Electromagnetic Characteristics of Frequency Selective Fabric Composites

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1. INTRODUCTION

FSS (frequency selective surface) consists of periodically arrayed elements and reflects or transmits electromagnetic waves in certain frequencies, which depend on element size and shape. It has been widely used as electromagnetic filters and studies of application to RAM (radar absorbing material) and RAS (radar absorbing structure) were performed lately [1].

FSS has been made of metal, such as copper and aluminum. The metallic FSS was fabricated by introducing PCB (printed circuit board) process to metallic foils attached to dielectric substrates or low lossy films coated with metal [2]. In this study, FSFCs (frequency selective fabric composites) with carbon fibers and dielectric fibers woven periodically were proposed. Carbon fibers, corresponding to metal parts due to high electrical conductivity, reflect incident waves, and glass fibers with low permittivity, corresponding to aperture parts, transmit most of the incident waves. Therefore, the proposed FSFC is used as an inductive FSS.

As shown in Table 1, compared to a metallic FSS, FSFC has a less precise size because it is difficult to realize perfect alignment of fibers and the exact width of fiber rovings. But, as RASs are fabricated with fiber-reinforced composites, FSFCs have little difference in mechanical and thermal properties, which leads to advantages over metallic FSSs in load bearing ability, embedment, maintenance and corrosion resistance, etc.

In this study, the electromagnetic characteristics of FSFCs were investigated in advance of the study of a RAS with FSFCs.

2. FABRICATION

A FSFC was fabricated in a plain-weave type with a square element in a cell size of 10 mm and an aperture size of 8 mm. T300 and E-glass rovings were used as carbon and dielectric fibers. Each roving has a width of 2.0 mm and the distance of the rovings is 0.5 mm. Specimens were cured and vacuum-bagged in an autoclave first for 30 min at 80°C under 1.2 atm and then for 2 hours at 130°C under 3.0 atm. The thickness of the fabricated FSFC is 0.125 mm. Figure 1 and 2 show the geometry and shape of a fabricated specimen.

3. SIMULATION

The main parameters that have the greatest influence on the electromagnetic characteristics of FSFCs are the distance between carbon fiber rovings and their width, by which element sizes are determined and resonance frequencies of the FSFCs shift. The additional parameters include electrical conductivity of carbon fiber, textile pattern, fiber undulation and fiber form, etc.

In general, the electrical conductivity of carbon fibers ranges from 10^4 S/m to 10^5 S/m. As a skin depth

Table 1. Characteristics of metallic FSS and FSFC

	Metallic FSS	FSFC
Material of FSS	Metal	Carbon fiber + dielectric fiber
Precision of pattern	Superior	
Mechanical and thermal property difference from dielectric substrate		Superior
Load bearing ability		Superior
Embedment		Superior
Maintenance		Superior
Corrosion resistance		Superior

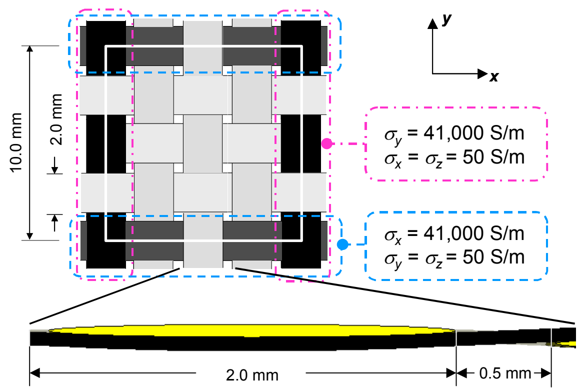

Fig. 1 Schematic of a fabricated FSFC.

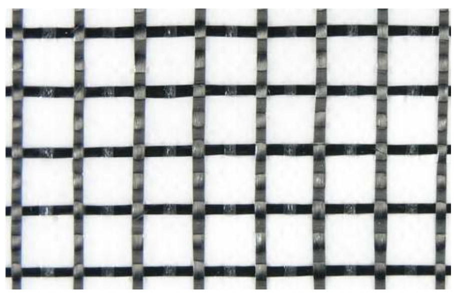

Fig. 2 a specimen of fabricated FSFC.

increases, electrical conductivity decreases. Considering the skin depth, the low thickness of carbon fiber rovings can lead to the transmission of an amount of electromagnetic energy in a certain frequency band. Textile pattern has an influence on fiber undulation, which can make incident waves more scattered. In addition, fiber forms, such as yarn and roving, are related to fiber undulation. Therefore, The effects of the electrical conductivity and undulation of carbon fiber rovings on the reflection and transmission of electromagnetic waves were required to be investigated.

A fiber roving can be regarded as a unidirectional fiber-reinforced composite. Its electrical conductivity can be predicted by using the rule of mixture about the electrical conductivity of the composite. But it is difficult to measure the fiber volume fraction of a roving in cured state. Therefore, the simulations were conducted by using CST Microwave Studio, a 3-dimensional analysis tool of electromagnetic field, in the cases of fiber volume fractions of carbon fiber roving, V_{f_r}, 0.5, 0.6 and 0.7. The electrical conductivity of the used T300 fiber is 5.9×10^4 S/m. Figure 1 shows the electrical conductivity of carbon fiber rovings in each direction in case of 0.7 V_{f_r}. The longitudinal conductivities in 0.5 and 0.6 V_{f_r} are 3.0×10^4 and 3.5×10^4 S/m. The simulation showed a small difference in transmitted powers, about ± 0.2 dB, in 2-30 GHz. That is, although the conductivity of the rovings depends on V_{f_r}, the change of V_{f_r} ranging from 0.5 to 0.7 make little effect on electromagnetic characteristics of FSFCs. It is an indication that V_{f_r} need not be measured and may be assumed to predicted the reflection and transmission of FSFC.

It was thought that the thickness of FSFC lower than the cell size of FSFC and wavelengths in our interesting frequency band might make the fiber undulation effect negligible. The simulations considering and not considering the fiber undulation showed that each transmitted power has a small difference of less than 0.4 dB. Therefore, the following simulations were conducted with the fiber undulation unconsidered and fiber rovings were modeled linearly.

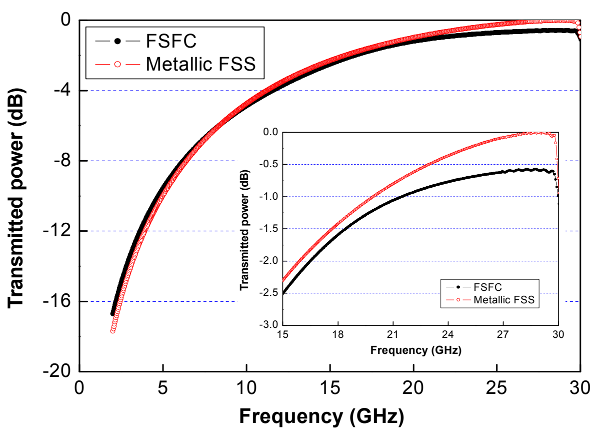

Fig. 3 Comparison of transmitted power between metallic FSS and FSFC.

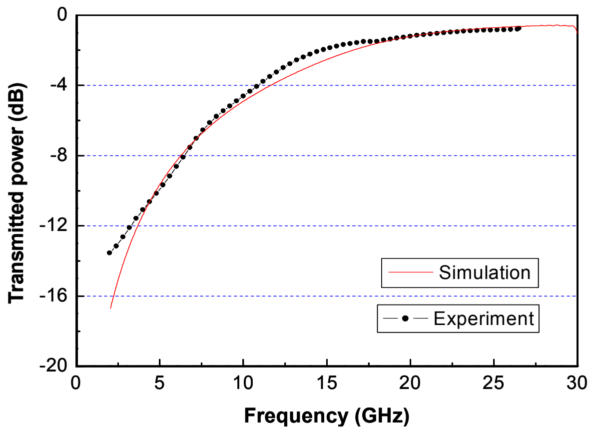

Fig. 4 Comparison between simulation and measurement.

Transmitted power of the FSFC was compared to that of the metallic FSS with the same cell and aperture size. Figure 3 shows that two FSSs have the similar transmitted power over the interesting frequencies except near resonance frequency, f_r. The reasons about the reflection of FSFCs near f_r are that the aperture is filled with dielectric fibers and a polymer matrix, not free space, and that electrical loss occurs while the electromagnetic waves travel in carbon fiber rovings.

4. MEASUREMENT

Free space method was used to measure transmitted power. As shown in Fig. 4, the predicted and measured results were found in good agreement. The discrepancy between them is ascribed to the imprecision of the cell and aperture size.

5. CONCLUSIONS

A FSFC, as an inductive FSS, was proposed consisting of carbon and dielectric fibers. The electromagnetic characteristics of the FSFC were investigated considering the electrical conductivity and undulation of carbon fiber rovings. It was confirmed through simulation and measurement that the proposed FSFC is a promising structure for RASs.

REFERENCES

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2. T. K. Wu, *Frequency Selective Surface and Grid Array*, 1995.