論文 97-8-3-04

Multimedia 機器에의 適用을 위한 CFRTP에 대한 電磁波 特性의 評價

The Evaluation of the Characteristics of Electromagnetic Waves on CFRTP for Multimedia Instrument Applications

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要約

通信 및 電子産業의 發達에 따라, 電磁波放射에 對한 炭素纖維強化樹脂(CFRTP)의 電磁波 遮蔽效果(SE)를 研究하는 것은 重要하다. 本研究에서는 炭素纖維(CF)의 遮蔽效果를 電波暗室內에서 實驗的으로 測定하였다. 使用한 樹脂는 PC, PP, PEI, PMMA 및 PA이다. 實驗은 分光分析器에 의해 銅遮蔽箱子와 모노폴안테나를 使用해 修行하였다. 實驗結果로부터 CF는 良好한 電磁波遮蔽材의 한 候補임을 알 수 있었다. SE는 CF의 積層數의 增加에 따라 增加하였다. 微小한 損傷의 增加는 CF의 平面密度, 透過두께 및 反射角의 增加로 인해 SE를 增加시켰다. SE에 미치는 다른 特性들은 母材樹脂, 안테나間의 距離 및 노이즈의 周波數에 따라 달랐다.

Abstract

As the communication and electronic industry develops, it is important to study the electromagnetic shielding effectiveness (SE) of carbon fiber(CF) reinforced thermal plastics (CFRTP) against the electromagnetic (EM) radiation. In this paper the shielding effectiveness of CFRTP was measured experimentally in an electromagnetic shielding room. The resin materials used were PC, PP, PEI, PMMA and PA. Experiments were carried out by using a copper box and a monopole antenna with a spectrum analyzer. From the experimental results it was found that CF was a good candidate as an electromagnetic shielding material. The sheilding effectiveness was found to be increased in the composite as the number of laminated layers of CF was increased. As the minor damage increased, the SE increased due to increasing of the plane density, transmitting thickness and reflected angle of the CF.

Other characteristics of the SE depended on the material used for the resin matrix, distance of the antennas and the noise frequency band.

Key words : CFRTP, Carbon fiber, Lamination, Composite material, Damage of CFRTP, Hybrid CFRTP, Electromagnetic wave, Shielding effectiveness of electromagnetic wave.

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· 論文番號 : 961213-065

· 修正完了日字 : 1997年 6月 24日

Ⅰ. Introduction

The demand for plastic composite materials is expected to increase along with the advance of the information society and the growth of multimedia and communications. Recently, electronic devices such as robots, personal computers and cellular phones have been in great demand increasing the need for plastic composites.

On the other hand, the electromagnetic environment with the increase in the use of multimedia instruments is being increasingly saturated with electromagnetic radiation making a threat to human health and causing interference to electromagnetic equipment.

For the well-being of people and the protection of instruments from interference caused by electomagnetic waves, it is necessary to develop a material for the shielding of electromagnetic energy. CFRTP is one material being investigated for this purpose. It has favourable attributes such as single-pass forming, is easily formed into casings for multimedia instruments and has also good recycling capabilities. In this paper we invetigate the shielding effectiveness of CFRTP and its electromagnetic ability with using a variety of resin matrixs and lamination layers and the effect of the shielding after compressive damage[1].

Ⅱ. Shielding and absorption of electromagnetic waves

For the protection of sensitive equipment, electromagnetic shielding material has the necessary for the shielding of noise frequencies caused by other electronic equipment.

CF satisfies the high strength and shielding effectiveness requirement for the protection of miniaturized and light goods.

The shielding of electromagnetic waves protects the internal equipment from external noise, and also effectively prevents the leakage of internally generated electromagnetic noise. Shielding materials have a large reflection coefficient causing incident electromagnetic waves on the material surface to be reflected away. The factors of the shielding effectiveness depend on i) shielding material, ii) thickness, iii) electromagnetic noise frequency, iv) distance from the electromagnetic noise source and v) capacity and shape of the shielding discontinuity[2].

Fig. 1 shows the damping (attenuation) mechanism of the electromagnetic waves by shielding materials.

$$I = R + D + C + T \tag{1}$$

Equation(1) shows the energy description of an incident wave I, from a transmitting antenna, on a typical shielding material. R is the sum of the reflected energies of R_1 and R_2. R_1 is energy of the reflection wave from the discontinuous face of the air/material interface, R_2 is the reflection from the discontinuous material/air interface, D is the damping loss within the material, C is a correction factor for the multi-reflected losses and T is the transmitted waves out of the shielding material. Thus the shielding effectiveness, SE, can be described as the following equation (2);

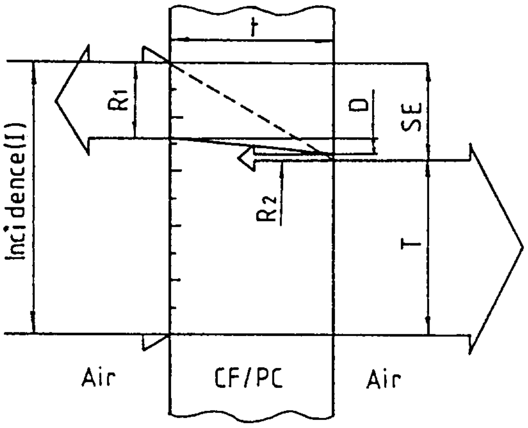


Fig. 1. Energy description mechanism of electromagnetic waves in CFRTP.

$$SE = I - T = R + D + C$$
$$= V_0 - V \text{ [dB]} \qquad (2)$$

where V_0 is the noise level without any specimen and V is the noise level with a shielding specimen at the receiving antenna.

For the absorption of electromagnetic waves in shielding materials, the electromagnetic energy should be converted to heat energy. There are 3 types of absorbing materials used. They are conductive absorbers, dielectric absorbers and magnetic absorbers. Additional classification of the absorbers is given by the frequency range over which the material can absorb the electromagnetic waves. These frequency bands are called narrow band, wide band or super wide band absorbers[3].

Ⅲ. Materials and experimental procedure

The materials used were a combination of carbon fiber and glass fiber reinforced thermal plastics, containing a fiber volume fraction of about 20 and 50 %. A textile fabric of continuous carbon fiber having a diameter of 7 micrometers, with 3,000 fibers in a thread were used in a matrix of either polycarbonate (PC), polypropylene (PP), polyetherimide (PEI), polymethylmethacrylate (PMMA) or polyamide (PA) plastics consisting of 50 micrometer films. The CFRTP were made into sheets about 0.4 mm in thickness with the fiber textile layer placed between two layers of the resin film.

The CFRTP sheets were then pressed for 15 minutes in a hot press at 523 K. Table 1 shows the material configurations used for the experiments.

The experiments were carried out by using a copper and specimen shielding box of a regular cube design with all sides 300 mm length with a 250 mm length monopole antenna as seen in Fig. 2.

The electromagnetic wave receiver was an ADVANTEST spectrum analyzer, Model R3361A, and all experiments were conducted within a electromagnetic shielded room (The Radio-frequency Semi-Anechoic Chamber in the Tokushima Provincial Industrial Technology Center). The measuring setup is described in Fig. 3.

Measurements were conducted over a frequency range of 1 MHz ~ 1 GHz with a frequency step of 500 Hz.

Ⅳ. Experimental results and disscussion

4-1 Effect of reinforcing fibers

The reinforcing fiber that were used was cross-textiles of a carbon fiber (CF), glass

Table 1. Sample construction used for experiments

No	Reinforcing Fiber	Layers	Matrix	Thick. (mm)	Remark
1	CF	1	PC	0.20	High modulus CF
2	CF	1	PC	0.43	Polycarbonate
3	CF	2	PC	0.85	"
4	GF	1	PC	0.40	"
5	GF	2	PC	0.75	"
6	CF	1	PP	0.42	Polypropylene
7	GF	1	PP	0.37	"
8	CF	1	PEI	0.41	Polyetherimide
9	GF	1	PEI	0.37	"
10	GF	2	PEI	0.75	"
11	CF	1	PMMA	0.34	Polym.methacrylate
12	CF	2	PMMA	1.06	" (Sandwich type)
13	CF	2	PA	1.00	Polyamide
14	GF	2	PA	0.79	"
15	CF	5	PC	2.76	Polycarbonate
16	C/G/C/G/C	5	PC	1.96	" (Hybrid type)
17	G/C/G/C/G	5	PC	1.97	"
18	G/G/C/G/G	5	PC	2.11	"
19	GF	5	PC	1.82	"
20	CF	5	PP	2.19	Polypropylene
21	C/G/C/G/C	5	PP	1.93	" (Hybrid type)
22	G/C/G/C/G	5	PP	2.05	"
23	G/G/C/G/G	5	PP	1.94	"
24	GF	5	PP	1.73	"
25	TISMO-N	1	PP	0.25	$K_2O \cdot 6TiO_2$, 30wt% Whisker mixture
26	Cu-1	1	-	0.04	Solid blank
27	Cu-2	1	-	0.05	Solid blank
28	Al-1	1	-	0.05	Solid blank
29	Al-2	1	-	0.28	Solid blank

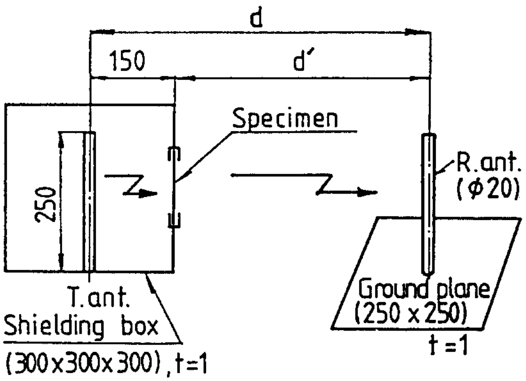


Fig. 2. Stationing of transmitting and receiving monopole antennas.

fiber (GF) or TISMO-N fibers ($K_2O \cdot 6TiO_2$, 30 wt%) in a resin matrix.

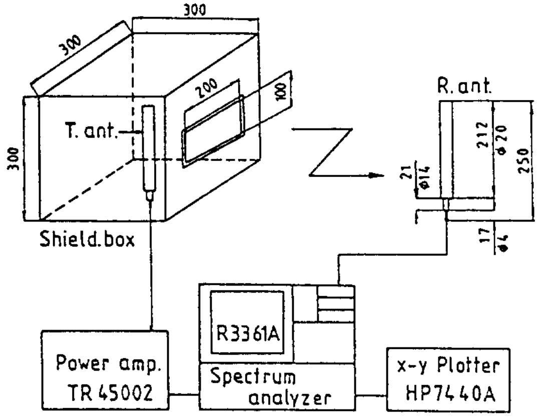


Fig. 3. Measuring system of electromagnetic noise for CFRTP.

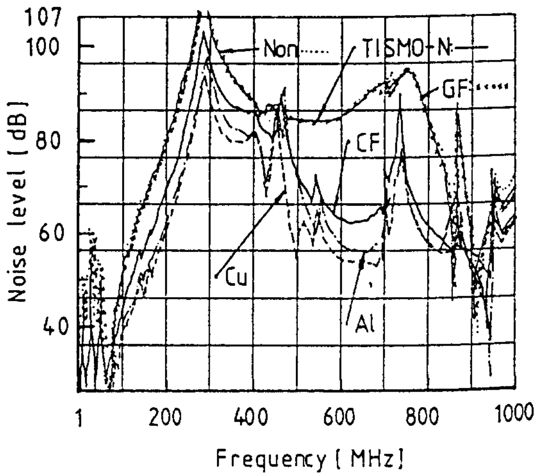


Fig. 4. Signal level of the shielding materials at an antenna distance of 500 mm.

Fig. 4 shows the received signal of the reinforced materials. GF and TISMO-N were found not to be effective shielding effectiveness, but CF is lower than copper and aluminum sheets.

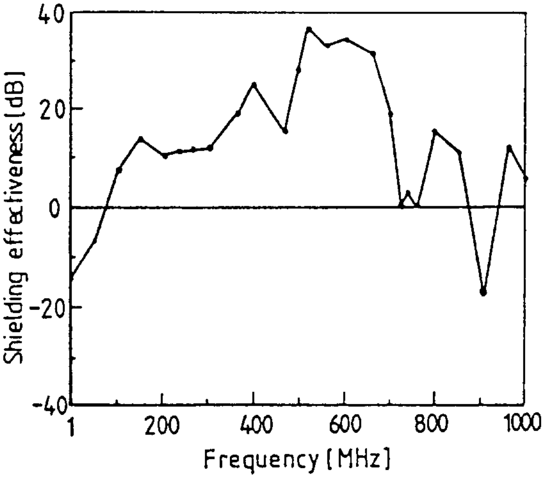


Fig. 5. Graph of shielding effectiveness of CF / PC (d=1,000 mm).

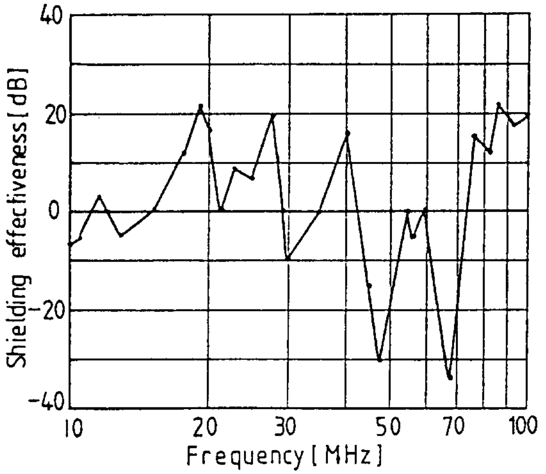
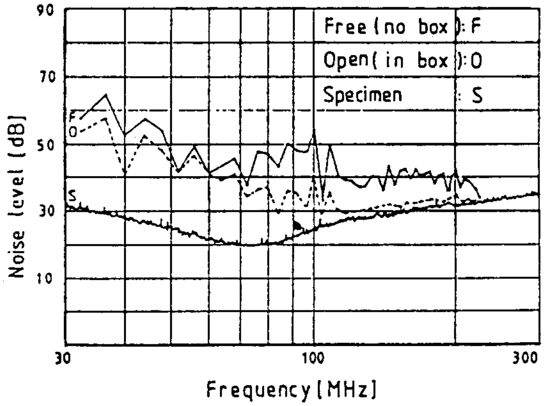


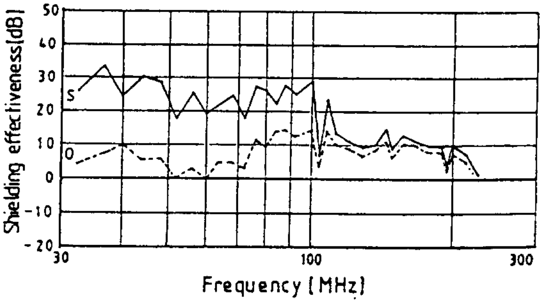
Fig. 6. Graph of shielding effectiveness of 5 layers of CF / PP (d=1,000 mm).

On the other hand, Fig. 5 and Fig. 6 show a negative shielding effectiveness of CF at certain frequency band width within the near field.

Also, the shielding effectiveness changed referred to the frequency band and the electromagnetic energy strength. Fig. 7 shows an absolute shielding effect of the shielding box and specimen under actual conditions using a crystal oscillator of 4 MHz with a lower power output(~1mW). CFRTP shielded almost all the electromagnetic noise of low energy, but showed negative shielding effectiveness with any frequency band.



(A) Measured noise



(B) Shielding effectiveness

Fig. 7. Effect of the shielding box on noise for mono layer of CF / PC 1L (d=300 mm).

4-2 Effect of resin matrixs

Matrix materials used were PC, PP, PEI, PMMA and PA. Fig. 8 shows the noise attenuation characteristics of monolayer of ma-

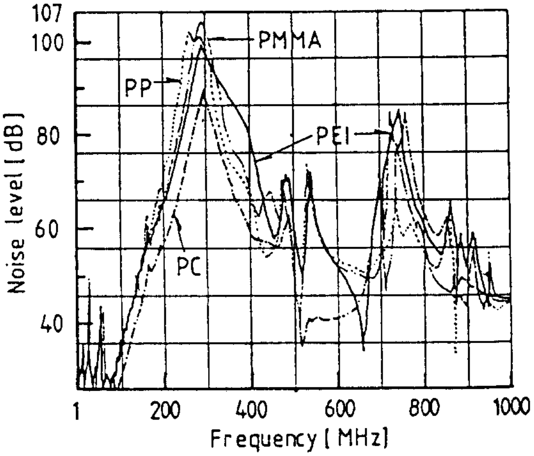


Fig. 8. Effect of resin of the shielding ability of CFRTP (Mono layer, d=1,000 mm).

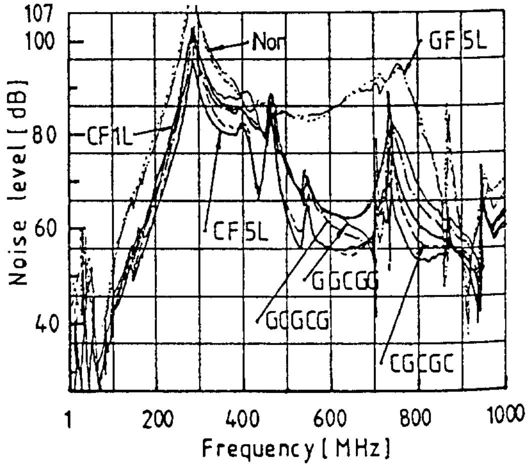


Fig. 9. Effect of the order of laminated layers between CF and GF on the noise for a 5 layer specimen (d=500 mm).

trixes at the distances of 1,000 mm between the transmitting and receiving antennas. The effect of the matrix varies according to the noise frequency, but makes little difference to the overall shielding ability of the CFRTP.

4-3 Effect of composite laminated layers

Regardless of the number of composite laminated layers, GF has no shielding of composite laminated layers of CF and GF in a PC matrix. In the case of CF, shielding effectiveness increased as the composite was laminated to 5 layers, which shows not to a large difference.

Table 2 Volume resistance of specimens.

No	Layers	Matrix	R_v(× 10^{-1} Ω)		
			273K	77.4K	20K
2	CF 1L	PC	6.385	0.652	7.211
3	CF 2L	PC	2.579	0.289	2.945
6	CF 1L	PP	4.29	0.485	68.391
15	CF 5L	PC	1.206	0.137	70.632
16	CGCGC	PP	4.951	0.762	6.688

CF is best located on the surface rather than the center of the composite laminated material for the reflection of electromagnetic waves. This is because CF has little or no electromagnetic wave absorption ability as CFRTP has a low volume resistance as can be seen in Table 2.

4-4 Effect of antenna distance

The transmitting antenna was set up at the center of the copper shielding box. Distances between the transmitting and recieving antennas for the measuring of noise frequencies were 300, 500, 600, 700, 900, 1,000, 1, 200 and 1,500 mm. Fig. 10 shows the noise diagram according to the distance between the transmitting and recieving antennas with a

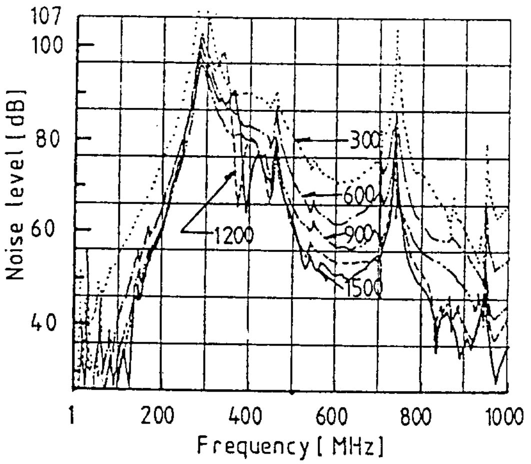


Fig. 10. Effect of antenna distance on a monolayer of CF/PP.

monolayer of CF/PP. The received electromagnetic energy and damping effects were decreased when the measuring distance between the antennas was increased, but the shielding effectiveness increased.

4-5 Compression damage effects

Damage effects are very important factor of consideration in many multimedia instruments as tensile strain often causes cracks. A crack in a casing brings about a marked lowering of the material strength and leakage of electromagnetic noise. Experiments were carried out by compressing a 50 and 100 mm diameter steel ball on the CFRTP to simulate impact damage. A universal testing machine was used with compressive weights of 500 kg to 5,000 kg with a 50 mm thick rectangular block of wood put as support for the specimen.

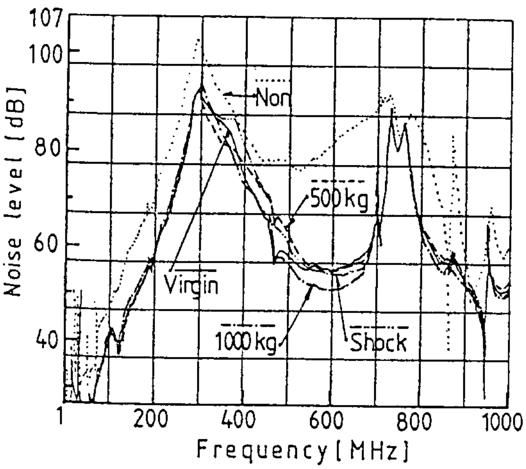


Fig. 11. Noise diagram of noise level vs frequency with various compressive loads using a 50 mm steel ball on CF/PC monolayer (d=600 mm).

Fig. 11 shows the noise diagram according to the compressive load for the investigation of the effect of tensile strain.

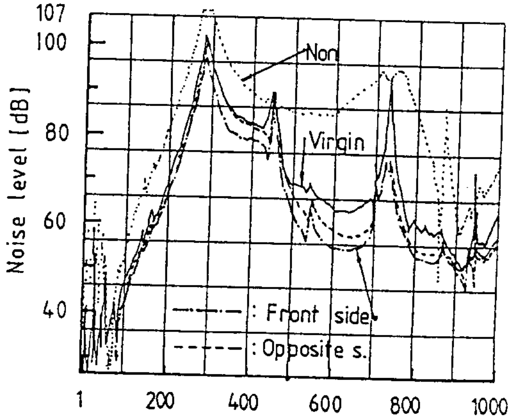


Fig. 12. Noise diagram of damaged specimens caused by a compressive load of 3,000 kgs using a 100 mm steel ball on a CF/PC mono layer (d=500 mm).

Fig. 12 shows the noise diagram of a CF/PC sample with a single 50 mm diameter concave spherical damage area caused by a 3,000 kg load with 100 mm diameter steel ball.

Fig. 13 shows the noise diagram of a hybrid sample GGCGG/PC 5 layer plate with damage by a 1,500 kg load with 50 mm diameter steel ball. The damaged specimen has a lower value of noise transmission rather than the undamaged specimen but there was some difference in the frequency band. This is because the increase of the plane density, transmitting thickness and reflection angle are larger than the increase of the tensile strain resulting in a greater shielding effect.

On the other hand, the measured noise value of the front side and the opposite side of the same damaged specimen was different. The value of front side was about 5 dB lower than the opposite side. But there is a large difference between the concave face and convex face of the hybrid samples as compared with the monolayer sheet against the shielding of EM waves. This was because the reflection coefficiency of the convex face and the concave face differs. This is not an issue since damage occurs on the outside of the casing.

Fig. 14 shows the noise diagram for research on the effect of the clearance limit between the carbon fiber threads in the textile needed for effective shielding.

The shielding effect of $c=0.5$ mm textile CF (HM) is the same as that of $c=0$ mm textile CF. The effect of $c=2$ mm textile CF is little larger, and $c>2$ mm is more larger than that. Therefore, it is considered that to make a satisfactory electromagnetic shielding material, a CF thread clearance of $c<2$ mm is needed.

V. Conclusions

In this paper, the shielding effectiveness of electromagnetic waves on CFRTP was investigated experimentally in an electromagnetic

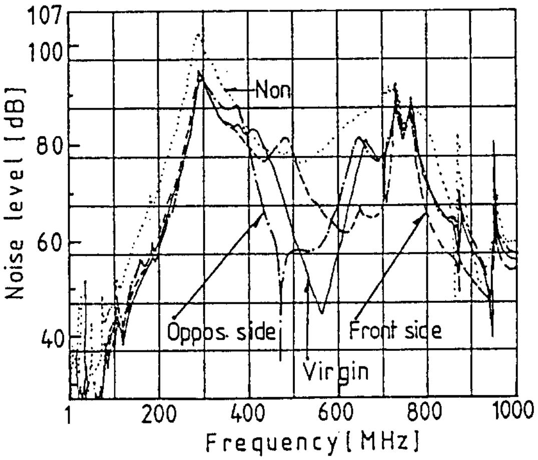


Fig. 13. Noise diagram of a damaged hybrid sample GGCGG/PC plate by a compression load of 1,500 kgs using a 50 mm steel ball ($d=600$ mm).

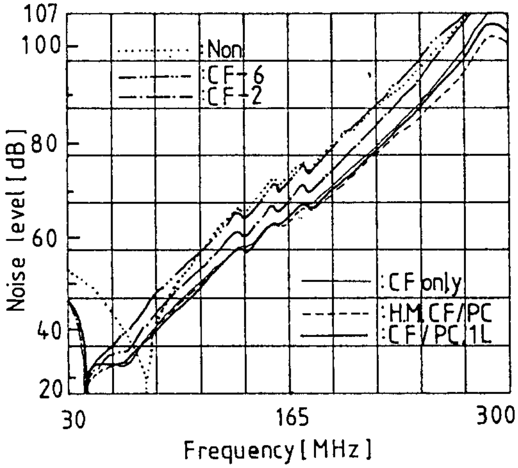


Fig. 14. Noise diagram of noise level vs frequency using CF textiles with various CF thread clearance distance($d=600$ mm).

shielding room. The results obtained are summarized as follows;

(1) The shielding effectiveness of electromagnetic waves differs from the frequency.

(2) GF and TISMO-N had almost no shielding effectiveness.

(3) CF has very good shielding effectiveness but at certain frequencies, has negative shielding properties.

(4) Shielding effectiveness of CF increased as the number of composite laminated layers increased but it does not show much variation.

(5) It is best to locate CF on or near the surface of the material because it has almost no absorption properties and it is more effective for reflecting EM waves.

(6) Minor compressive damage increased the shielding effectiveness due to the increase of the reflection coefficient.

Acknowledgement

We are very grateful to The Korea Research Foundation, Sumitomo Heavy Industrials, Otsuka Chemicals and Tokushima Industrial Technology Center for supporting this study.

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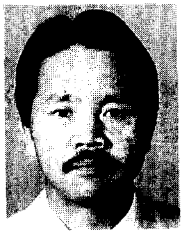

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