

# Electromagnetic Interference Shielding Characteristics for Stainless Wire Mesh and Number of Plies of Carbon Fiber Reinforced Plastic

Min Sang Lee, Hee Jae Shin, In Pyo Cha, Hyun Kyung Yoon, Seong Woo Hong, Min Jae Yu, Hong Gun Kim, Lee Ku Kwac

**Abstract**—In this paper, the electromagnetic shielding characteristics of an up-to-date typical carbon filler material, carbon fiber used with a metal mesh were investigated. Carbon fiber 12k-prepregs, where carbon fibers were impregnated with epoxy, were laminated with wire meshes, vacuum bag-molded and hardened to manufacture hybrid-type specimens, with which an electromagnetic shield test was performed in accordance with ASTM D4935-10, through which was known as the most excellent reproducibility is obtainable among electromagnetic shield tests. In addition, glass fiber prepregs whose electromagnetic shielding effect were known as insignificant were laminated and formed with wire meshes to verify the validity of the electromagnetic shield effect of wire meshes in order to confirm the electromagnetic shielding effect of metal meshes corresponding existing carbon fiber 12k-prepregs. By grafting carbon fibers, on which studies are being actively underway in the environmental aspects and electromagnetic shielding effect, with hybrid-type wire meshes that were analysed through the tests, in this study, the applicability and possibility are proposed.

**Keywords**—Carbon Fiber Reinforced Plastic (CFRP), Glass Fiber Reinforced Plastic (GFRP), Stainless Wire Mesh, Electromagnetic Shielding.

## I. INTRODUCTION

CURRENTLY, seriousness of damages due to electromagnetic waves to human bodies are on the rise along with environmental pollutions such as air, water and noise pollutions caused by rapid industrialization, and such electromagnetic waves are triggering diverse side-effects as they are closely related to the whole life of modern people such as TV, PC and mobile [1].

In particular, as human bodies are easily and directly exposed to electromagnetic waves produced by electronic devices and in diverse industries, not only mental side-effects such as weakened skin resistance, hallucination, insomniac and

declined leaning ability but also physical diseases such as various cancer, brain tumor, deformity birth and DNA damage are provoking [2].

Furthermore, there have been many cases reported, in whole industries, where malfunctions of devices lead to different results in works or productions, accidents occurred due to malfunctions not only trigger dangers to workers but also cause malfunctions of telecommunication devices such as national defence radar [2].

Therefore, to address problems caused by diverse types of electromagnetic wave noises that are occurred in electronic devices or that affect electronic devices, concerns and studies are greatly rising on electromagnetic shielding materials and technologies; while restrictions tend to increase on the use of lead, which is popularly being used as an electromagnetic shielding material in existing industries due to its high electromagnetic shielding rate; under the circumstance that the environmental problems are caused by recent global warming that was responded by the “Carbon Tax” according to the Kyoto Protocol effectuated from October 2012 and the necessity of environmental-friendly materials to replace fossil fuels is increasing.

Park compared the electromagnetic shielding effectiveness with the existing AP box by using carbon fiber 3k prepreg and metal wire mesh [2]. Cha verified that since 3k prepreg were used; the electromagnetic shielding effectiveness ratio has decreased by a study using carbon fiber 12K prepreg and metal wire mesh [4]. Lee studied on the electromagnetic Interference properties of fiber reinforced polymer composites with carbon nanotubes [7].

In this paper, we verified using glass fiber prepreg to experiment electromagnetic shielding effect of the wire mesh by measuring variously metal mesh laminated to the long life of the carbon fiber prepreg 12K for electromagnetic wave shielding of a hybrid form.

As such, the electromagnetic shielding materials are being spotlighted in the environmental, weight reduction and energy saving aspects. Materials laminated with carbon fibers and wire meshes are verified as effective at more than a certain level in achieving additional weight lightening. Therefore, hybrid-type shielding materials, which are developed one-step further than shielding materials that are used with carbon fibers only, are proposed, in this paper, to confirm electromagnetic shielding effect corresponding to it, to propose directivities toward which such hybrid-type materials can be grafted with diverse whole

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industries and general devices; thereby, a type to be studied in a mechanical characteristic term in the future is suggested in this paper.

## II. SPECIMEN FABRICATION

The carbon fibers used in this study are the 12k-fabric prepreps manufactured by Hankuk Carbon Co., Ltd. and the wire meshes are 400 x 400 stainless meshes.

The specimens were manufactured in accordance with ASTM D4935-10 standard specimens and carbon fiber 12k-prepreps and wire meshes were cut to the sizes of 380mm x 180mm, laminated appropriate to each specimen type, and heated in an oven for 60 minutes at 85°C and 90 minutes at 125°C to be vacuum bag-formed.

The specimens were fabricated, in accordance with the ASTM D4935-10, to the size as shown in the figure using a diamond cutter to reduce its residual stresses and damages. Fig. 1 shows the dimensional mimetic diagram of the specimens and Fig. 2 the specimens manufactured by being formed [3].

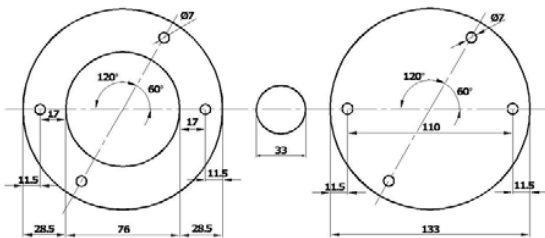


Fig. 1 ASTM D 4935-10 Specimen size

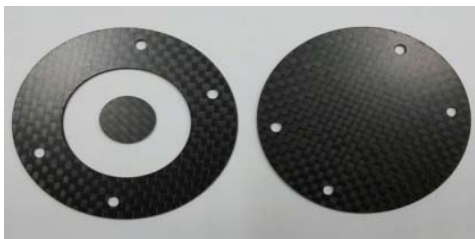


Fig. 2 Fabricated Specimens

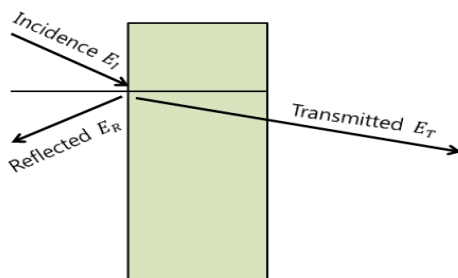


Fig. 3 Schematic of an electromagnetic wave shielding

## III. THEORY AND PRINCIPLE OF THE ELECTROMAGNETIC WAVE SHIELDING

If an electronic wave meet a medium while travelling, a part the wave reflects like light does, and the rest penetrates into the

medium. The penetrated electronic wave can be absorbed into the medium due to the medium characteristics, and such is shaped as shown in Fig. 3 [4].

While the reflection, absorption and penetration phenomena of an electronic wave at boundaries between heteromaterials are determined by the dielectric permittivity and permeability of the medium, the reflection of an electronic wave is decided by the impedance,  $Z$  of the medium [2].

In addition, the impedance is defined by the electric field ( $E$ ) and the magnetic field ( $H$ ) of the electronic wave, and can be written by the square root of the permeability vs. the permittivity of the medium as presented in (1) [2].

$$Z = \frac{E}{H} = \sqrt{\frac{\mu_r}{\epsilon_r}} \quad (1)$$

In Fig. 3, if the electric fields of the incident, reflection and penetration wave of the electronic waves transmitted to the medium  $E_I$  and  $E_R$  and  $E_T$  respectively, the reflection coefficient,  $S$  and the penetration coefficient,  $T$  at the boundary can be calculated by (2) and (3) [2].

$$S = \frac{E_R}{E_I} = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad (2)$$

$$T = \frac{E_T}{E_I} = \frac{2Z_2}{Z_2 + Z_1} \quad (3)$$

where,  $A$  and  $B$  are the impedances of the medium 1 and 2, respectively, and are the same ( $S=0$ ) if the electronic wave is not reflected at the boundary surface. Such condition is called 'impedance matching'. If impedances are coordinated, all incident waves penetrate into the medium 2, of which penetration coefficient is  $T=1$  [2].

The concept of an EMI shield is to absorb or reflect the waves through desired materials such that the external waves shall not be transmitted into an indoor environment or system. The shield capability can be defined by the extent to which it can attenuate an electromagnetic wave introduced into an object [1].

$$SE(\text{dB}) = 10 \log \left( \frac{P_T}{P_R} \right) \quad (4)$$

Considering the material thickness and electrical characteristics, we can derive the following equation:

$$\begin{aligned} SE(\text{dB}) &= 20 \log \left[ e^{at} \frac{(1+K)^2}{4K} \left\{ 1 - \left( \frac{K-1}{K+2} \right)^2 e^{-2rt} \right\} \right] \\ &= 20 \log(e^{at}) + 20 \log \left\{ \frac{(1+K)^2}{4K} \right\} + 20 \log \left\{ 1 - \left( \frac{K-1}{K+2} \right)^2 e^{-2rt} \right\} \end{aligned} \quad (5)$$

The ratio between electromagnetic impedance and shield material impedance symbol denoted as;  $t$ , the material thickness;  $g$ , the propagation constant ( $=a+ib$ ) of the electromagnetic wave; and  $a$ , the attenuation constant of the electromagnetic wave. In (5), the first term is called adsorption loss, the second term is called reflection loss, and the third term is called multi-reflection correction. The EMI shield

effectiveness is found by the sum of the absorption, the reflection of the electromagnetic wave introduced, and the multi-reflection between the medium boundaries. The electromagnetic wave can be shielded effectively by utilizing these losses according to the characteristics of the electromagnetic wave to be shielded. That is, when electromagnetic energy arrives at an arbitrary object (shielding material), the travel path of the electromagnetic wave is distributed by three phenomena, namely reflection, transmission, and adsorption. Here, shielding is defined by combining the reflection and the adsorption when a criterion is set within a system. With respect to the actual electromagnetic measurement, the signal that is generated at the antenna on the generation side is called  $P_T$ , and the signal received by the antenna on the receiving side is called  $P_R$ . Assuming that a signal on the receiving side, in which a shield is arranged between the generation and the receiving sides using a shielding material, is  $P'R$ , we can calculate the effectiveness of the EMI shield by using (4). Fig. 4 shows this arrangement [1].

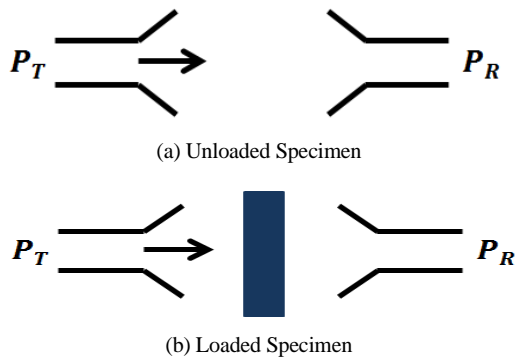
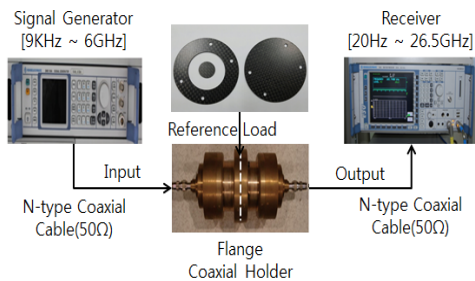


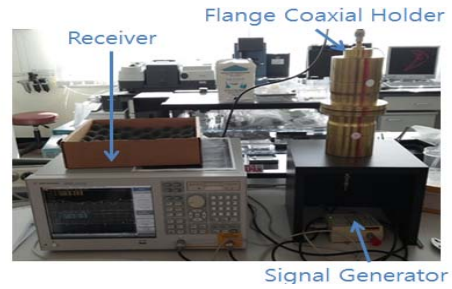
Fig. 4 Schematic view of the electromagnetic wave shielding measure

The frequency bandwidths applied in this experiment were ranged from 30MHz to 3GHz; however, the reliable phase was extracted as from the bandwidths of 500MHz to 1.5GHz, and the action range was estimated as about from 90 to 100dB[5].

When measuring the specimens according to the test method specified in the ASTM D4935-10 [6], the specimens were fabricated in a washer-type, and their coaxial lines, circum- and inner-centers were continuously connected like the system shown in Fig. 5 [7].



(a) The test procedure of ASTM D 4935-10



(b) Test Measurement look

Fig. 5 System configuration of ASTM D 4935-10

IV. RESULTS AND DISCUSSION

The tests were conducted with a total of 11 specimens and each specimen was laminated by type as presented in Table I.

TABLE I  
NUMBER OF LAYERS OF EACH SPECIMEN

Type	CFRP(Ply)	GFRP(Ply)	Wire Mesh(Ply)
1	1	0	0
2	2	0	0
3	2	0	1
4	3	0	0
5	3	0	1
6	4	0	0
7	4	0	1
8	5	0	0
9	0	3	0
10	0	3	1
11	0	3	2

In the first test result, as shown in Fig. 6, the specimen type 1 – 4 presented averages of 62.7, 81.1, 99.1 and 103 dB, respectively, and the specimen laminated with two sheets of carbon fiber 12k-prepregs presented an electromagnetic wave shielding effect of about 20db, which was higher than that of a sheet of carbon fiber 12k-prepreg. In addition, the specimens laminated with a sheet of the fiber and with a sheet of the wire mesh showed that the electromagnetic shielding rate improved by 18 and 22dB, respectively, than that of the 12k-prepreg; thus, it was verified that the wire mesh has a higher shielding effect with a shielding rate near to 120dB at around 1.1GHz.

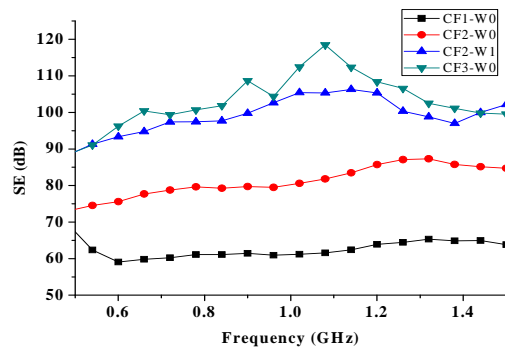


Fig. 6 Electromagnetic wave shielding rate with respect to the frequency of type1 ~ type4

In the second test result, which is shown in Fig. 7, the specimen type 5 presented 97.9dB and the type 91.9dB, respectively. Wherein, the specimen laminated with 3 sheets of carbon fiber 12k-prepregs and a sheet of wire mesh presented a higher shielding effect by 7dB than that of the specimen laminated with 4 sheets of 12k-prepregs; thus, it was verified that both specimens presented the highest electromagnetic shielding rates at around 1.5GHz.

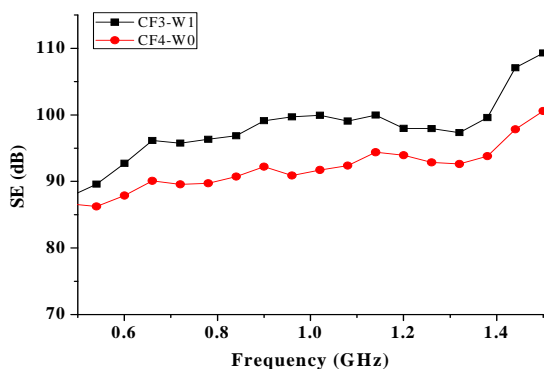


Fig. 7 Electromagnetic wave shielding rate with respect to the frequency of type5 and type6

In the third test, as shown in Fig. 8, the type 7 showed the shielding rate of 103.db and the type 8 95.8dB, respectively. In the test, the specimen laminated with 4 sheets of 12k-prepregs and a sheet of wire mesh presented a higher shielding rate by about 7dB than that of the specimen laminated with 5 sheets of 12k-prepregs; further, the specimen used with carbon fibers presented the lowest shielding rate at around 0.6-0.7GHz unlike the existing while the specimen laminated with the hybrid-type wire mesh showed the highest shielding rate. As such, through the aforementioned three tests, it was verified that the wire mesh has a corresponding to or higher electromagnetic shielding effect than that of the carbon fiber, which was generally considered excellent.

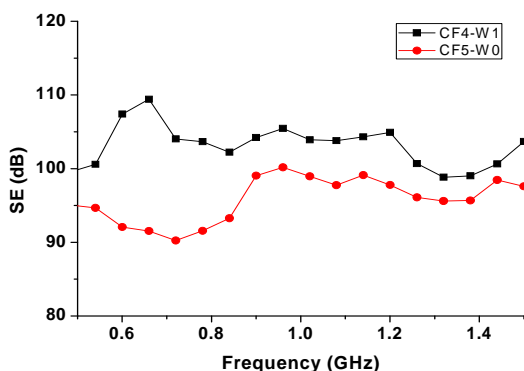


Fig. 8 Electromagnetic wave shielding rate with respect to the frequency of type7 and type8

In addition, the shielding rates appeared differently in each test presented depending on the frequencies; however, such is considered being affected by the thicknesses of the specimens.

Further, the specimens laminated more than 3 sheets of 12k-prepregs, 2 sheets of 12-k prepregs and a sheet of wire mesh, and a sheet of hybrid-type seem to have achieved a high shielding phase of more than 90dB.

In the fourth test, last test, as shown in Fig. 9, the specimens type 9-11 presented the shielding rate of 21.9, 67.6 and 81.7dB, respectively. The glass fiber 3-sheet-prepreg lamination presented a minor shielding rate; however, showed that the shielding rate increased by 45dB when a sheet of wire mesh was added and by about 60db when with two sheets of metal meshes. Further, similar values were obtained in the aforementioned tests with a sheet of carbon fiber 12k-prepreg and two sheets of prepregs; thus, the performance on the electromagnetic shielding effect was again verified.

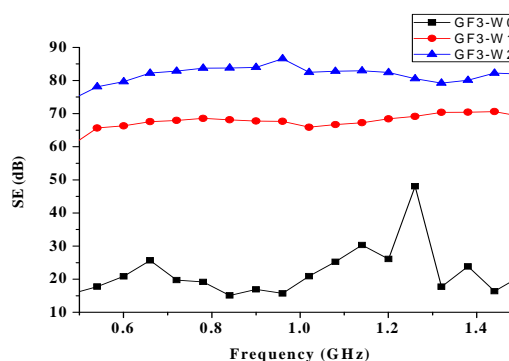


Fig. 9 Electromagnetic wave shielding rate with respect to the frequency of type9 ~ type11

## V. CONCLUSION

In this paper, the electromagnetic shielding effect of wire meshes and existing carbon fibers were compared to examine the applicability of wire meshes and to propose the hybrid-types with carbon fibers; thereby, the following results were deduced.

- (1) The carbon fiber 12k-fabric prepreg-laminated specimens and the wire mesh-laminated hybrid specimens presented higher shielding rates of more than 90dB although slightly different by each specimen; however, the hybrid-type specimens presented higher shielding rates by about 7dB in average than those of the specimens laminated with the carbon fiber 12k-fabric prepreg only; thus, it was verified that the wire mesh has an excellent electromagnetic shielding effect.
- (2) To reconfirm the aforementioned result, the hybrid specimens laminated with glass fiber prepregs, which have insignificant shielding effects, to verify the electromagnetic shielding effects of wire meshes, to graft with wire meshes, and to develop diverse electromagnetic shielding materials.
- (3) On the ground of the aforementioned results, the wire meshes that are relatively light-weighted and thinner than carbon fiber 12k-fabric prepregs are likely to be effectively used or applied in electromagnetic shielding fields in each industry, operating equipment, etc.

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