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Patrizia Savi, Damiano Cirielli
Dept. of Electronic and Telecommunications
Politecnico di Torino
Torino, Italy
patrizia.savi@polito.it

Davide di Summa, Giuseppe Ruscica,
Isabella Natali Sora
Department of Engineering and Applied Sciences
University of Bergamo
Dalmine, Italy

Abstract—**Shielding against electromagnetic interference (EMI) is a crucial point in aerospace industry and for civil applications. In recent years, the mechanical and electrical properties of composites materials filled with carbon nanotubes or graphene have been analysed with the aim of substituting to standard metal structures used for electromagnetic shielding.**

In this work, an eco-friendly material as biochar obtained from biomass pyrolysis is used as filler in cement and the shielding properties of the composite in X-band are analysed.

Keywords—biochar; cement composites; dielectric permittivity; rectangular waveguide; scattering parameters measurements; shielding effectiveness (SE).

I. INTRODUCTION

Biochar (abbreviation for bio-charcoal) is a solid product from biomass pyrolysis, characterized by high carbon content. Common biochar includes wood char, bamboo char, straw char and rice husk char [see e.g. 1-13].

The most common application of biochar is its use as soil amendment agent. Biochar with low ash content can be used as fuel material [14-15].

In recent years, composites materials formed by a matrix and a filler derived from natural biomass have been gained attention for their potential applications [16]

Electromagnetic shielding in buildings is currently limited to niche sectors, such as the protection of electronic equipment sensitive to electromagnetic interference and the shield of the workspace in the presence of adverse radiations from telecommunication systems [17-18].

Currently, the protection of sensitive environments from electromagnetic pollution is achieved by a shielding with metal sheets [19]. However, the metal sheets are heavy structures, difficult to overlap on the building envelope and they make the place uncomfortable for human activities. As cement itself lacks the ability to shield electromagnetic radiation, composites are needed in order to shield the electromagnetic radiations.

During last decades, different studies focused their attention on innovative shielding cementitious composites aiming to develop innovative and cost-effective materials [20-22]. Desirable properties for filler in the composites include chemical and physical stability, sufficient mechanical resistance, high durability, large surface area, and good electrical conductivity.

Biochar seems an attractive filler for improving the shielding effectiveness (SE) properties of composites. To the best of our knowledge, studies on the usage of biochar-based cementitious composites as effective electromagnetic waves attenuator are limited [23].

In this paper, we first briefly introduce the preparation process of the composite: a commercial biochar with two different mix formulations mixed together with ordinary Portland Cement. Samples were prepared pouring the final composite in silicone moulds. Then, the shielding properties of the samples were investigated in the X-band.

II. MATERIALS AND METHODS

A. Materials and sample preparation

Commercial biochar (Carlo Erba reagents) in the form of granulate has undergone to a reactivation process at 750 °C for 4h. Two different mix formulations were prepared using biochar granulate at 1% (B1) and at 10% (B10) by weight of cement keeping constant the ratios of superplasticizer at 1.5% (necessary for an acceptable workability) and variating water ratio from 35% (in B1 case) up to 55% (in B10 case). The biochar was mixed together with ordinary Portland Cement (PC) matrix (grade 52.5 R) compliant with ASTM C150 requirements [24].

Moreover, a reference specimen (B0) was realized mixing only PC together with a water and superplasticizer ratios equal to 35% and 1,5% by weight of cement respectively.

The samples preparation consisted of three steps. At first, the selected ratio of biochar granulate was mixed together with PC and with the superplasticizer using a mechanical mixer for 4 minutes until obtaining a homogeneous mixture.

Then, the obtained composite was poured into rectangular silicone moulds (dimensions 22,86 x 10,16mm and 4mm of thickness) for shielding effectiveness analysis (SE) analysis and into cylindrical moulds (diameter 40mm and thickness 15mm) for permittivity analysis.

Finally, all the specimens were kept at $90 \pm 5\%$ relative humidity (RH) for initial 24 hours. After that, the samples were demolded and immersed in water until the end of curing period occurred at room temperature (20 ± 2 °C) for

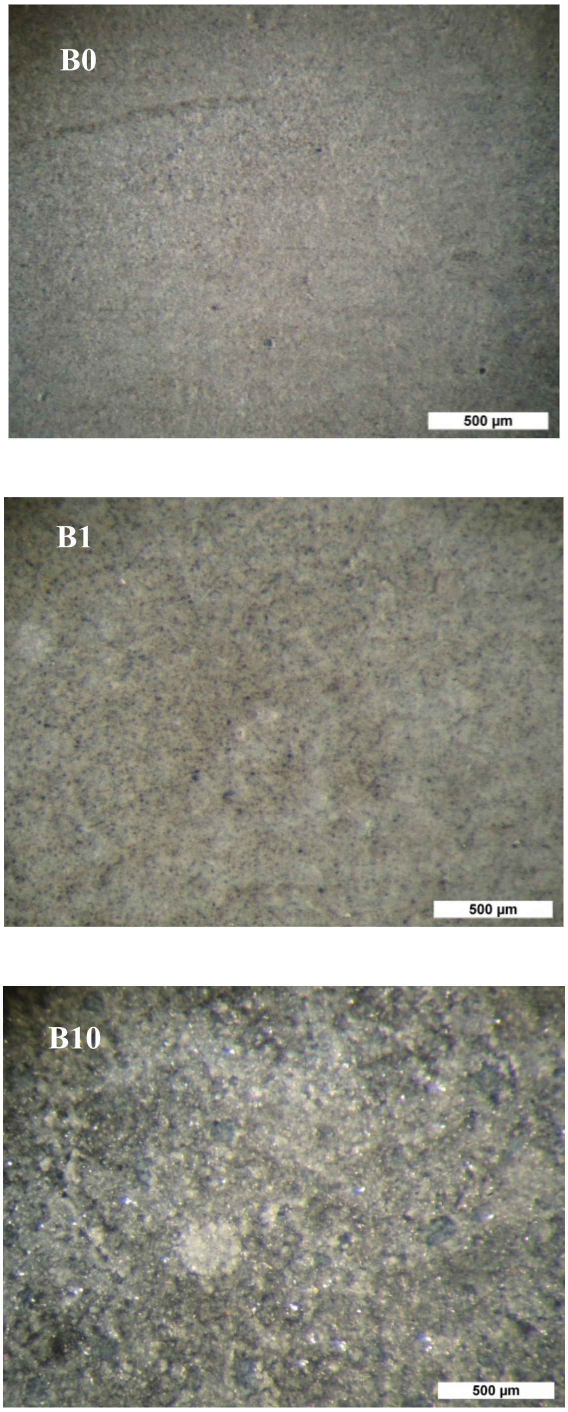

Fig. 1. Image of B0, B1 and B10 samples obtained by an optical microscope (Leica) enlargement 5x .

28 days. The image of sample B0, B1 and B10 obtained with an optical microscope are shown in Fig.1 and show a homogeneous distribution of the biochar in the composites.

B. *Complex permittivity measurements*

The complex permittivity of cement composites filled with pyrolyzed biochar was measured in the frequency range 1-12

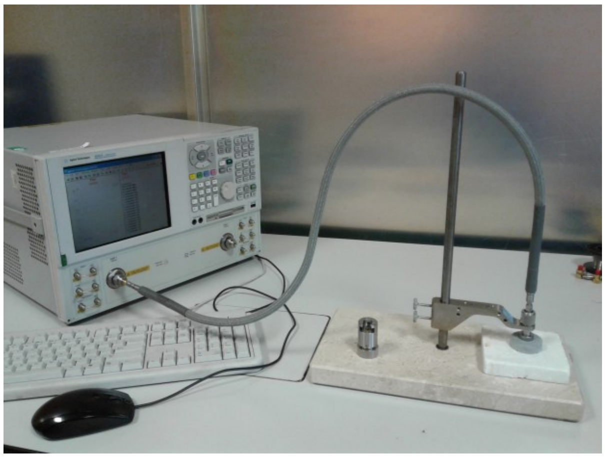

Fig. 2. Complex permittivity measurement setup.

GHz using a commercial open-ended coaxial sensor (Agilent 85070D) and a Network Analyzer (E8361A, see Fig. 2). A standard calibration short/air/water was performed before each measurement. This measurement system was chosen because it allows a wide-band characterization and can be used on samples of small dimensions [25-26].

In our study, in order to satisfy the requirements of the measurement setup, samples of cylindrical shape of 40 mm in diameter and around 10 mm in thickness were used.

C. *SE measurement setup*

The Shielding effectiveness of our samples was investigated in X-band (8-12 GHz) measuring the scattering parameters in a rectangular waveguide (22.86 x 10.16 mm).

To obtain a correct dominant mode excitation in the waveguide, two waveguide straight pieces were inserted between the launchers and the measured sample. A waveguide spacer of thickness 5 mm was used as sample holder. An example of the tested specimen press-fitted in the brass 10 mm waveguide spacer is shown in Fig. 3.

An Agilent E8361A network analyser was used to measure the scattering parameters and a Maury Microwave X7005E calibration kit was used to perform a standard short-thru-matched load calibration.

The SE can be obtained by subtracting the measured transmission coefficient (S_{21}) of the empty waveguide from the S_{21} when the sample is placed in the cross section of the waveguide [27-28]:

$$SE_{E|dB} = 20Log\left|\frac{S_{21}}{S_{21|spec}}\right| \quad (1)$$

III. RESULTS

The complex permittivity was measured on several samples of plain cement (B0), and cement filled with 1 wt% (B1) and 10 wt% (B10) of biochar. The real part ε'_r represents the stored

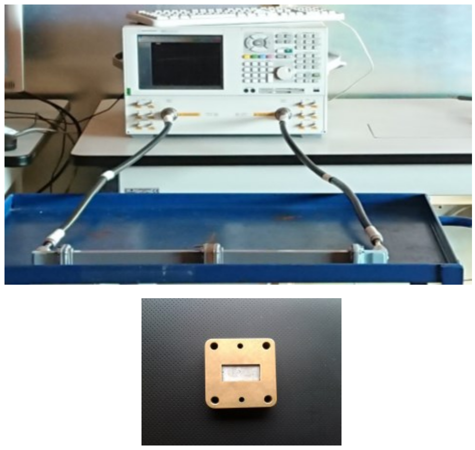

Fig. 3. Waveguide measurements setup (left panel) and spacer with a sample (right panel).

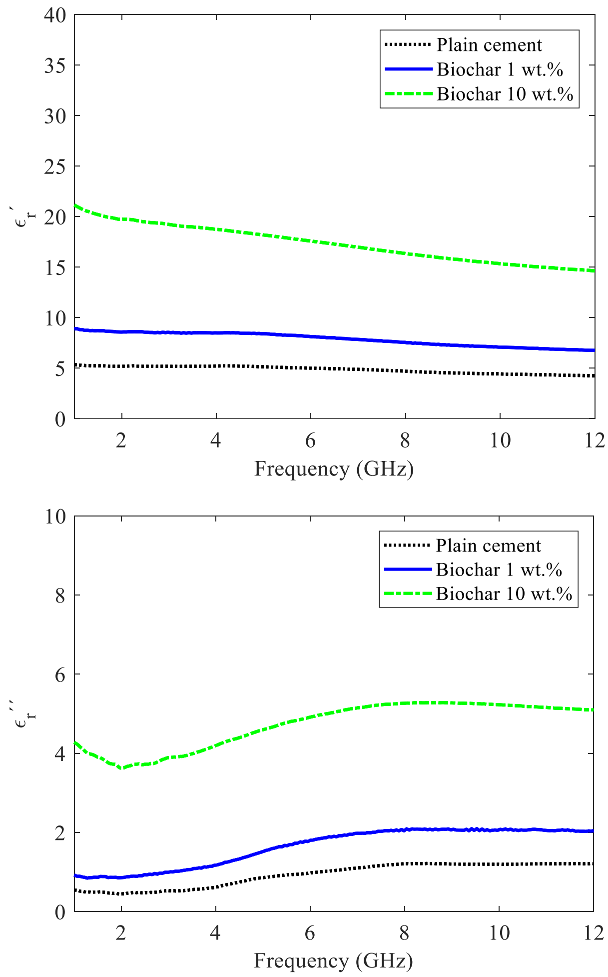

Fig. 4. Complex permittivity measurements of reference cement and cement composites filled with biochar B1 and B10. Real part (top panel), immaginary part (bottom panel).

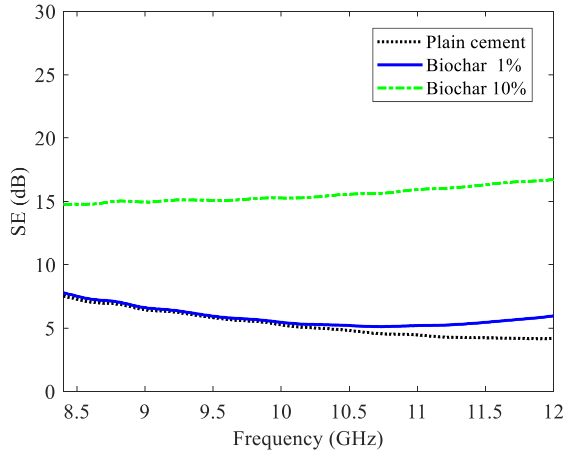

Fig. 5. Shielding effectiveness of reference cement and cement composites filled with biochar B1 and B10.

energy, the imaginary part ε''_r provides information about the dissipated energy. As shown in Fig. 4, for all composites the ε'_r compared to B1 with respect to the reference plain mortar. At a frequency of 8 GHz, composite B10 shows ε'_r value of 17, whereas B1 and the reference composite displayed 7 and 4, respectively. The same mix formulation was used to make samples with rectangular shape (thickness 4 mm) to be inserted in the WR90 waveguide holder (see Fig. 3). The scattering parameters of the empty waveguide and of the waveguide with the samples were measured and the SE evaluated as (1). Results are shown in Fig. 5. As it was expected from the permittivity measurements, composite B10 shows the highest value of SE around 15 dB, whereas the plain cement (B0) and the composite B1 have a comparable value. For general use, the SE is considered good if it ranges from 10 dB to 20 dB (see Table I).

grade	Excellent	Very good	Good	Moderate (fair)
SE (dB)	>30	30-20	20-10	10 - 7

Table I. Classification of shielding effectiveness for general use.

IV. Conclusions

In this work, composites based on cement Portland and commercial biochar were made to investigate the shielding properties of the composites. Two different weight percentage of biochar (1% and 10%) were used and samples of different shapes suited for the measurements of the permittivity and the measurements of the scattering parameters in X-band were realized. From the measured transmission coefficient the shielding effectiveness of the various samples was evaluated and compared. While the composite with 1% of biochar has a behavior similar to the plain cement, the composite with 10% of biochar reaches a SE of 15 dB at 8.5GHz. Although the composite with 10% of biochar (B10) cannot be used for electronic devices commercial applications, it could be potentially used for designing green and sustainable microwave attenuators in the field of building constructions.

ACKNOWLEDGMENT

This work was supported by the "Study on electromagnetic radiation shielding materials for construction industry" project funded by the Department of Engineering and Applied Sciences of the University of Bergamo.

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