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SHIELDING EFFECTIVENESS TESTS OF LOW-COST CIVIL ENGINEERING MATERIALS IN A REVERBERATING CHAMBER

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Abstract—In this paper, test study on low-cost civil engineering construction material is presented. In fact, in several civil constructions the strategy is to build up to first "fence" to EMI that limits interferences while using only in some limited areas high-cost ad hoc shielding material. The materials used in this study are tested at the Università di Napoli Parthenope, formerly Istituto Universitario Navale (IUN) Reverberating Chamber (RC) according to a nested approach. Tests are made in the frequency range from 2 to 18 GHz and show that low-cost materials are able to achieve about 16 dB of shielding effectiveness (SE) in contrast to ad hoc materials that show about 50 dB in SE.

1. INTRODUCTION

Recently, due to the presence of electronic devices in daily lives, new developments in the characterization of civil materials, employed in civil constructions whose activities are sensible to electromagnetic field interferences, are accomplished. The continuous grow in electromagnetic environmental installations has determined radiation hazard problem for applications such as medicine, finance or applications of government institutes. Many hospitals are concerned about the impact of electromagnetic interference (EMI) between wireless technologies and medical equipment. The first step is to make staff, patients and visitors aware of the potential effects of

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electromagnetic interferences. Further, the electromagnetic shielding evaluation is becoming an effective measure in blocking the involuntary emission of any communications device for data security of financial or government offices. In other words, electromagnetic shielding is used to confine electromagnetic energy within the bounds of a specific region and/or to prevent the propagation of such energy into a designated area.

Investigation on new designing materials is accomplished either for low-cost solutions in civil and medical construction or for ad hoc material for a total, but no more low-cost protection in special areas, e.g., the government buildings. The civil construction strategy, according to the European building regulation, requires new materials to be employed as a first fence to EMI or to digital information security in the working environments. Conductive mixtures, e.g., metal fibres, or absorbing mixtures are added to the traditional civil materials to improve their shielding properties. As matter of fact, there is increased interest in the use of alternative materials, e.g., waste metallic materials, from industrial activities, which present significant advantages in economic, energetic and environmental terms [1–5]. An holistic approach to determine the optimum amount of metallic fiber by considering the electromagnetic shielding properties of the materials must be accomplished in order to verify that the material under test (MUT) is suitable for the specific project solutions for which they are intended.

The shielding effectiveness (SE) is a typical measure used to assess the shielding properties of a civil material. Several experimental, analytical and numerical techniques to model civil materials for EMI interferences by evaluating their SE have been developed [6–14].

An effective approach to evaluate the SE of civil materials is given in [9] by the use of the reverberating chamber (RC). The RC is an isotropic multipath environment that better represents the real life environments where the fields are incident on the MUT with different polarizations [10–15]. In this paper, the RC is first employed to evaluate the SE of shields made with several civil materials having different mechanical properties. Experiments are carried out at RC of the Università di Napoli Parthenope, formerly Istituto Universitario Navale (IUN) to obtain a conceptually simple and fast method that aims to emulate the SE of civil shields.

2. THE RC MEASUREMENTS METHOD

Simple from a geometric point of view, the RC is a complex electromagnetic environment that provides an electromagnetic field of the same type encountered in the real-life conditions [16–25]. As matter of fact, the RC is a chaotic environment [19] in which the input electromagnetic field is randomized by means of different stirring techniques. The IEC 61000-4-21 standard [9] describes a particular approach to use the RC, the nested RCs approach, i.e., a smaller RC within a bigger RC, for measuring the SE of materials. Different research groups apply this technique to evaluate the SE of civil engineering materials [10–14]. The first formulation for the SE of the material under test (MUT) proposed in [10] has been improved during the years by considering new effective procedures which overcomes the drawbacks of the earlier ones.

However, although the above mentioned methods overcome the deficiencies of the earlier approaches, they are focused on the SE value of a civil engineering material. It must be noted that a simple material sample exhibits a SE value different from one of an enclosed shield. As matter of fact, the SE of a civil material always provides higher values than the ones of an enclosed shield apart from leakage, and in real operating conditions, one should consider shielding effectiveness of an enclosure.

In this work, a previous nested RC SE test to compare several civil materials having different shielding characteristics is used; this SE test is conceptually simple and fast and aims to emulate the electromagnetic characteristics of civil constructions and is essentially shown in [10]; SE is achieved as follows:

$$\mathrm{SE} = 10\log_{10}\left(\frac{P_{ORC,s}}{P_{IRC,s}}\right) \tag{1}$$

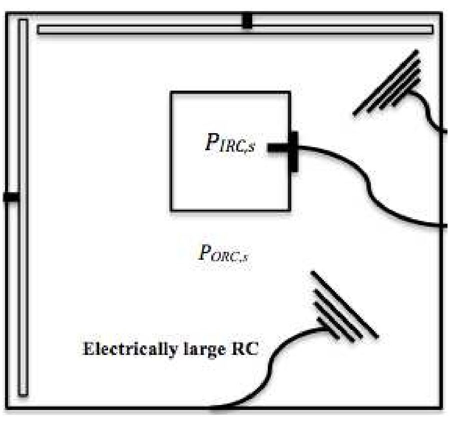


Figure 1. Sketch of the IUN RC set-up measurements.

where $P_{ORC,s}$ is the power received inside the outer chamber with the sample in the aperture and the source in the outer chamber, and $P_{IRC,s}$ is the power received inside the inner chamber with a sample (see Fig. 1).

Since in this case the aperture is a whole wall of the fixture, SE will essentially go to zero (dB scale) with no sample in the aperture [9], and its behaviour approximates that of two contiguous chambers with one side in common [13, 14].

In short, we compare fast SE of civil materials with different shielding characteristics by the comparison of the corresponding SE of a metallic fixture that aims to emulate the real operating conditions of shielding of the civil materials.

3. MECHANICAL PROPERTIES OF COMPOSITE MATERIAL

In this section, for reader completeness, a description of the cement composite material (CCM) employed in RC measurements is given. The materials used to prepare the CCM materials are cement (CEM) I 42,5 R, fly ash (FA), marble sludge (MS) and calcareous aggregate. The chemical composition, particle size distributions and physical properties of CEM, FA and MS are reported in Table 1. Steel fibers are employed whose dimension are 0.16 mm diameter and 30 mm length. Six CCM mixtures are prepared employing different amount of steel fiber as reported in Table 2. Further, CCM mixtures with two different metallic grids are developed. A reference mixture, without fiber, is also prepared.

The samples obtained with different amounts of fiber were characterized through the determination of some selected technological properties: apparent density, sorptivity, water absorption capacity (WAC), dynamic modulus of elasticity (DME), workability of the fresh mixture. The results of the technological characterization are summarized in Table 3. Finally, a preliminary study of a new type of construction material, called geopolymer (G0 in Table 3), is also performed. This kind of material is able to incorporate a large amount of industrial waste, and for this reason it is considered an environmental friendly material [26–31].

4. EXPERIMENTAL RESULTS

In this section, a meaningful set of experimental results is shown. Before that, a brief description of the calibration procedure is summarized. For the evaluation of SE of the enclosed shield, the power

Table 1. Chemical composition (%wt) of CCM material employed in the measurements.

	CEM	**FA**	**MS**
CaO	60.84	4.32	53.76
SiO_2	20.66	53.75	2.13
Al_2O_3	4.89	28.12	0.12
Fe_2O_3	3.24	6.99	0.69
MgO	1.94	1.59	0.15
SO_3	2.95	-	-
Na_2O	0.12	0.87	-
K_2O	0.84	1.89	-
Cl^-	0.94	-	-
LoI*	5.76	6.01	42.74

Table 2. Mix proportion of the CCM material samples employed in measurements. G0 is the geopolymer one. CM0, CM2, CM4, CM6 and CM8 are the CCM materials with inside 0, 2, 4, 6, 8%wt of steel fiber, respectively.

Mixture	**G0**	**CM0**	**CM2**	**CM4**	**CM6**	**CM8**
Cement [kg/m^3]	-	440	440	440	440	440
Natural aggregate [kg/m^3]	854	1456	1434	1402	1370	1339
Steel fiber [kg/m^3]	-	0	94	188	282	376
Fly ash [kg/m^3]	208	53	53	53	53	53
Marble sludge [kg/m^3]	-	118	118	118	118	118
Activating solution [kg/m^3]	138					
Acrylic Admixture [l/m^3]	-	7.25	8.96	10.56	12.23	14.82
Water/cement	N.A.	0.5	0.5	0.5	0.5	0.5

Table 3. Mechanical properties of CCM material samples. G0 is the geopolymer one. CM0, CM2, CM4, CM6 and CM8 are the CCM materials with inside 0, 2, 4, 6, 8%wt of steel fiber, respectively.

Mixture	**G0**	**CM0**	**CM2**	**CM4**	**CM6**	**CM8**
Density [kg/m^3]	2160	2298	2360	2422	2485	2547
Slump [kg/m^3]	S5	S4	S4	S3	S2	S2
WAC [%]	9.52	10.7	12.8	14.2	15.8	18.7
Sorptivity [mm/min$^{1/2}$]	0.064	0.072	0.079	0.084	0.088	0.0094
DME [GPa]	38	37	37	38	41	43

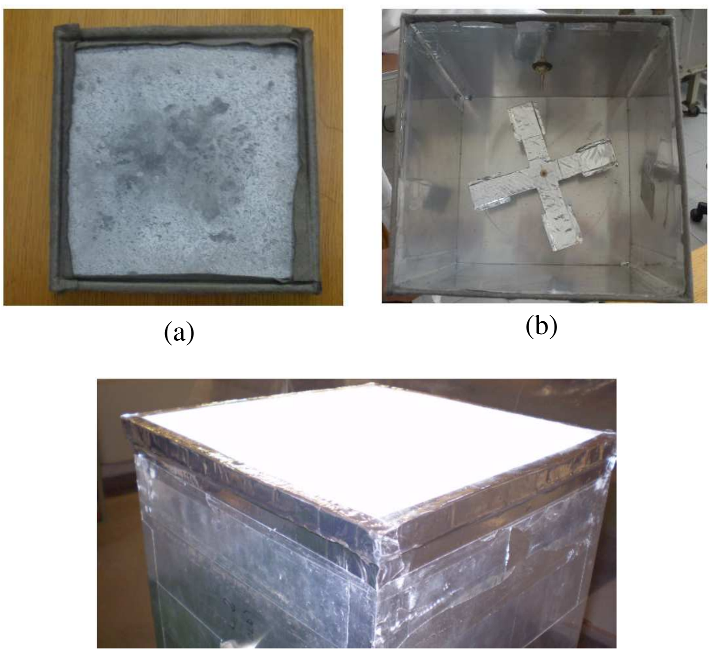
levels in the enclosure are monitored by a small probe placed on one of the enclosure wall. Large reflections at the antenna terminal can occur due to the mismatch of the monopole antenna to the transmission line used to deliver power to the probe terminal. To overcome this issue, a correction of the SE is made. In particular, the reflection due to the mismatch must be corrected. Two separate calibrations are performed: a transmission one and a reflection calibration procedure. The scattering coefficients $\dot{S}_{12}$ and $\dot{S}_{22}$ are measured. Port 1 is permanently connected to the horn antenna in RC. Port 2 is connected one after the other to the horn antenna in RC (horn-horn, hh) and to monopole antenna within the enclosure (horn-monopole, hm), see Fig. 1. Therefore, SE is achieved as follows

$$\mathrm{SE} = \left\langle \left|\dot{S}_{12}\right|^2 \right\rangle_{hh} - \left\langle \left|\dot{S}_{12}\right|^2 \right\rangle_{hm} + \left(1 - \left|\left\langle \dot{S}_{22} \right\rangle\right|^2\right) \tag{2}$$

All the terms in Eq. (2) are taken in dB values.

This correction is applied to avoid the strong mismatch error affecting measurements that are performed in the IUN RC, a $8\,\mathrm{m}^3$ metallic chamber, wherein three mechanical stirrers are present. The first one (S1), placed on the left of the entrance door, has a rectangular shape about $1.84\,\mathrm{m} \times 0.45\,\mathrm{m}$; the second stirrer (S2) and the third stirrers (S3) have a Greek-cross shape. The former has bars in the size about $1.84\,\mathrm{m} \times 0.25\,\mathrm{m}$ and is placed in front of the entrance door. The (S3) stirrer has bars in the size about $1.20\,\mathrm{m} \times 0.18\,\mathrm{m}$ and is placed in the ceiling. The S1, S2 and S3 stirrers work in continuous mode with maximum speeds of 190, 390 and 320 rate per minute (rpm), respectively. In Fig. 1, a sketch of the IUN RC with the inner enclosure employed in the measurements is shown.

In all experiments, the transmitting and receiving antennas used in the RC are both Ets-Lindgren double-ridged waveguide horn certified to work in the 1–18 GHz frequency range. An Agilent Technologies Vector Network Analyzer (VNA) is used in experimental tests. Measurements by shifting the measuring frequency in the designed bandwidth (2–18 GHz) by steps of 225 MHz are performed. 3000 independent samples are acquired at each frequency point. It must be noted that the statistical independence of the acquired samples has been verified by the autocorrelation function (not shown to save space). The scattering coefficient S_{21} is measured, and an off-line data analysis is carried out. The software used to acquire and to off-line analyze the data is developed in LabVIEW, a graphical development environment of the National Instruments (NI). The experimental setup involves an enclosure with an edge dimension of 30 cm, with five walls of aluminum and an empty wall, hosting the CCM under test. A stirrer randomizing the received field is present inside the enclosure (see Fig. 2). Measurements can be divided into three parts. In the first one, the low-cost civil engineering materials are obtained. The CCM is manufactured with a random distribution of metal fibers, i.e., iron



(a) (b) (c)

Figure 2. A particular electrical contact of the sample and the enclosure employed for the SE measurements.

nails, within the material. In the second part, low-cost material is also employed. The CCM with different metallic mesh grids is employed. A mesh grid can be imaged as a continuous net of iron nails distributed according to a well-defined placement along a plane. In the third part, measurements are performed with a no low-cost shielding material joined to the CCM under test. Finally, the first trial is also made on a new type of civil material, the geopolymer one. In all the experimental results, the SE of enclosed shield for several CCM is accomplished.

In the first part of the experimental results, the realized samples under test are cement constructed material manufactured using an intensive mixer tool, by varying the percentages of added steel fibers. In particular, six samples are created employing only CCM, CCM with 2%wt, 4%wt, 6%wt and 8%wt of steel fibers. It is important to note that all measurements have been accomplished taking particularly care of the edge treatment of the material employed in the SE evaluation. Accordingly, to avoid the leakage due to the imperfect contact between material and cavity wall, the electrical contact of the sample to the enclosure is ensured by an absorbing fabric coating (see Fig. 2). SE values obtained with no sample are very close to 0 dB except the measurement uncertainty, as expected (base line); they are not here shown for shortness. From an electromagnetic point of view, materials used in this first part of measurements are composite materials with a volumetric random distribution of metal particles embedded in an host dielectric. This last one is weakly-lossy since some fluid components, e.g., water, are present inside the material, which increase the electric polarizability. Fig. 3 shows SE values obtained from measurements

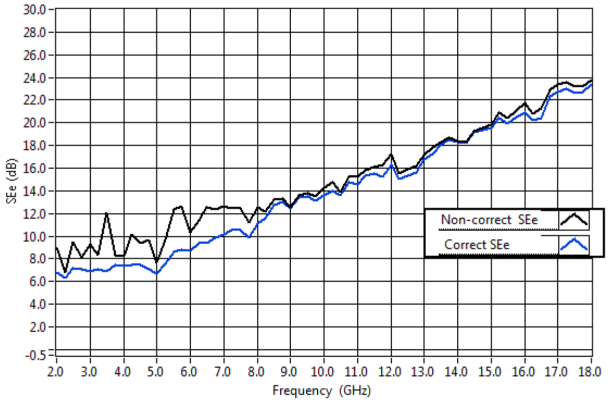


Figure 3. SE values relative to the only CCM where the evaporation process is not completely accomplished.

on CCM only where the evaporation process has not been entirely accomplished. In such conditions, measurements provide SE values of the enclosed shield, which increase with frequency by achieving considerable values. Accordingly, the CCM has been oven-dried for one week under 80-degree temperature to remove any residual fluid component. Fig. 4 shows the SE values obtained from the CCM after the evaporation process is completed. As expected, the SE values are considerably lower than the first one, with a maximum value equal to 2 dB around high frequencies (14–18 GHz). It is important to note that in order to verify the uncertainty related to the repeatability of the proposed procedure, measurements of the CCM have been evaluated, removed from setup, reinserted and evaluated again. Two independent experiments of the same sample show values that differ from each other by at most ±1 dB; this value range obviously includes the uncertainty due to different positions of the enclosure as well.

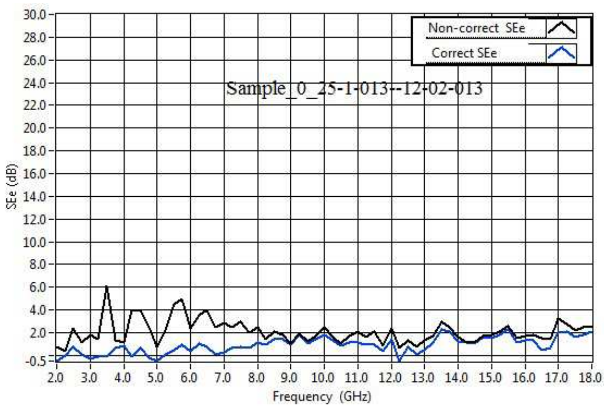


Figure 4. SE values relative to the only CCM where the evaporation process completed.

To improve the SE of the enclosed shield, a CCM with 2% of iron's fiber is considered (see Fig. 5). Results show that an increasing value equal to 2 dB on average is obtained for the shielding value of the enclosed shield with a maximum value of 7 dB in correspondence with the resonance frequency zone, i.e., from 2 to 3.5 GHz.

In order to confirm this trend and obtain an improving in the SE values, a CCM with a greater concentration of iron's fiber is evaluated. As matter of fact, a CCM with 4%wt of nails is employed. Fig. 6 shows the SE values of the enclosed shield obtained from measurements. A quantitative analysis shows that as far as the previous case, improved

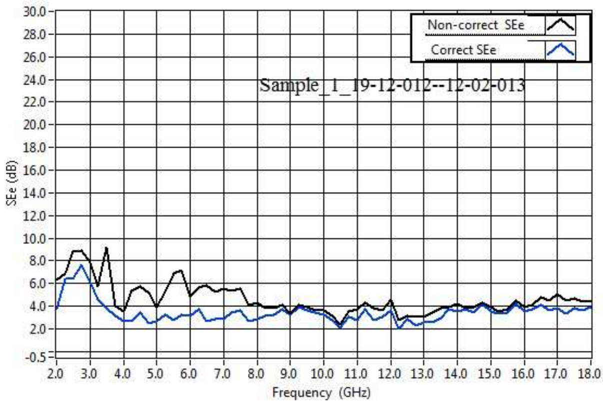


Figure 5. SE values relative to the CCM with 2%wt of nails.

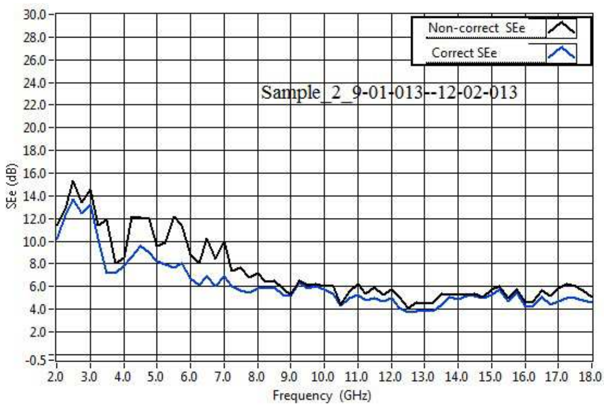


Figure 6. SE values relative to the CCM with 4%wt of nails.

SE values are obtained. It can be noted that for the frequency range from 2–8 GHz, values of SE greater than the previous one (i.e., the 2%wt case) are obtained. In fact, a dynamic about 8 dB is obtained in the 4%wt case for frequencies smaller than 8 GHz (see Fig. 6). According to [7], for the frequency range from 8 to 18 GHz, the improvement in the SE values is much smaller than the previous one. Although small fluctuations are present, for frequencies higher than 8 GHz the SE values remain close to 5 dB that is about 1 dB more than the 2%wt case.

To obtain higher SE values, a CCM with 6%wt of iron nails is considered (see Fig. 7). Results confirm what previously obtained with an increasing of about 3 dB for frequencies higher than 8 GHz

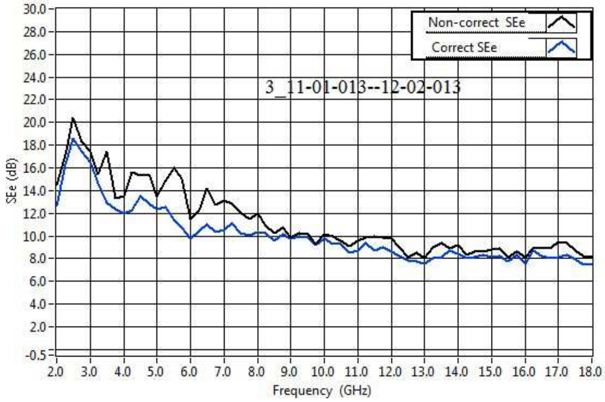


Figure 7. SE values relative to the CCM with 6%wt of nails.

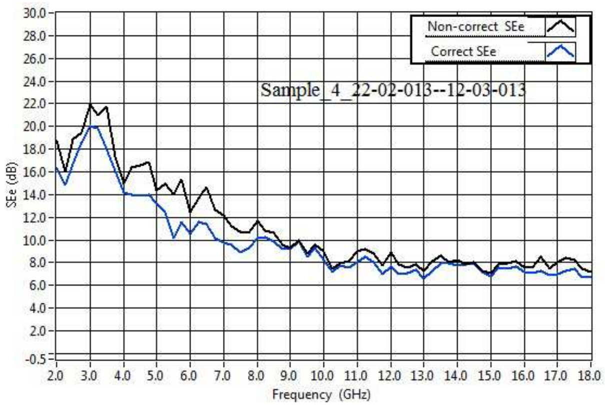


Figure 8. SE values relative to the CCM with 8%wt of nails.

with respect to the 4%wt case.

Measurements of SE values have been also carried out in the case of 8%wt. Fig. 8 shows the obtained SE values. From a quantitative comparison, one can note that no enhancement is obtained in the SE values with respect to the 6%wt case. While it is true that an increasing about 2 dB is obtained for the SE values in the frequency range 2–5 GHz, and no variations are present respect to the 6%wt case over the 5 GHz. To overcome this issue, due to the random distribution of nails within the CCM that cannot be properly managed when the number of nails increases, measurements of CCM with different metallic mesh grids are obtained. In particular, two square meshes sides, respectively

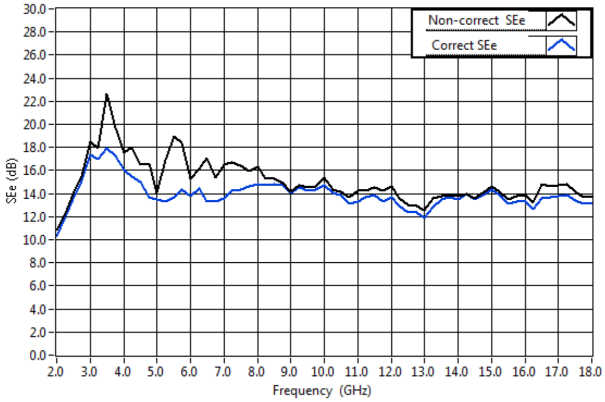


Figure 9. SE values relative to the CCM with a metallic mesh grid.

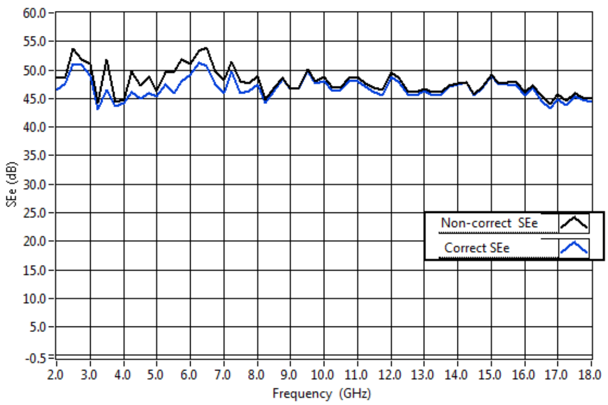


Figure 10. SE values obtained from absorbing fabric to the CCM.

equal to 0.001 m and 0.005 m, are employed. The two grids are dipped into the CCM, in the middle of the material. Fig. 9 shows the results obtained when a metallic grid with a side of 0.001 m is employed. A value about 14 dB is achieved for the SE in the full frequency range, a part from the initial frequency range, i.e., from 2 to 5 GHz, in which due to a resonance, the SE values grow up to 18 dB. It is important to emphasize that the employment of CCM with metallic grids (or nails) is low cost, i.e., economical convenient. Further, better results can be obtained by properly placing the grids close to the edges and/or by placing metallic grids in a asymmetric way in the material under test. The obtained shield can be used in *ab initio* realization of civil offices as well as smeared upon a surface as a coating.

In the third part of measurements, an absorbing fabric is used and joined to the CCM. Fig. 10 shows the result obtained in this last case. The SE value is almost constant around 48 dB on average, except for the higher frequencies, i.e., from 16 to 18 GHz, where its value stands for 45 dB. It must be noted that the employment of absorbing fabric is much more expensive than the previous techniques. On the other hand, a value of SE much higher than the previous one can be accomplished. This type of measurements can be employed in different typologies of shielding rooms, such as government offices, in order to avoid unwanted and dangerous electromagnetic disturbances. A first trial to evaluate the SE of a new type of civil engineering material, i.e., the geopolymer one, is also performed (see Fig. 11). Although the performance is not

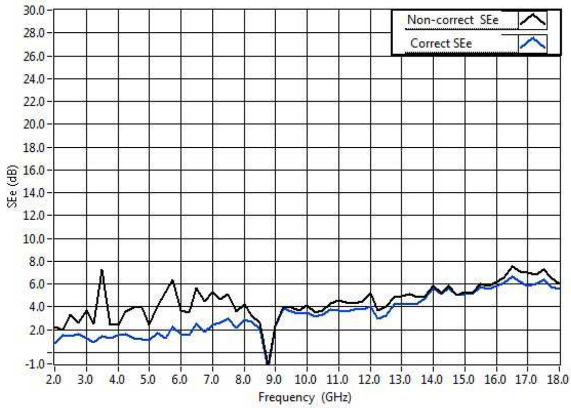


Figure 11. SE values relative to the geopolymer material.

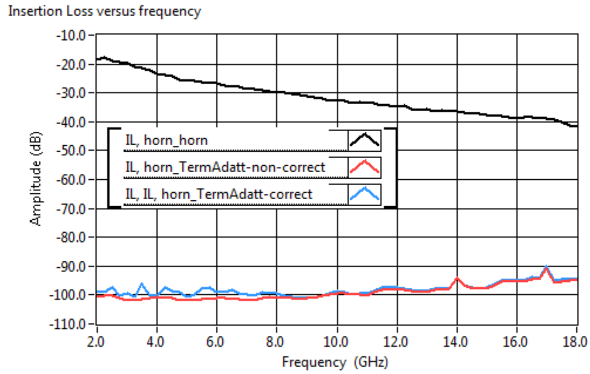


Figure 12. Insertion loss of the outer RC (black line) and the insertion loss of the enclosed shield under test (blue line).

good enough, it is interesting to note that by changing the proportion of the mixture, a different SE in the desired frequency band can be obtained.

Finally, to make sure that the experimental results are not affected by the noise, the dynamic of the measurement system is accomplished for the entire frequency range. In Fig. 12, the insertion loss of the outer RC (black line) and that of the enclosed shield under test (blue line) are reported. The difference between the values of these two curves gives back the dynamic of the system. It is important to note that the measurements of the enclosed shield are accomplished with a matched load on the receiving antenna in the outer RC. The obtained results represent the noise level of the system. A quantitative analysis shows that the dynamic of the measurements system, i.e., the difference between the black and blue lines in Fig. 12, goes from 80 dB at 2 GHz to 55 at 18 GHz. The dynamic of the system is about 10 dB more than the SE value measured in the case of the CCM joined to the absorbing fabric to ensure that measurements are noise free.

5. CONCLUSIONS

In this paper, a conceptually simple and effective technique to measure the SE of metallic fixtures that aim to emulate real operating conditions of civil materials, is accomplished at IUN RC. It has been proven that a first fence to EMI interference can be achieved by employing low-cost materials, e.g., iron nails or mesh grids, that can be used in *ab initio* realization of civil constructions such as office or medical centers, as well as smeared upon a surface as a coating. Experiments, done in the frequency range from 2 to 18 GHz, show that low-cost materials are able to achieve about 16 dB of SE. On the other hands, the SE of ad hoc materials is also accomplished to obtain about 50 dB in SE for a total but non low-cost protection. These materials can be employed in special areas, e.g., the government office, to avoid dangerous electromagnetic disturbances. A first trial to the SE of a new type of civil engineering construction materials is also completed. This last one is the topic of future experiments on the SE characterization of new civil materials.

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REFERENCES

1. Andini, S., F. Montagnaro, L. Santoro, G. Accardo, R. Cioffi, and F. Colangelo, "Mechanochemical processing of blast furnace slag for its reuse as adsorbent," *Chemical Engineering Transactions*, Vol. 32, 2299–2304, 2013.
2. Colangelo, F. and R. Cioffi, "Use of cement kiln dust, blast furnace slag and marble sludge in the manufacture of sustainable artificial aggregates by means of cold bonding pelletization," *Materials*, Vol. 6, No. 8, 3139–3159, 2013.
3. Cioffi, R., F. Colangelo, F. Montagnaro, and L. Santoro, "Manufacture of artificial aggregate using MSWI bottom ash," *Waste Management,* Vol. 31, 281–288, 2011.
4. Colangelo, F., R. Cioffi, F. Montagnaro, and L. Santoro, "Soluble salt removal from MSWI fly ash and its stabilization for safer disposal and recovery as road basement material," *Waste Management,* Vol. 32, 1179–1185, 2012.
5. Colangelo, F., R. Cioffi, M. Lavorgna, L. Verdolotti, and L. de Stefano, "Treatment and recycling of asbestos-cement containing waste," *Journal of Hazardous Materials*, Vol. 195, 391–397, 2011.
6. Koledintseva, M. Y., J. Drewniak, and R. Dubroff, "Modeling of shielding composite materials and structure FR microwave frequencies," *Progress In Electromagnetics Research B*, Vol. 15, 197–215, 2009.
7. Koledintseva, M. Y., S. K. R. Chandra, R. E. Dubroff, and R. W. Schwartz, "Modeling of dielectric mixtures containing conducting inclusions with statistically distributed aspect ratio," *Progress In Electromagnetics Research*, Vol. 66, 213–228, 2006.
8. Ellgardt, A. and D. Mansson, "Modeling shielding effectiveness for composite walls of concrete and carbon filaments," *Progress In Electromagnetics Research M*, Vol. 28, 15–25, 2013.
9. IEC 61000-4-21, "Electromagnetic compatibility (EMC), Part 4–21: Testing and measurement techniques — Reverberation chamber test methods," International Electrotechnical Commission, Geneva, Switzerland, 2003.
10. Hatfield, M. O., "Shielding effectiveness measurements of materials using mode-stirred chambers: A comparison of two approaches," *IEEE Trans. Electromagn. Compat.*, Vol. 30, 229–238, 1988.
11. Holloway, C. L., D. A. Hill, J. Ladbury, G. Koepke, and R. Garzia, "Shielding effectiveness measurements of materials using nested

reverberation chambers," *IEEE Trans. Electromagn. Compat.*, Vol. 45, 350–356, May 2003.

12. Holloway, C. L., D. A. Hill, M. Sandroni, J. Ladbury, J. Coder, G. Koepke, A. C. Marvin, and Y. He, "Use of reverberation chambers to determine the shielding effectiveness of physically small, electrically large enclosures and cavities," *IEEE Trans. Electromagn. Compat.*, Vol. 50, 770–782, Nov. 2008.
13. Gifuni, A. and M. Migliaccio, "Use of nested reverberating chambers to measure shielding effectiveness of nonreciprocal samples taking into account multiple interactions," *IEEE Trans. Electromagn. Compat.*, Vol. 50, 783–786, Nov. 2008.
14. Van de Beck, S., R. V. Ardatjew, H. Schipper, and F. Leferink, "Vibrating intrinsic reverberation chambers for shielding effectiveness measurements," *International Symposium on Electromagnetic Compatibility (EMC) Europe 2011*, 133–136, York, 2011.
15. De Leo, R., G. Gradoni, A. Mazzoli, F. Moglie, G. Moriconi, and V. M. Primiani, "DSP cement composite for electromagnetic shielding: Practice and experimental analysis," *International Symposium on Electromagnetic Compatibility (EMC) Europe 2009,* 1–4, Athens, 2009.
16. Ferrara, G., M. Migliaccio, and A. Sorrentino, "Characterization of GSM non-line-of-sight (NLOS) propagation channels generated in a reverberating chamber by using bit-error-rates (BER)," *IEEE Trans. Electromagn. Compat.,* Vol. 49, No. 3, 467–473, 2007.
17. Sorrentino, A., G. Ferrara, and M. Migliaccio, "The reverberating chamber as a line-of-sight wireless channel emulator," *IEEE Trans. Antennas Propag.,* Vol. 56, No. 6, 1825–1830, 2008.
18. Sorrentino, A., F. Nunziata, G. Ferrara, and M. Migliaccio, "Reverberating chamber profile identification," *IET Microwave, Antennas & Propagation*, Vol. 6, No. 13, 1468–1472, 2012.
19. Sorrentino, A., L. Mascolo, G. Ferrara, and M. Migliaccio, "The fractal nature of the electromagnetic field within a reverberating chamber," *Progress In Electromagnetics Research C*, Vol. 27, 157–167, 2012.
20. Sorrentino, A., G. Ferrara, and M. Migliaccio, "An effective indicator for NLOS, nLOS, LOS propagation channels conditions," *Proceedings of EUCAP 2012,* 1422–1426, Prague, Czech Republic, Mar. 26–30, 2012.
21. Ferrara, G., A. Gifuni, and A. Sorrentino, "Test on antennas in a reverberating chamber and comparison with anechoic chamber," *Proceedings of EUCAP 2012*, 2154–2157, Prague, Czech Republic, Mar. 26–30, 2012.

22. Sorrentino, A., G. Ferrara, and M. Migliaccio, "The kurtosis index to characterize near LOS conditions in reverberating chambers," *IET Microwave, Antennas & Propagation*, Vol. 7, No. 3, 175–179, 2013.
23. Sorrentino, A., G. Ferrara, A. Gifuni, and M. Migliaccio, "Antenna pattern in a multipath environment emulated in a reverberating chamber," *Proceedings of EUCAP 2013*, 3561–3165, Gothenburg, Sweden, Apr. 8–12, 2013.
24. Sorrentino, A., G. Ferrara, and M. Migliaccio, "On the coherence time control of a continuous mode stirred reverberating chamber," *IEEE Antennas and Propagation*, Vol. 57, No. 10, 3372–3374, 2009.
25. Gifuni, A., A. Sorrentino, A. Fanti, G. Ferrara, M. Migliaccio, G. Mazzarella, and F. Corona, "On the evaluation of the shielding effectiveness of electrically large enclosures," *Advanced Electromagnetics, Special Issue on AES 2012*, Vol. 1, No. 1, 84–91, 2012.
26. Ferone, C., F. Colangelo, R. Cioffi, F. Montagnaro, and L. Santoro, "Use of reservoir clay sediments as raw materials for geopolymer binders," *Advances in Applied Ceramics*, Vol. 112, No. 4, 184–189, 2013.
27. Ferone, C., F. Colangelo, R. Cioffi, F. Montagnaro, and L. Santoro, "Mechanical performances of weathered coal fly ash based geopolymer bricks," *Procedia Engenering*, Vol. 21, 745–752, 2011.
28. Ferone, C., F. Colangelo, F. Messina, L. Santoro, and R. Cioffi, "Recycling of pre-washed municipal solid waste incinerator fly ash in the manufacturing of low temperature setting geopolymer materials," *Materials*, Vol. 6, No. 8, 3420–3437, 2013.
29. Ferone, C., G. Roviello, F. Colangelo, R. Cioffi, and O. Tarallo, "Novel hybrid organic-geopolymer materials," *Applied Clay Science*, Vol. 73, 42–50, 2013.
30. Colangelo, F., G. Roviello, L. Ricciotti, C. Ferone, and R. Cioffi, "Preparation and characterization of new geopolymer-epoxy resin hybrid mortars," *Materials,* Vol. 6, No. 7, 2989–3006, 2013.
31. Iucolano, F., B. Liguori, D. Caputo, F. Colangelo, and R. Cioffi, "Recycled plastic aggregate in mortars composition: Effect on physical and mechanical properties," *Materials & Design*, Vol. 52, 916–922, 2013.