Shielding Effectiveness of Concrete with Graphite Fine Powder in Between 50MHz to 400MHz

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***Abstract*— The shielding effectiveness (SE) of building materials is of concern due to the possibility of electromagnetic interference on sensitive equipment located inside the building. The SE of building material could be obtained directly using measurement but it requires expensive and elaborate setup. Alternatively, analytical method is preferable to predict the SE of building material for various conditions regarding the parameters to be evaluated such as thickness, moisture content, percentage of conducting materials added and so forth. Since most of the building materials are non-magnetic, its relative permittivity will be an important parameter for SE calculation. The effective permittivities of the concrete samples between 50 MHz to 400 MHz are measured using a TEM parallel plate. In this work, the SE of concrete samples are compared for various concentrations of graphite fine powder. It is found that a concrete of thickness 20 cm with 12wt% of graphite fine powder is able to provide a maximum of 2.4 dB additional shielding at 360 MHz. It is also observed that reflection loss is the dominant mechanism that contributes on the SE of a concrete with graphite fine powder.**

***Keywords*— Shielding effectiveness, graphite fine powder, concrete, TEM parallel plate, dielectric measurement.**

I. Introduction

Conceptually, a shield is a barrier to the transmission of electromagnetic (EM) fields and shielding effectiveness (SE) is the ratio of the EM fields incident on the barrier to the EM fields transmitted through the barrier [1]. In other words, SE defines the capability of a barrier or material in attenuating the incoming EM field. The higher the value of the SE, the better the barrier is in reducing the incoming EM field.

A lot of researches had been carried out investigating the SE of building materials for example plasterboard, bricks, and concrete [2-7] due to the awareness on Electromagnetic Interference (EMI). EMI is a conducted and/or radiated electromagnetic signal from any electrical or electronic devices. This EMI interact with any other electronic devices to degrade the performance of other equipment and system.

Consequently, the demand on shielding to protect sensitive electrical and electronic devices is highly needed. The common shielding technique is an enclosed conductive room based on Faraday's cage [1]. However, the conductive structure is costly and impractical for normal building. It is desirable if the shielding mechanism is implemented in the walls of the building by introducing selected material in the concrete.

The usual method to determine the SE of building material like concrete is by experimental measurements. There are well-established standards used for SE measurement such as EN 50147-1:1997 [8], IEEE 299-2006 [9], ASTM 4935 [10]. Measurements by [8] and [9] are based on twin-antenna method where the antennas are facing one another according to the setup stated in the standard. This standard is prepared for enclosure structure where the equipment under test (EUT) is a large, building-type structure so that the biconical or log-periodic antenna can be placed inside the enclosure for measurement. However it is costly and impractical to apply these standards for concrete material if one intends to look at the effect of certain parameter to the SE because a new and large structure needs to be constructed for every changes of the parameters of the concrete. More over further study on the effects of building door which is made of concrete needed to be undertaken. It may be difficult to build or even impossible to build a door by using concrete. While in [10], it requires the users to prepare the specimen in thin-sheet so that it can be place in between two coaxial line. It is difficult for porous material like concrete and not possible for reinforced concrete.

Besides the techniques mentioned above, nested reverberation chamber is also used for SE measurement. The method enables the EUT to be exposed to a more complex but realistic environment where fields are incident on the material with various polarizations and angles of incidence. However the measurement process has grown increasingly complex, mistakes can be made and accuracy may decrease [11-14].

Due to the restrictions mention above and simplicity sake, only analytical calculation of SE is considered in this work. The operating frequency is in between 50 MHz to 400 MHz due to the limitation of TEM parallel plate. Section II presents a brief description of concrete as a building material. The focus of the research is on the SE of concrete for various concentrations of graphite fine powder. The concrete with graphite fine powder are prepared with various concentrations. In section III, the analytical formulation which is used for SE calculation is presented. The relative permittivity of concretes with various concentrations of graphite fine powder is measured using a TEM parallel plate [18] and will be shown in section IV. Finally the result and discussion are given in section V.

II. BUILDING MATERIAL

Concrete is a well-known building material consisting of cement, water, sand and aggregates. All of those are mixed together uniformly and through a chemical reaction called hydration, the mixture hardens and gains strength to form the rock-like mass known as concrete.

The attenuation offered by a concrete is contributed by its inherent shielding behaviour which relies on its composition and moisture content. It was found that the SE of a concrete is greatly influenced by its moisture content [7].

Reinforcement bars which are frequently added to the concrete not only provide additional strength to the concrete but increase its SE as well, at particular frequency range depending on the reinforced grid size and the diameter of the bar [15]. Besides the reinforcement bars, additional components like metal fibres, carbon fibres, and so on can also be added to the concrete to increase the SE. These conductive-based additives contribute mainly to the reflective loss [16].

In this work, instead of investigating the SE of a normal concrete, the SE of concrete with graphite fine powder will be discussed in the following sections. The effects of the windows, ventilation holes, doors will not be considered.

III. SHIELDING EFFECTIVENESS OF CONCRETE

The propagation of EM waves through a material can be described by Maxwell's equations with corresponding boundary conditions. Dielectric properties of lossless and lossy materials influence EM field distribution. It is necessary to know the dielectric property (relative permittivity, ε and relative permeability, μ) of the material to understand the physical processes of the propagation.

The complex relative permittivity, ε^* of a material can be expressed as (1). The real part of the complex permittivity, ε' is the dielectric constant which represents the energy stored by the material when it is exposed to electric fields, where the imaginary part, ε'' represents the dielectric loss factor. It describes the energy absorption and attenuation within the material [17].

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (1)$$

The SE of a material is the contribution from the contribution of reflection, absorption and multiple re-reflection loss [1].

$$SE_{dB} = A_{dB} + R_{dB} + M_{dB} \quad (2)$$

By definition, the reflection loss, R_{dB} is

$$R_{dB} = 20\log_{10}\left(\left|\frac{(\eta_o + \eta)^2}{4\eta_o \eta}\right|\right) \quad (3)$$

where $\eta_o = \sqrt{\varepsilon_o \mu_o}$ and $\eta = \sqrt{\dfrac{j\omega\mu}{\sigma + j\omega\varepsilon}}$ are the intrinsic impedance of free space and material respectively. μ and ε is the permeability and permittivity of the of the material, $\sigma = \varepsilon''\varepsilon_o\omega$ is the conductivity of the material, and ω is the angular frequency.

The absorption loss A_{dB} is

$$A_{dB} = 20\log_{10}\left(\left|e^{\gamma d}\right|\right) \quad (4)$$

where $\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}$ is the propagation constant and d is the thickness of the material.

The multiple re-reflection, M_{dB} is represented by:

$$M_{dB} = 20\log_{10}\left(\left|1 - \left(\frac{\eta_o - \eta}{\eta_o + \eta}\right)^2 e^{-\gamma d}\right|\right) \quad (5)$$

Based on (3)-(5), it is found that permittivity and permeability of the material are important parameters in order to determine the SE of the material. Since concrete is a non-magnetic material, its permeability is always equal to unity.

IV. DIELECTRIC CHARACTERISTIC OF CONCRETE

There are a wide variety of techniques which can be used to determine the permittivity of the material. The suitable technique chosen for measurement depend on several factors like the frequency of interest, format of the material (liquid, solid, sheet, and powder), sample size restriction, destructive or non-destructive and so on [17].

In this work, the SE of two types of concrete is investigated, which are concrete with and without graphite fine powder. The weight of cement, sand, water and graphite for concrete with and without graphite fine powder are shown in Table 1. When the concrete harden on the next day of fabrication, it is treated by wrapping with a plastic bag as curing process.

TABLE I
SAMPLES ARE PREPARED WITH VARIOUS GRAPHITE FINE POWDER CONCENTRATION

Sample	Weight percent (wt%) of graphite fine powder
Normal concrete	0
1	7.2
2	9.6
3	12

The concrete permittivities are measured by using the TEM parallel plate as described in [18]. This structure offers the convenience for the users in preparing the sample for measurements (cuboids shape) and it can be fabricated easily with low cost. The complex relative permittivities of concrete with and without graphite fine powder are shown in Fig. 1 and Fig. 2.

Based on Fig. 2, the addition of graphite fine powder into the concrete has successfully increased the real part of the relative permittivity of the concrete. In other word, it has increase the capability of the concrete to store more energy from the incoming EM wave. It is the same for the imaginary part of the relative permittivity. The difference between imaginary part of the relative permittivty for sample 1 and 2 is not obvious.

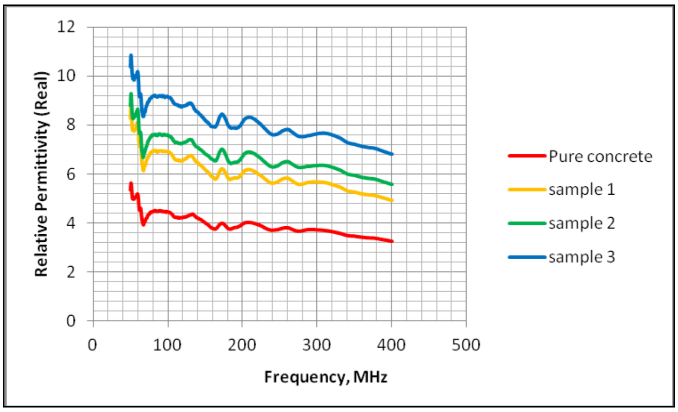

Figure 1. The real part of relative permittivity for pure concrete, sample 1, sample 2, and sample 3.

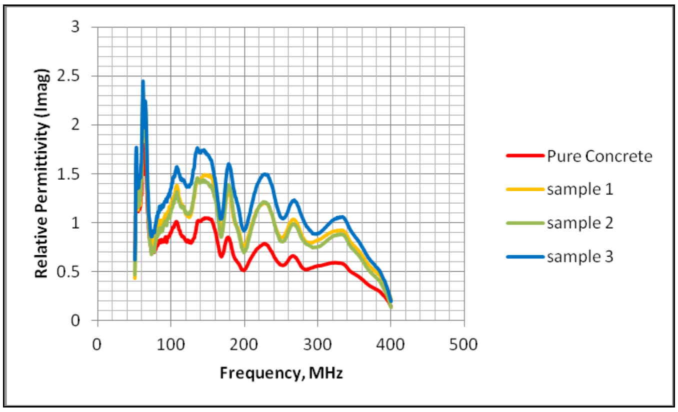

Figure 2. The imaginary part of relative permittivity for pure concrete, sample 1, sample 2, and sample 3 .

V. Result and Discussion

The SE of the concrete is calculated by using (3)-(5) analytically. The thickness of the material is fixed at 20 cm in this work. The SE of the materials is evaluated from 50 MHz to 400 MHz as shown in Fig. 3.

The graphite fine powder has successfully increased the SE of a pure concrete. However, the effect of adding more graphite fine powder is insignificant at frequencies between 200 MHz to 250 MHz. At around 200MHz, it seems futile to add more graphite as same SE level is achieved. In between 200 MHz to 250 MHz, adding more graphite fine powder does not increase the multiple re-reflection loss but reduce it further. The fluctuation of the multiple re-reflection loss is due to the exponential term in (5).

The contribution of reflection loss, absorption loss and multiple re-reflection loss to the overall SE is illustrated in Fig. 4, Fig. 5 and Fig. 6 respectively. It is found that reflection loss contributes most of the SE as compared to other losses. Generally the reflection loss follows the trend of the real part of relative permittivity where this parameter determines the characteristic impedance of the concrete. The characteristic impedance of the concrete with graphite fine powder decreased when more graphite fine powder is added and hence induces more reflection.

The concrete with graphite fine powder does not contribute much to the absorption loss especially at lower frequencies. Absorption loss is a parameter which relies on the conductivity, permeability and thickness of the material. In this work, the thickness of the concrete is fixed at 20 cm, furthermore it is a non-magnetic material, so the absorption loss is limited to the contribution from the conductivity. Based on Fig. 2, it indicates the conductivity of concrete with and without graphite fine powder. The addition of the graphite fine powder does not enhance the conductivity much, so similar absorption loss is achieved for sample 1, sample 2 and sample 3.

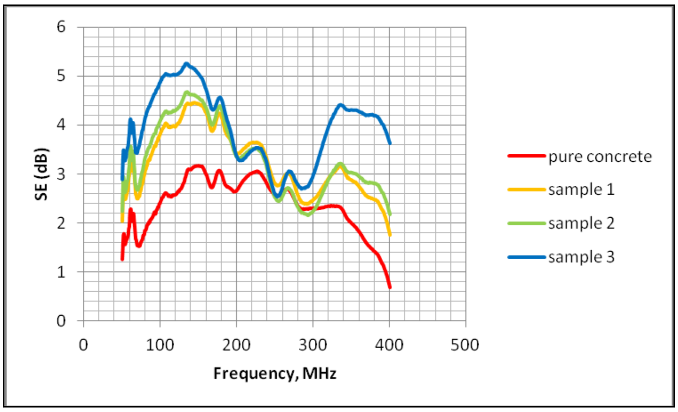

Figure 3. The SE of pure concrete, sample 1, sample 2 and sample 3

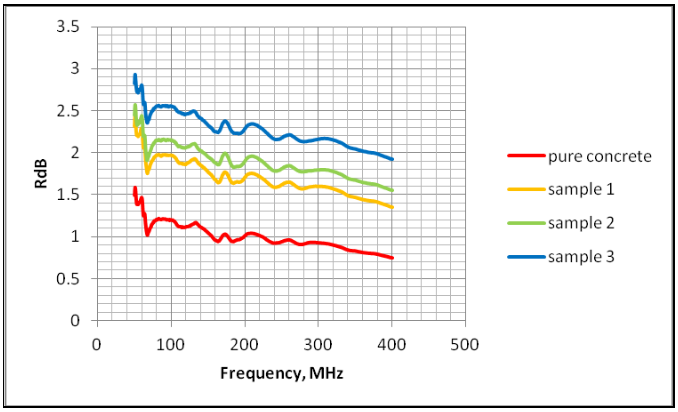

Figure 4. The reflection loss (R_{dB}) of pure concrete, sample 1, sample 2 and sample 3

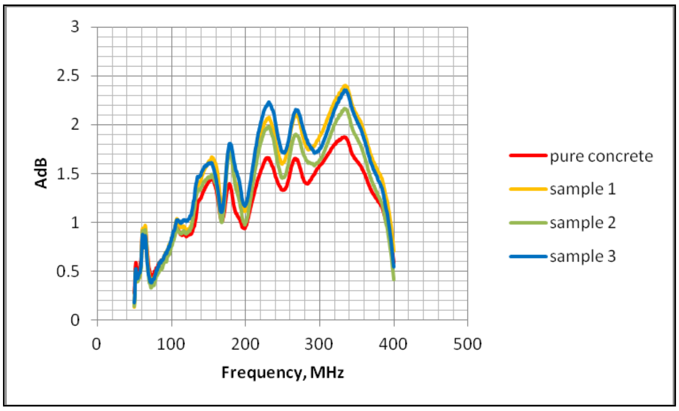

Figure 5. The absorption loss (A_{dB}) of pure concrete, sample 1, sample 2 and sample 3

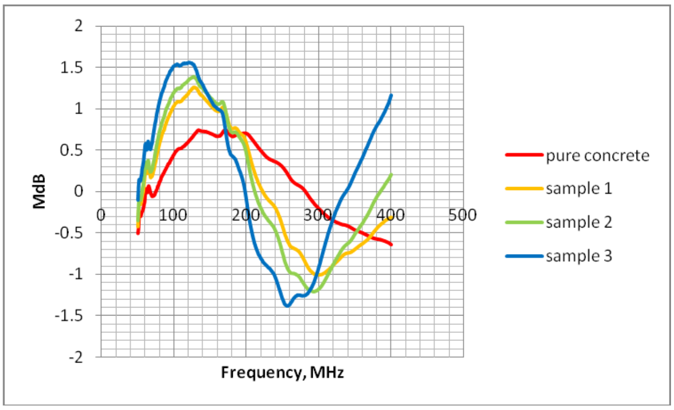

Figure 6. The multiple re-reflection loss (M_{dB}) of pure concrete, sample 1, sample 2 and sample 3

CONCLUSION

This work presents a simple and convenient way to determine the SE of concrete material as compared to experimental measurements which involve high cost and elaborate setup. Based on the result, it is concluded that the addition of the graphite fine powder successfully increase the SE of a normal concrete. A maximum of 2.4 dB additional shielding occur at 360 MHz when 12 wt% of graphite fine powder is added into the concrete. The mechanism that contributes more to the SE is the reflection loss as the addition of the graphite fine powder decreases the characteristic impedance of the pure concrete. The results of this work can be applied to the construction of building material for protection against electromagnetic interference.

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