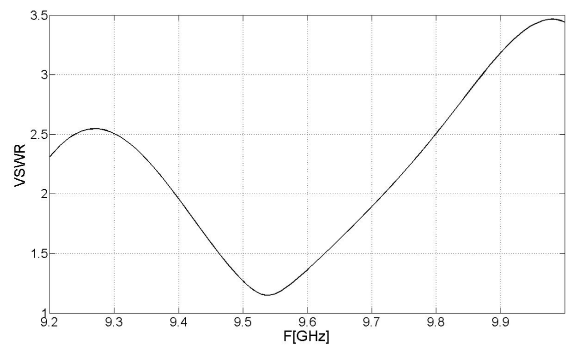

Figure 5 VSWR of MECSSA structure

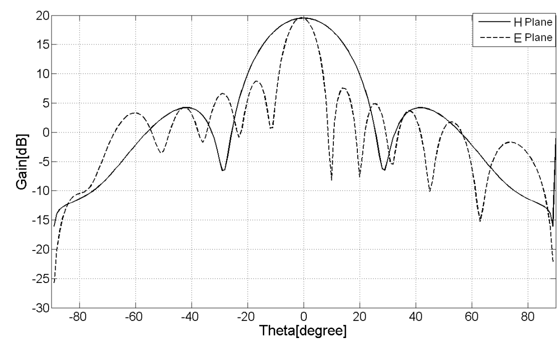

Figure 6 Radiation pattern of MECSSA structure

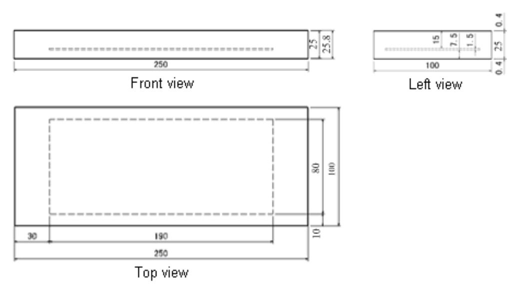

Figure 7 Specimen model and size of MECSSA structure

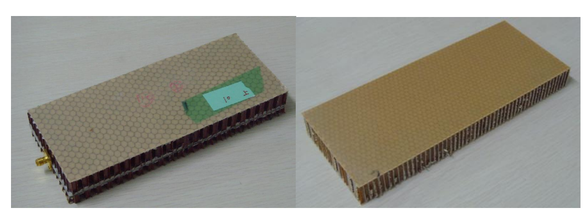

Figure 8 The test specimens of MECSSA structure

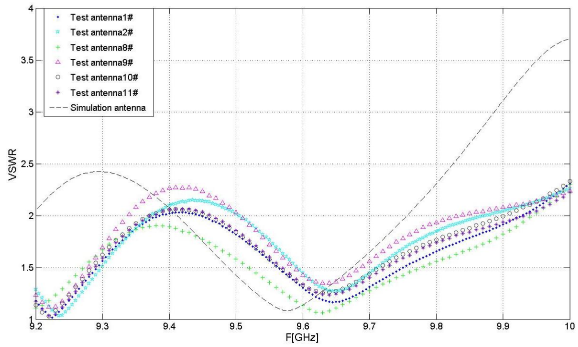

Figure 9 VSWR of micro-strip antenna arrays

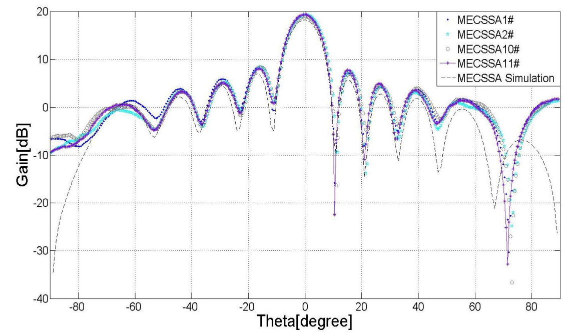

Figure 12 Radiation pattern of MECSSA structure

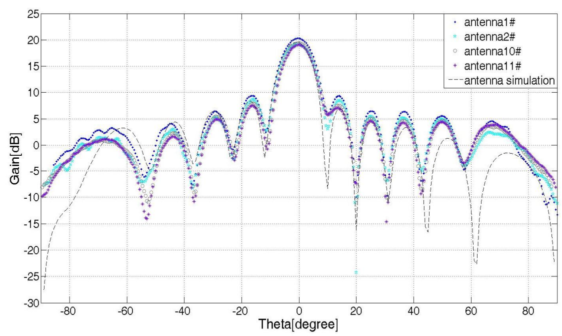

Figure 10 Radiation pattern of micro-strip antenna arrays

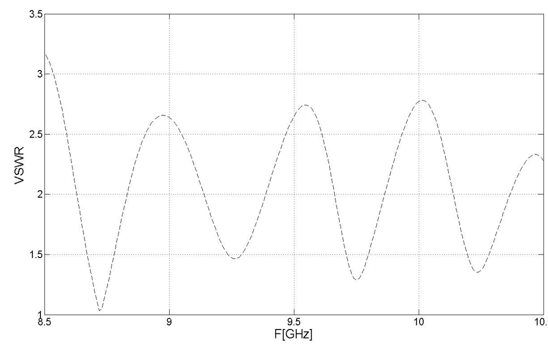

Figure 13 Validated simulation results of RF of MECSSA structure

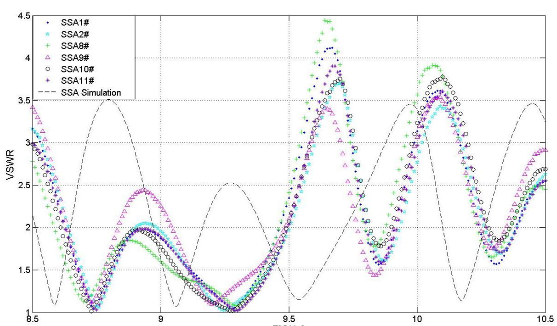

Figure 11 VSWR of MECSSA structure

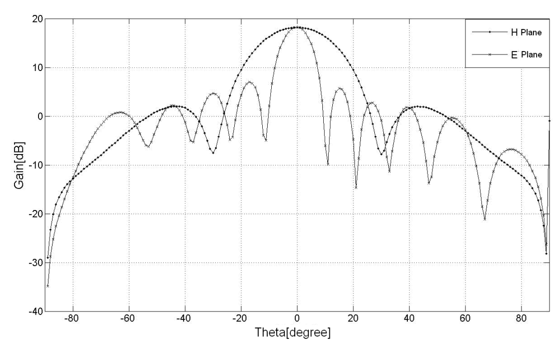

Figure 14 Validated simulation results of radiation pattern of MECSSA structure

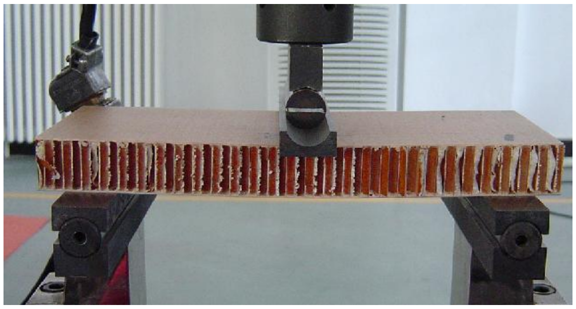

Figure 15 Three point bending test of MECSSA structure

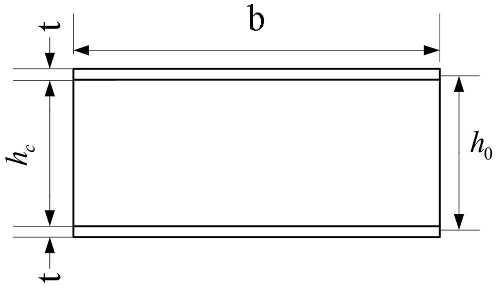

Figure 16 The transverse dimensions of MECSSA structure

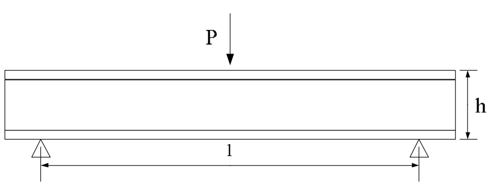

Figure 17 the load model of MECSSA structure

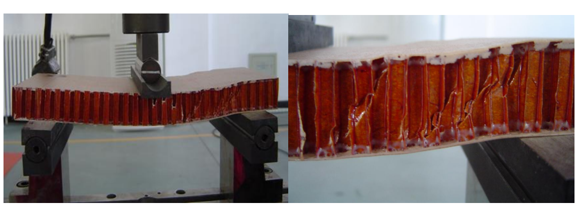

Figure 18 MECSSA structure failure mode

Table 1 The failure load and failure mode of MECSSA structure

Specimen	**Failure load P(KN)**	**Failure mode**
1#	5.53	Honeycomb core shear instability
2#	5.65	Honeycomb core shear instability
3#	5.59	Honeycomb core shear instability
4#	5.63	Honeycomb core shear instability
5#	5.23	Honeycomb core shear instability
average	5.58	-

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