



## ELECTROMAGNETIC SHIELDING OF CEMENT-GRAPHITE POWDER BETWEEN 100 TO 2000 MHz

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### ABSTRACT

Electromagnetic interference (EMI) issue is of concern as it may cause the malfunction of other electrical or electronic devices. Extra protection can be provided not only to the equipment but also to the human inside a building if the shielding capability can be embedded directly into the building material. The inherent shielding of the cement powder is not adequate to eliminate the incoming electromagnetic (EM) field efficiently (less than 2dB from the result of this work). Hence this work is carried out to improve the shielding effectiveness (SE) of cement powder by mixing graphite fine powder as a conductive filler into the cement powder. The increment in the loss factor reflected that the addition of the conductive filler has increased the conductivity of the mixture. The addition of 30 percent of graphite into the cement powder is able to produce 110dB of shielding at 900MHz at 10cm.

**Keywords:** shielding effectiveness, reflection loss, absorption loss, dielectric constant, loss factor, graphite fine powder, cement powder.

### INTRODUCTION

The proliferation of various type of electrical devices ranging from the generation and transmission of electricity, domestic appliances and industrial equipment, to telecommunications and broadcasting has lead the society to live in an electromagnetic environment. This has created a new form of pollution known as electromagnetic pollution or electromagnetic interference (EMI) (Montrose, 1996). EMI consists of many unwanted radiated signals which can cause unacceptable degradation of system or equipment performance. Therefore it is important to provide shielding protection to the electrical and electronic devices.

The conventional shielding technique is by building a shielding room or Faraday cage which is made of metallic material. However it is bulky, expensive, prone to oxidation and only provides protection for certain area inside a building. The current researches start to focus on improving the shielding capability of the building itself since it can provide protection not only to electrical and electronic devices but also human inside the building (Paul, 2006).

A lot of researches related to the shielding effectiveness (SE) of building material had been carried out (Cao & Chung, 2003, 2004; Sandrolini & et al., 2007; Wen & Chung, 2004). The inherent shielding provided by building material is very limited. It is reported that a concrete wall with thickness 300 mm and 5.5 percent of moisture content is able to provide 3-10 dB of shielding in between 0.03 GHz to 1 GHz (Sandrolini *et al.*, 2007). Hence different kinds of shielding and absorbing material in the form powder, fibre, filament and so on are added to the building material to further enhance its SE (Guan, Liu, Duan, & Cheng, 2006).

In this work, the focus of investigation is on the cement powder. Cement powder is a basic ingredient in building constructions. Different percentages of graphite fine powder are added into the cement powder to enhance its SE. Their dielectric properties will be identified based

on the transmission/reflection dielectric measurement techniques by using APC-7 connectors. Its SE is calculated analytically.

### Concept of shielding

Shielding effectiveness (SE) is a measure which shows the capability of a barrier in attenuating the incoming EM field. A barrier can attenuate the EM field because it introduces three kinds of losses on the incoming EM field, which is reflection loss, RdB, multiple reflection loss, MdB and absorption loss, AdB, as shown in equation (1) (Paul, 2006).

$$SE_{dB} = R_{dB} + M_{dB} + A_{dB} \quad (1)$$

where

$$R_{dB} = \frac{(\eta_o + \eta)^2}{4\eta_o\eta}$$

$$M_{dB} = 1 - \left( \frac{\eta_o - \eta}{\eta_o + \eta} \right)^2 e^{-\gamma d}$$

$$A_{dB} = e^{-\gamma d}$$

$\eta_o = \sqrt{\epsilon_o \mu_o}$  and  $\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\epsilon}}$  are the intrinsic

impedance of free space and material respectively.  $\mu$  and  $\epsilon$  is the permeability and permittivity of the material,  $\sigma = \epsilon'' \epsilon_o \omega$  is the conductivity of the material,  $\omega$  is the angular frequency,  $\gamma = \sqrt{j\omega\mu(\sigma + j\omega\epsilon)}$  is the propagation constant and  $d$  is the thickness of the material. Permittivity is a quantity used to describe the reflection of EM wave at the interfaces and the attenuation of wave energy within materials. It is always expressed as a complex parameter as shown in equation (2) (Begley, 2010). Based on equation (1), it shows that the SE of a material correlates closely to the permeability and permittivity of the material. These parameters can be retrieved from the dielectric measurement.



Permittivity is a quantity used to describe dielectric properties that influence reflection of EM wave at the interfaces and the attenuation of wave energy within materials. The complex relative permittivity,  $\epsilon^*$  of a material to that of free space can be expressed as equation (7). The real part of the complex permittivity,  $\epsilon'$  is the dielectric constant which represents the energy that is able to be stored by the material when it is exposed to electric fields, where the imaginary part,  $\epsilon''$  represents the loss factor. It describes the energy absorption and attenuation within the material (Begley, 2010).

$$\epsilon^* = \epsilon' - j\epsilon'' \quad (2)$$

## EXPERIMENTS

### Cement-graphite powder preparation

Cement powder is neither a magnetic nor conductive material and hence it does not provide significant shielding (Sandrolini *et al.*, 2007). Graphite fine powder is frequently used especially for an improvement of electrical conductivity, antistatic properties as well as thermal conductivity of the filled material (Krupa, Novák, & Chodák, 2004).

In this work, the HmBG graphite fine powder is added to the cement powder as electrical conductive filler to enhance the SE of cement matrix. The cement powder used in this work is Holcim Top Standard Cement.

The weight of the cement powder and graphite fine powder in each of the samples are shown in Table-1.

Both of the materials are blended together evenly before they are undergoing the dielectric measurement. The illustrations of the graphite fine powder, cement powder and graphite-cement mixture are shown in Figure-1.



**Figure-1.** The graphite fine powder (a), cement powder (b) and graphite-cement mixture (c).

**Table-1.** Samples of cement powder with graphite fine powder are prepared according to the composition.

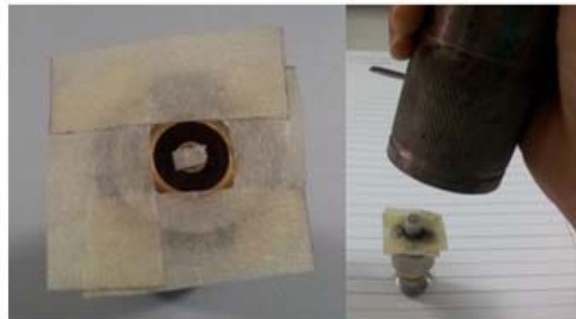
Samples	Amount of graphite fine powder (g)	Amount of cement powder (g)
1	0	10
2	0.7	9.3
3	1.1	8.9
4	1.5	8.5
5	1.9	8.1
6	2.3	7.7
7	3	7

### Dielectric measurement

A pair of APC-7 connectors as shown in Figure-2 is used for dielectric measurement. The samples in the form of powder are placed into the slot as shown in Figure-3 and compressed by using a 6 kg steel block to ensure the air is eliminated, as shown in Figure-3. After that, both APC-7 connector are combined and connected to the network analyzer (NA) as shown in Fig. 4 to obtain its S-parameters. The Nicolson-Ross-Weir (NRW) conversion formulation with specific calibration (Yee, Sayegh, Kazemipour, & Jenu) is used to convert the S-parameters to the dielectric properties (complex relative permittivity) of the composites.



**Figure-2.** A pair of APC7 connectors is used for dielectric measurement.



**Figure-3.** The powder is placed into the connector and compressed with a 6kg of steel block.



**Figure-4.** Dielectric measurement setup.



## RESULTS AND DISCUSSIONS

### Dielectric constant and loss factor

The dielectric properties of the samples are illustrated in Figure-5 to Figure-7. It is found that the dielectric constant increase gradually as the percentage of the graphite increases. When the graphite is added in small amount, the increment of the dielectric constant is linear throughout the whole frequency range. However as the percentage of the graphite exceed 19 percent (sample 5 onward), the dielectric constant start to behave exponentially.

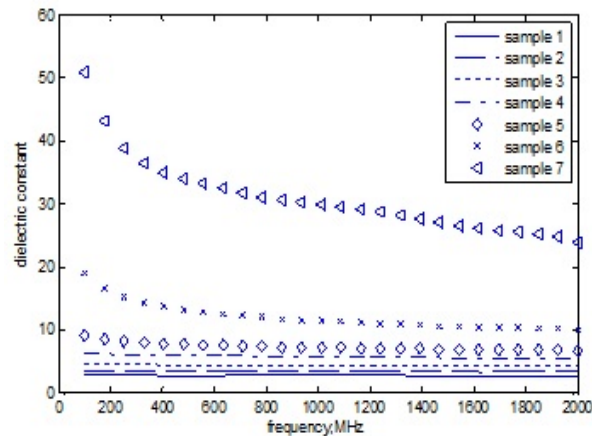


Figure-5. The dielectric constant of all the samples.

On the other hand, the loss factor does not experience significant changes when the percentage of graphite is below 15 percent (sample 1 to sample 4). However, when more graphite is added, the increment on the loss factor become more significant, especially when the percentage of the graphite reaches 30 percent. The increment in the loss factor indicates the increment in the conductivity of the mixture as the conductivity is linearly dependent on the loss factor.

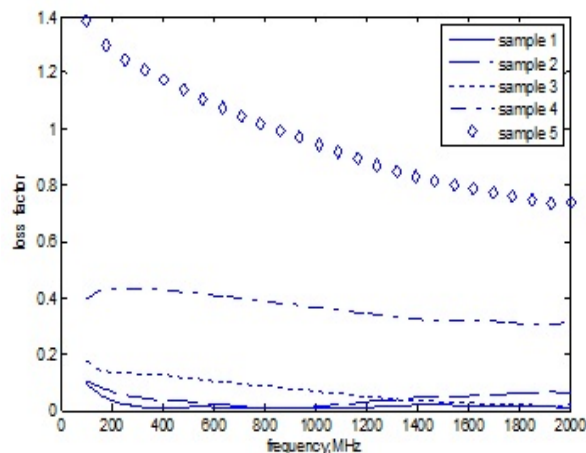


Figure-6. The loss factor of sample 1 – sample 5.

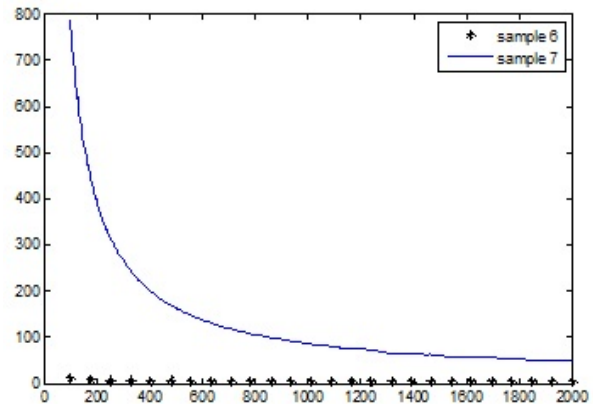


Figure-7. The loss factor of sample 6 and sample 7.

### Analytical calculation of SE

The relative permeability of all the samples is unity since the graphite-cement mixture is non-magnetic material. Based on the measured dielectric properties in the previous section, the SE of all the samples with thicknesses of 10 cm is calculated based on equation (1). The results are shown in Figure-8 and Figure-9.

The inherent shielding provided by the cement powder is limited and below 2 dB. In other word, it allows around 79 percent of the incoming EM field to penetrate it. However, the SE of the cement powder slowly increases with the addition of graphite. The fluctuation of the SE at a lower amount of graphite is due to the multiple reflection loss. The fluctuation in the SE disappears as more graphite is added into the cement. This is because the multiple reflection effect is inferior compared to the reflection loss and absorption loss. As the percentage of the graphite increases up to 30 percent, more than 40 dB of SE can be achieved. It is found that, the reflection loss and absorption loss are the main contributors to the SE of the graphite-cement mixture. The reflection loss contributes more at lower frequencies, whereas the absorption loss contributes more at higher frequencies.

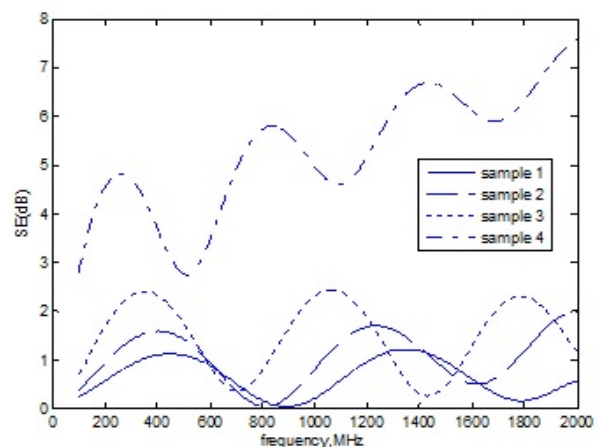
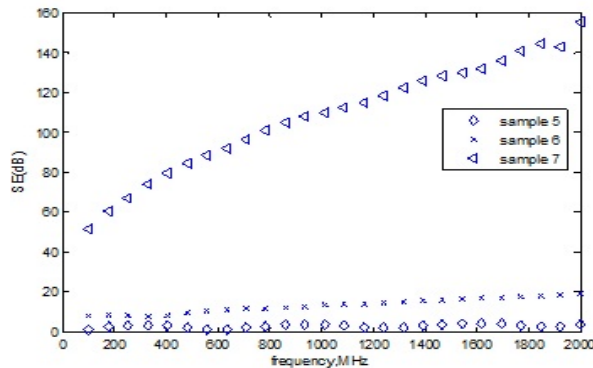


Figure-8. The SE of sample 1 to sample 4.



**Figure-9.** The SE of sample 5 to sample 7.

It is found that the dielectric constant determine the trend of the reflection loss because it determined the characteristic impedance of a material (Khee Yee, 2013). The reflection loss depends on the impedance matching between the material and the medium before the material. For instance, if the EM wave propagates from air to the material, the reflection loss depends on the characteristic impedance of the air ( $377\Omega$ ) and the material itself. If both of the characteristic impedances are comparable, it results in lower reflection loss and vice-verse. When an EM wave is impinging on a metal material from air, it experiences great changes of characteristic impedance (from  $377\Omega$  to nearly  $0\Omega$ , for perfect conductor) the mismatching results in higher reflection loss.

Absorption loss is a function which greatly relies on the loss factor, permeability and thickness of the material. For a non-magnetic material as in the subject of this research, the absorption loss depends strongly on the loss factor of the material.

## CONCLUSIONS

The addition of the graphite fine powder has successfully increased the shielding effectiveness of the cement powder. The dielectric measurement indicates the dielectric constant of the samples increase steadily as the percentage of graphite increases and the effect of the graphite on the loss factor is inferior when its percentage is lower than 11 percent. It experience significant raise when 19 percent of graphite is added into the cement powder. This results in a significant increment in the absorption loss. The effect of the multiple reflection loss become inferior as the absorption and reflection dominate. Hence the fluctuation due to the multiple reflection loss cannot be reflected in the resultant SE of graphite-cement mixture when the percentage of the graphite is above 19 percent.

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