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Electromagentic Wave Absorption Properties of Carbon Microcoils/Nanocoils

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The electromagnetic (EM) wave absorption properties in the GHz region (12-110 GHz) by the carbon microcoils/nanocoils (CMC) with a 3D-helical/spiral chiral structure, which were obtained by the catalytic pyrolysis of acetylene, were measured using the open space method. It was found that the reflection loss over –20dB in several specified band regions, which is a target value for commercial applications, were obtained for CMC/PMMA beads or foams with an addition of only 1-3 wt% CMC. The reflection loss increased with increased the thickness of the absorption layers. Double-layer absorption composites of CMC/PMMA foams with different coil lengths of CMC and the addition amount showed higher EM absorptibities than that of the single-layer composite. It was found that the CMC/PMMA double layer foams containing 1-3 wt % CMC could effectively (>-15~ -20dB) absorb the EM waves in 50-110GHz wide GHz regions while absorb sharply (>-20dB) at some specific bands in the region of 5.6-50 GHz.

Key words: carbon microcoil, carbon nanocoil, electromagnetic wave absorption

1. INTRODUCTION

In recent years, electromagnetic (EM) waves applications, especially in GHz regions, have significantly expanded. However, so-called "EM pollution" problems, such as EM wave interference (EMI) of electronic devices and instruments, miss-actions in the transportation systems of railways, airplanes, or medical instruments, etc., by the EM waves have appeared along with the increasing use of the EM waves in the GHz regions. Conductive metal films are generally used for shielding the EM waves in the MHz regions. Ferrites, carbon powders, metal-coated carbon fibers or synthetic organic fibers are also used for the shielding/absorbing of the EM waves in MHz and lower GHz regions. Shielding materials usually have no EM wave absorption properties while they can effectively reflect and shield EM waves, and thus the EM pollution problems are not solved fundamentally by the conventional shielding materials. Varadan et al. first paid much attention to EM wave absorption using chiral materials in which the conductive chiral polymers showed an excellent of EM wave absorption property [1]. We found that the (carbon microcoils) CMC/polyurethane (or PMMA) composites could absorb the EM waves in the 2-18 GHz region [2-8] and 12.4-110 GHz.[9-10] For example, the CMC/polyurethane or CMC/PMMA sheet composites containing 1-3 wt% CMC could sharply absorb the EM waves above –20dB, and the effect of coil length, CMC addition amount, CMC heat-treatment and exposure time on the EM absorption properties was examined in detail.[9] Jin-Hong Du et al. also reported on the microwave EM characteristics of CMC/paraffin wax composite.[11]

In this study, we examined the EM absorption property of the CMC, which was embedded into PMMA beads or PMMA foams, in the higher GHz regions (12~110GHz) using the open space method. The effect of the addition amount of the CMC in these composites, thickness of the composite layers, etc. on the absorptivity of the EM waves were examined in detail. The EM wave absorption mechanism by CMC is also discussed.

2. EXPERIMENTAL

As-grown CMC obtained using a Ni catalyst at 700-800°C was used as absorption materials. The detailed preparation procedure and morphology of the CMC are shown in ref. 12. Polymetylmetacrylate (PMMA) was used as a matrix of the CMC composites. The CMC/PMMA beads were prepared by the conventional dispersion polymerization of methyl methacrylate (MMA), in which the CMC was uniformly dispersed into MMA monomer solution and polymerized at 50℃ for a 4-hr while mixing (500 rpm). The bead samples were filled spontaneously without pressing in 150x150x3~13 mm^3 measurement cells (PET box). The CMC/PMMA foams were prepared by foaming of the CMC/PMMA melts and molded in a 150 x 150 mm^2 frame placed on an Al plates (1 mm thickness). Two-sheet-laminated absorption composites with a total thickness of 26 mm were prepared by stacking and laminating two CMC/PMMA sheets or foams with different coil length and coil addition amount. The reflection loss (absorptivity) of the EM waves was measured using the Free Space Microwave Measurement System (JFCC-HVS). The measured EM band regions were 5.6 ~ 110 GHz.

3. RESULTS AND DISCUSSION

Fig. 1 shows the representative CMC used as the EM wave absorbers. The CMC have relatively regular-coiling patterns with a coil diameter of 2-6 μm, coil length below 300 μm,

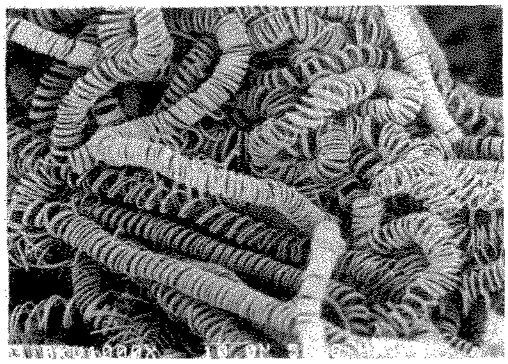

Fig. 1. Representative carbon microcoils (CMC) using as EM wave absorbing materials.

Fig. 2 shows the CMC/PMMA beads containing CMC of a coil length below 90 μm by 1 wt% addition. The beads have a sphere or slightly elliptic form and with black color, and the bead size is 0.01~2 mm diam. depending on the mm

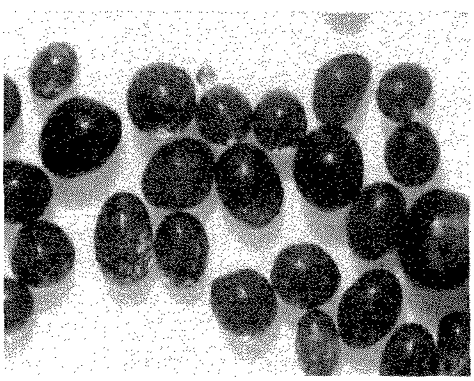

Fig. 2. CMC(1wt%)/PMMA beads.

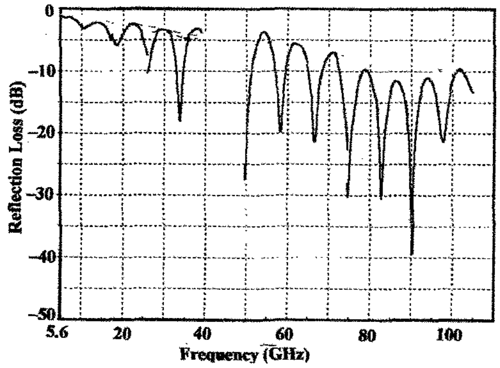

Fig. 3. Reflection loss of CMC(1wt%)/PMMA.

diam. were used. Fig. 3 shows the reflection loss of the CMC/PMMA beads containing CMC (1 wt%). It can be seen that strong (above -20dB) and relatively periodic EM wave absorption peaks were attained at 50-110 GHz, while small absorption in the frequency below 30 GHz.

Fig. 4 shows the effect of the thickness of CMC/PMMA bead absorption composite layers on the reflection loss is shown. It can be seen that the high absorption was obtained for the sample of above 8 mm thick, while low absorption for the thickness of below 5 mm.

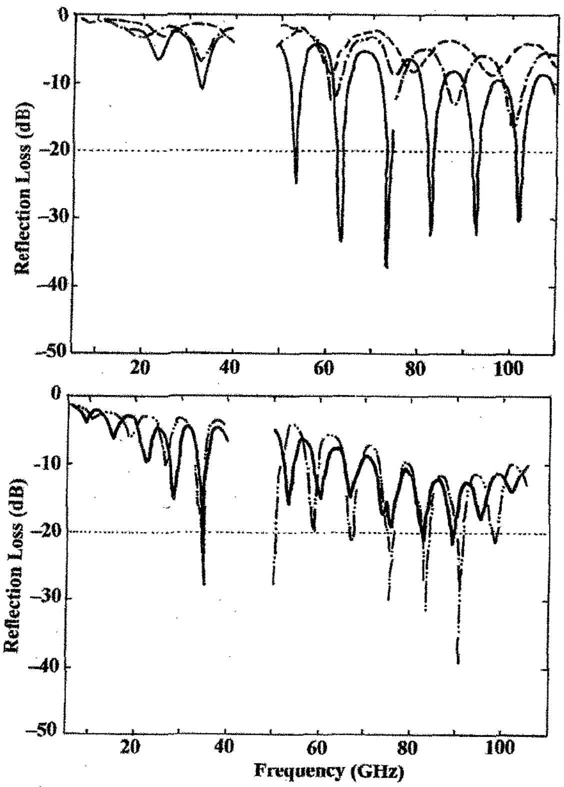

Fig. 4. Reflection loss of CMC(<90μm, 1wt%)/PMMA beads. Thickness of bead layers: (- - - -) 3 mm, (- - -)5 mm, (———) 8 mm, (— · · —)10 mm, (▬▬) 13 mm.

Fig. 5 shows the CMC/PMMA foams containing CMC with a coil length of 150-300μm by 3 wt%, in which PMMA matrix was foamed by two times of the original volume. The CMC/PMMA foams have a color between gray and black color and with many large pores. Fig. 6 shows the reflection loss of the CMC/PMMA foams with the CMC addition amount of 1 wt% and 3 wt%. It can be seen that the CMC/PMMA foams containing 1 wt% CMC showed a high reflection loss (-20~-35 dB) at specific frequencies in the 50-110 GHz regions. On the other hand, CMC (3 wt%)/PMMA foams

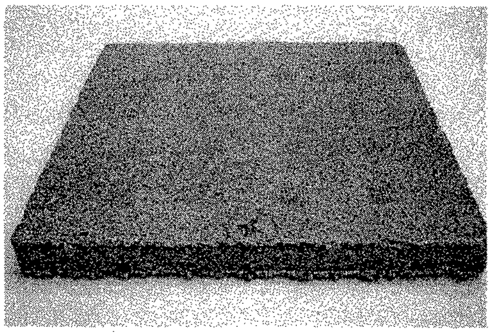

Fig. 5. CMC/PMMA foams.
CMC: 150~300 μm, 3 wt%, foaming ratio: 2 times.

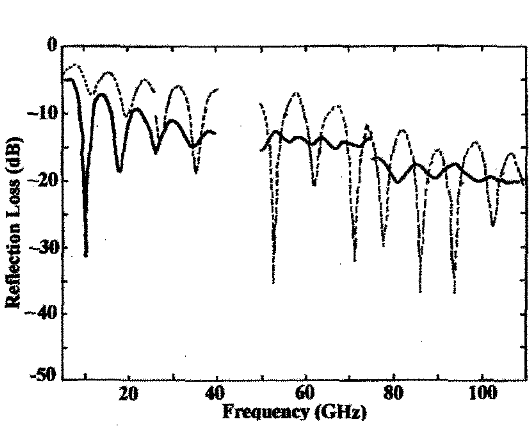

Fig. 6. Reflection of CMC/PMMA foams.
CMC (150~300μm) content: (------) 1 wt%, (——) 3 wt%.

showed averaged high reflection loss of about -20dB over the wide frequencies in 80-110GHz and of about -15dB in the 50-80GHz. Furthermore, the reflection loss of CMC (3wt%)/PPMA in the lower frequencies of 5-40 GHz was higher than that of CMC (1wt%)/PMMA. That is, the higher reflection loss, wider absorption band and lower absorption frequency of the CMC/PMMA foams could be obtained by higher addition of CMC in PMMA forms. Fig. 7 shows the reflection loss of CMC (1wt%)/PMMA forms with both one layer of 26 mm thick and two layer-laminated foams with different coil length of 150-300 μm and 300-500 μm (total thickness:26 mm). It can be seen that two layer foams showed more excellent reflection loss (above -20dB) at wider frequency ranges of the 50-110 GHz and also about -15dB in the 10-40GHz, while one layer sample show poor reflection loss. Fig. 8 shows the reflection loss of the two layer-laminated foams with different coil lengths and coil contents. It can be seen that the two layer-laminated foams show high reflection loss (above –15 dB) at higher frequencies of 50-110 GHz and also show sharp and strong absorption (above –20dB) at specific frequencies in lower frequencies of 5-40 GHz. Especially, the two layer-laminated foams of CMC (150-300μm, 3 wt%)/PMMA//CMC(150-300μm, 1 wt%)/PMMA show a high reflection loss above –20dB over wide frequencies of 70-110 GHz. These results show that it is possibility that high reflection loss can be attained by making multi-absorption layers with different coil lengths and coil contents.

Materials generally absorb the EM waves by the three mechanisms dielectric loss, conductive loss, or magnetic loss. For example, Du et al. reported that the CMC/paraffin wax composite is mainly a kind of dielectric loss material with a small magnetic loss and diamagnetism in the Ku band.[11] However, the CMC is a kind of representative chiral material with micro-coiling morphology and thus expected to have different interactions with the EM waves from unchiral materials. Accordingly, it is necessary to discuss the interaction of the CMC with EM waves from the chiral materials view

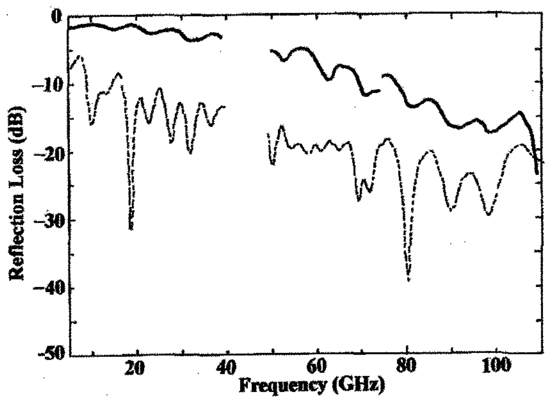

Fig. 7. Reflection loss of CMC(1 wt%) /PMMA foams.
(——) one sheet (thickness: 26 mm), CMC(300~500μm). (------) two sheets (total thickness: 26 mm), CMC(300~500μm)/PMMA// CMC(150~300μm)/PMMA.

point, not from simple dielectric materials without chirality. The correlation of the coiling-chirality of the CMC with EM waves is not well known. However, it is considered that these EM absorption materials must have a chiral structure and high chiral parameters to obtain an effective absorptibity in the GHz regions. In the case of the materials with a 3D-helical/spiral structure, the optimum relationship between the coil diameter (D_c), coil pitch (P) and fiber diameter (D_f) are D_f/Dc=0.1~0.2 and P/D_c=3. The ratio of the P/D_c of the CMC used is smaller than these values. Accordingly, the CMC must have a larger coil pitch, coil diameter, and coil length for obtaining a higher absorption property.

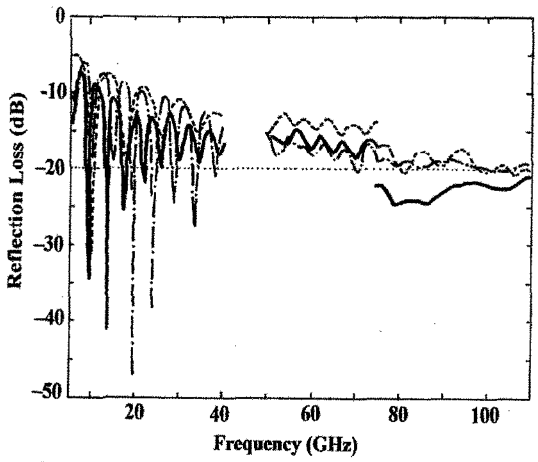

Fig. 8. Reflection loss of CMC/PMMA stacking layer forms. Total thickness of absorbing layer: 26 mm. CMC coil length and content of CMC in PMMA : (......) single sheet (150-300μm, 3 wt%), (— · —) double sheet (150-300μm, 3 wt%)/(300-500μm, 1 wt%), (▬▬) double sheet (150-300μm, 3 wt%)/(150-300μm, 1 wt%).

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