

Shielding effectiveness measurement of cement-graphite block in between 3.8 GHz to 6 GHz

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ABSTRACT

Due to proliferation of electronic devices, the electromagnetic field (EMF) exposure affect human health in long term and operation of electronic devices if the radiation level is too high. Hence, shielding is used to reduce the radiation exposure. Since it is more practical to improve the shielding capability of the building itself, this project intends to investigate the shielding effectiveness (SE) of cement added with graphite. Eight cement-graphite specimens with different percentages (0%, 3%, 7%, 11%, 15%, 19%, 25% and 30%) are prepared. They have been casted into the waveguide mold with size of 4.75 cm x 1 cm x 2.22 cm and taken for measurement directly. The SE measurement setup involve a pair of waveguide with frequency range of 3.8 GHz to 6 GHz and vector network analyser (VNA). Throughout the study, it is found that the percentage of graphite powder will affect the SE of the specimens. The SE is independent on its curing duration. More than 11% of graphite is needed to improve the SE of cement block in between 3.8 GHz to 6 GHz. The highest SE of 33 dB is achieved when the sample contains 30% of graphite with thickness of 1 cm.

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1. INTRODUCTION

The presence of electromagnetic interference (EMI) sources due to the proliferation of mobile phones, mobile phones based station, antennas, sensors for wireless communication and internet of things (IoT) has exposed us to long term radiation. According to world Health Organization (WHO), human health will be affected if long-term exposure to strong electromagnetic (EM) field [1-2]. Besides, it may also influence many medical equipment that are sensitive to EMI. In this context, developing new building materials which are able to reduce the EM wave propagation have become the concern of many researchers nowadays [3-9].

Every new materials requires test to identify their capability in attenuating incident EM wave. Shielding effectiveness (SE) measurement become increasingly importance as the results of these emerging high-performance multi-functional materials with great electromagnetic interference (EMI) shielding efficiency. In order to attenuate the electromagnetic field efficiently, the materials should possess good electrical conductivity [6-7]. Hence these innovative materials are coated or mixed with conductive fillers.

Based on the Schelkunoff Theory [10, 11], the SE of material is deduced when a material with finite thickness and infinite size is exposed to electromagnetic field in far field region. In order to realize this condition, coaxial TEM cell method has been proposed at the beginning. It is an expanded coaxial line with taper at both ends to enable the connection to measurement instruments and coaxial cables. Two standards namely ASTM ES7 (withdrawn in 1988) and ASTM D4935 (withdrawn in 2005 and then reissued with minor changes) which are working based on this method have been proposed in the past [12-14].

The expanded coaxial line in ASTM ES7 has continuous inner conductor. When a washer test sample is inserted, it forms a continuous contact in between inner conductors, sample and outer conductor. It is operating in transverse electric (TEM) mode to simulate the far field condition as mentioned by Schelkunoff theory. The sample size is infinite since it is extended up to the outer conductor radially. Its operating frequencies are restricted in between 1 MHz to 1.8 MHz as moving toward to higher frequency will results higher order mode reflection at its taper. The reflection tends to perturb the TEM mode at the center and affect measurement inaccuracy. The challenge of this method is on its sample preparation. It is not difficult to prepare thin sheet of washer to be fitted into the slot perfectly. Any gap in between the sample and the sample holder tends to influence the SE measurement results [15].

ASTM D4935 has similar structure and concept as ASTM ES7. However, it uses a coaxial test cell with a discontinued inner conductor and a flanged outer conductor [16-17]. The measurement frequencies are between 30 MHz and 1.5 GHz [16]. In practice, certain limitations arise at lower frequencies due to the limited dynamic range of the network analyzer and the capacitive coupling operation. When there is a contact among the cell's parts during measurement time, there will be altered measurement result due to the contact impedance is in series with the sample. This technique is only suitable for very thin sample with thickness less than 1/100 of wavelength of the electromagnetic wave in free space [16].

Besides these methods, free space method which is conducted in anechoic chamber is also working based on Schelkunoff theory as well [18-20]. Either transmitting or receiving antenna are placed inside the chamber, the remaining instrument such as network analyzer or signal generator are located outside the chamber to reduce the interference. Since absorbers are surrounded, it creates a free space situation. The chamber is divided into two sections by a metallic plane which split the chamber into two sections eliminate the diffraction at the sample edge. It is found that this method requires sample size at least 1 m^2 , and to form a wide metallic plane inside anechoic chamber is burdensome [17].

IEEE-STD-299 is very similar to the free space method. However, it is used for measuring SE for enclosures with the smallest linear dimension of 2 m in the frequency range between 9 kHz and 18 GHz. The transmitting antenna is placed outside the enclosure whereas the receiving antenna is located inside the enclosure. This method is suitable for the SE evaluation of shielding room, the evaluation of small enclosures and shielding materials cannot be performed as they do not evaluate the individual properties of the shielding materials [21-22].

Nested reverberation chamber technique is an upgraded technique which considers multi-directional electromagnetic radiation, unlike Schelkunoff theory from multi-direction. It requires a smaller reverberation chamber to be placed inside a bigger reverberation chamber [23, 24]. This smaller chamber is equipped with a window fixture for mounting the material under test (MUT). The receiving antenna is mounted internally while the transmitting antenna is attached to the large reverberation chamber. It will generate fields with many polarization directions and statistically uniform as well as constant on average [23]. The SE of MUT is measured by comparing the ratio between the window uncovered with material and the window covered with the material. The disadvantage of this method is the requirement of paddle wheel to stir the modes in both chambers.

Each techniques discussed above have its own advantages and disadvantages and the SE measurement technique to be chosen is strongly depend on the measurement requirement such as whether oblique incident is of concern (Nested reverberation chamber technique), size of the specimen, operating frequency range, measurement space (IEEE-STD-299 technique requires big sample at lower frequency. Far field distance must be achieved according to this standard), shape of the sample (toroidal (ASTM ES7) or thin sheet (ASTM D4935)). In this work it is proposed to use the waveguide as a part of experimental setup for SE measurement. This technique is chosen rather than the other techniques discussed above is because the setup is easy and it requires a cuboid shape of sample which reduce the hassle in sample preparation. Since the EM wave is confined in guided medium, there is no leakage of EM wave from the sample edge.

In this paper, SE measurement of an improved cement-graphite block is measured by using waveguide pairs. This measurement setup consists of a vector network analyzer (VNA), and a pair of waveguides. The cement graphite samples are cast by a mold which has same cross section as the waveguide, hence the whole hold can be measured without removing the samples from the cast. This method examines the variation of the S_{21} parameter with and without the samples. Since the size of the mold aperture is 4.75 cm x 2.2 cm x 1 cm, it can be shaped easily. The SE measurement is conducted from 3.8 GHz MHz to 6 GHz

by considering the cut off frequency of TE₁₀ mode of the waveguide. The following sections will describe the project methodology which includes sample preparation, SE measurement setup, results and discussion.

2. RESEARCH METHOD

2.1. Sample preparation

Eight samples which contain different percentage of graphite as listed in Table 1 are prepared. In order to determine the mass of the powder needed. The volume of the mold is calculated. The mold used in this work is shown in Figure 1. It is made of aluminium in order to match the dimension of waveguide used in SE measurement. The holes surrounded the mold enable it to be tighten together with the other two waveguides during the SE measurement. The block casted from this mold will have dimension of 4.75 cm x 2.2 cm x 1 cm.

A smooth wooden plane is taped with the masking tape to serve as the bottom support during the casting process. The tape makes the removing process easier. The cement-graphite powder is mixed together by adding water until a sticky paste is obtained. Adding too much water will cause shrinkage and unevenness of cement-graphite surface. Figure 2 shows the cement paste when it is inserted into the mold. In order to eliminate the air bubble inside the specimen, the mold is vibrated and placed on a flat surface for the hardening process. The mold on the wooden plane is taped to stabilize it and prevent leakage of the paste from the bottom.

Table 1. Percentage of graphite in sample

Sample	Percentage of Graphite (%)
S0	0
S3	3
S7	7
S11	11
S15	15
S19	19
S25	25
S30	30



Figure 1. Mold for casting cement-graphite block

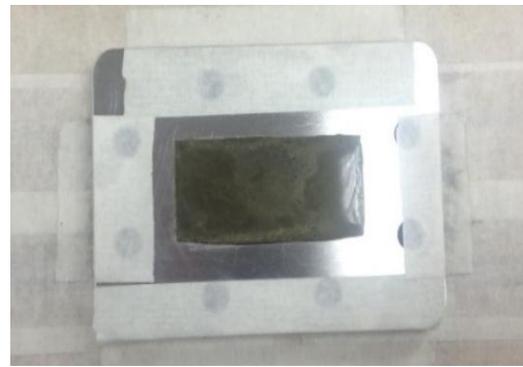


Figure 2. Cement paste is poured into the mold

2.2. SE Measurement setup based on waveguide

The SE measurement is conducted in between 3.8 GHz to 6 GHz as it is restricted by the operating frequency of the waveguide. Waveguide has been chosen as the sample holder because it enable the casting process to be carried out easily. Furthermore as the nature of the cement, if it is removed from the cast, it is brittle and the edge of the sample might be broken and increase the measurement inaccuracy.

The SE measurement setup is shown in Figure 3. This setup consist of a vector network analyzer (VNA), and a pair of waveguide with its launcher. The waveguides are connected to VNA through a pair of SMA coaxial cables. The SE of the samples are calculated based on (1). Is the transmission coefficient measure directly from VNA when there is empty mold is inserted into the system whereas is the transmission coefficient when mold with sample is inserted in between the waveguide. Before the measurement begin, the VNA must be calibrated to remove systematic errors.

$$SE_{dB} = S_{21dB_without\ sample} - S_{21dB_with\ sample} \quad (1)$$

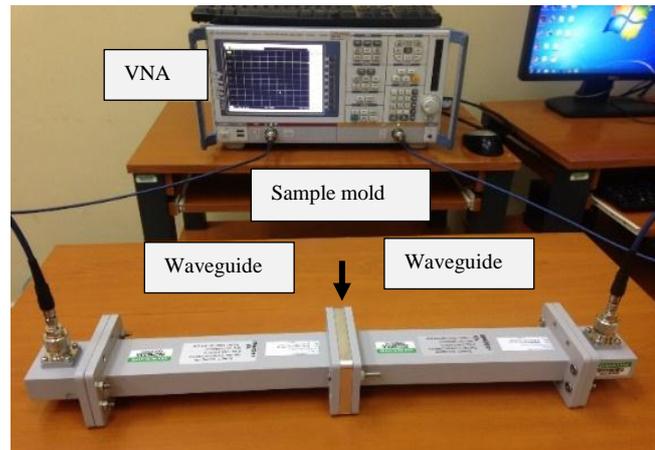


Figure 3. SE measurement setup

3. RESULTS AND ANALYSIS

3.1. Effect of curing period to the SE

Curing is an important stage for the strength development and durability of concrete [25]. The samples developed in this work undergo curing session immediately after it is casted. It is removed from the wooden support at the 7th day and kept under room temperature. It is not removed from the metallic cast, the whole metallic cast will be placed in between two waveguides during the measurement. By doing so it can avoid the leakage problem as the harden cement is brittle.

Based on [25], it is reported that the compressive strength of concrete will become stable after 28 days, hence this section intent to discuss the effect of curing period to the SE capability of cement-graphite block. Once the cement-graphite block is removed from the wooden support, SE measurement is conducted and repeated at day 7, day 14, day 21 and day 28.

The SE of the sample that contains 0% of graphite is shown in Figure 4. In general, the trend of the SE reading is similar for all days. They are very close to each other which fluctuate along the whole range of frequency. This scenario has indicated the SE of harden cement is independent on its curing period. The SE of the cement block is independent of its strength, which means stronger cement block does not increase its capability in attenuating the electromagnetic field. For better illustration, the standard deviation of the measurements reading are shown in Figure 5. Different standard deviations are found at different frequency since there are 200 data in between 3.8 GHz to 6 GHz. The highest standard deviation of 0.38 dB is achieved at 4.097 GHz. This figure is consider small and negligible, since it only contribute around 2% difference of the electromagnetic transmission.

Another set of measurement is conducted on the specimen with 30% graphite powder. The specimen is measured twice which is on 7th day and 14th day. Based on Figure 6, it is found that the SE of the cement-graphite block is higher ranging in between 26 dB to 33 dB in the whole frequency range. Similar observation is found where the trend of the SE is similar in both days and the curing duration does not affect the SE of the cement block even though graphite is introduced into the cement matrix. Hence the SE measurement for the other samples are conducted once they are removed from the wooden support.

3.2. SE of Cement-graphite block

The SE of cement-graphite samples with different percentage of graphite powder are compared. Specimens are prepared and the measurements are repeated thrice, the average reading is taken as shown in Figure 7. Based on Figure 7, it can be observed that the addition of the graphite has improved the SE capability of cement. The SE increment is proportional to the percentages of graphite. It is interesting to observe that when the sample contains only 3% of graphite, it does not improve its SE at all. Since graphite powder is well dispersed within cement powder, 3% of graphite is not adequate to form conductive layer to reflect EM wave.

When the amount of graphite is increased to 7%, there is some improvement on the SE capability at frequency above 4.7 GHz. However, 7% of graphite is still not able to reduce EM wave with larger wavelength (frequency below 4.7 GHz). This situation is confirmed by observing the SE reading of sample

with 11% of graphite. When the amount of graphite increase consecutively, its ability to attenuate the EM wave become better. Based on the measurement, it is noticed that the graphite have enhanced the SE of cement completely in between 3.8 GHz to 6 GHz when the percentage of graphite is reaching 15%. The SE reading increases around 1 dB for every 1% of graphite powder added ranging from 15% to 30%. At percentage of 30%, the SE of the sample is ranging from 32 dB to 35 dB at whole frequency range. In order word, it means the cement-graphite specimen is able to shield 98% of the EM wave. The results presented in Figure 7 is based on the sample thickness of 1 cm. When the sample thickness is enhanced, it could even provide more shielding.

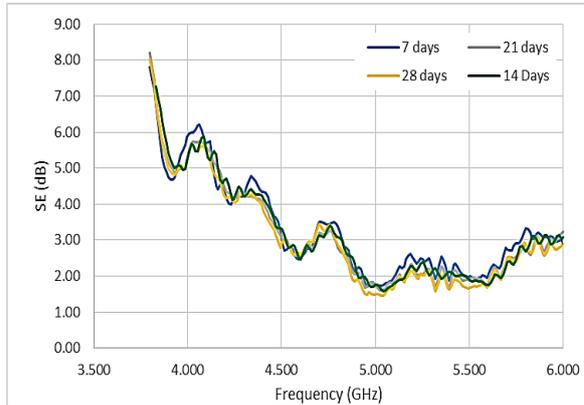


Figure 4. SE measurement of cement-graphite block with 0% graphite in different days

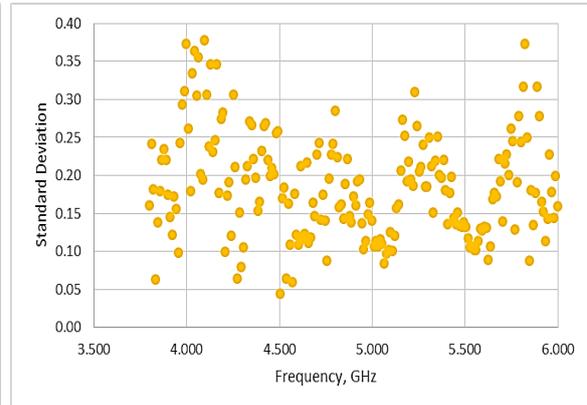


Figure 5. SE measurement of cement-graphite block with 0% graphite in different days

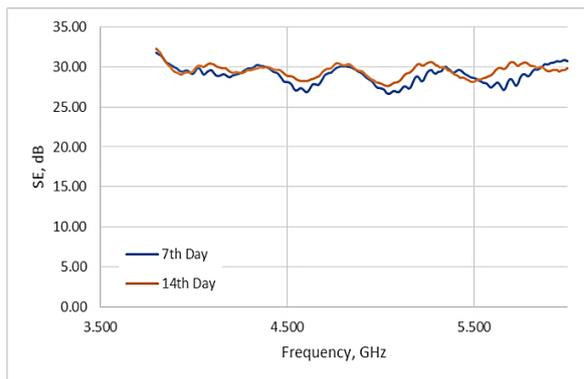


Figure 6. SE measurement of cement-graphite block with 30% graphite in 7th and 14th days

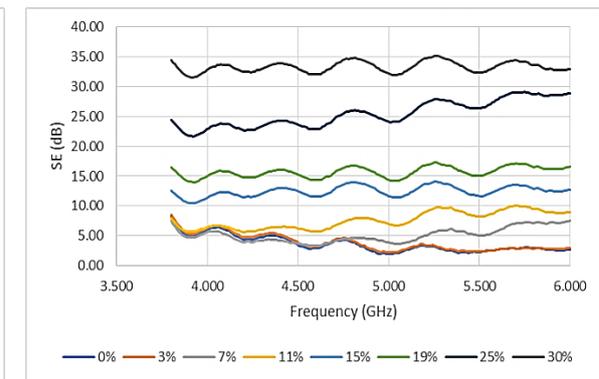


Figure 7. SE measurement of cement-graphite block with different percentage of graphite

4. CONCLUSION

This work has presented the SE of cement-graphite block in between 3.8 GHz to 6 GHz. The SE measurement is conducted based on waveguide setup. This measurement setup is more robust and convenient as it requires small cuboid shape of sample which is easy to be prepared. Since the cement cast is a part of the measurement setup, there is no leakage of EM wave due to air gap, hence eliminate the measurement uncertainty. Based on the measurement results, it is concluded that the SE is independent on the curing duration. SE measurement can be carried out even the strength of the block is not confirmed yet as it only introduces 0.38 dB of maximum standard deviation based on the measurement conducted in 7th, 14th, 21th and 28th days. It has been found that the SE of cement can be enhanced easily at higher frequency by mixing more than 3% of graphite into the cement whereas more than 11% of graphite is needed to improve the SE of cement in between 3.8 GHz to 6 GHz completely. The addition of graphite in the cement powder has successfully increase the conductivity of the cement-graphite block. As the results, more than 32 dB of SE is achieved in between 3.8 GHz to 6 GHz for 1 cm thick of sample with 30% of graphite. Future work can focus on the investigation of cement block strength when graphite is introduced into the cement.

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