HIGH FREQUENCY ELECTROMAGNETIC SHIELDING BY BIOCHAR-BASED COMPOSITES

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Introduction

Nowadays, the interest in shielding electronic devices and communication instruments against electromagnetic (EM) radiation is growing more and more, in order to improve their efficiency and lifetime. This requirement is sometime extended to entire buildings, for which shielding materials are applied as a coating on wall surfaces. The use of shielding elements directly mixed with currently used building materials has been considered only recently: it may represent a sustainable route, especially if the additional materials are eco-friendly and cost-effective [1]. As the main drawback of EM-shielding materials refers the drop of mechanical properties due to high filler concentration [2], coating approaches and non structural materials have been used for EM-shielding applications [3]. This opened the way for the production of materials that do not require superior mechanical properties, but only a great shielding efficiency. The shielding efficiency (SE) of a material depends on its intrinsic properties, i.e., conductivity σ and permittivity ε. Thus, due to high σ, metals are well suited for many EM-shielding applications, but they also have disadvantages, such as heavy weight, corrosion propensity, mechanical stiffness, and high cost. Conversely, conducting composites show light weight, flexibility, low cost and a tunable shielding response as well. Among the materials with these properties, promising for EM-shielding applications, carbon-based composites recently emerged as a reliable solution. In particular, an eco-friendly material derived from waste, matching these requirements, is biochar [4], a carbonaceous material produced by thermal treatment of biomass (e.g., from agricultural or food waste), showing good enough properties to be considered as a practical alternative to the use of other more performing carbon-based materials, such as graphene or carbon nanotubes, which are much more expensive and require complex synthesis procedures. In this work, we investigate EM-shielding properties of composites made of biochar inclusions dispersed into non-structural materials of interest for building construction, namely cement, epoxy resins and HDPE. We performed a microwave characterization of biochar composites based on these materials, yielding their complex permittivity. The evaluation of the SE of the measured materials and composites, and of other combinations obtained by suitable mixing rules, allowed simulating the electromagnetic behavior of composites as a function of biochar loading.

Results and discussion

The SE of the selected biochar-based composites has been assessed starting from a microwave characterization in the frequency range 100 MHz–8 GHz of cement, HDPE and epoxy matrices, and biochar-epoxy composites. This frequency range covers the bands from UHF to C, used for communications, including GPS,Wi-Fi, and Bluetooth devices, mobile phones, and radar systems.

To this aim, a multi-step approach, summarized here and detailed below:

- measurement of the complex dielectric constant of all the matrices,
- determination of the dielectric constant of biochar as an inclusion material (which, in principle, might be different from the starting biochar powders) by measuring several concentrations of a specific composite (epoxy + biochar) and employing a proper mixing rule,
- application of the same rule (inversely) to deduce the effects of biochar addition to the other matrices.

The output of measurements is the complex permittivity of the material, $\varepsilon = \varepsilon' + j\varepsilon''$; an example is given in Figure 1, where the real part of permittivity ε' and loss tangent $\tan \delta = \varepsilon''/\varepsilon'$ are shown for neat epoxy and for an epoxy composite containing 25 wt.% of biochar. The oscillations in the measured values are due to the geometry of the measurement cell and are common in measurement techniques based on microwave transmission lines. The value of $\tan \delta$ measured for pure epoxy is in quite good agreement with those commonly reported, especially at high frequencies, where spurious oscillations are small. At lower frequencies, the measurement is less precise but still in an acceptable range.

For an electromagnetic wave propagating into a material with negligible magnetic properties and under the far field conditions (kr>>1, where k is the wave number and r is the source-detector distance), the overall shielding efficiency SE is expressed, in decibels (dB), as

$$SE = 10log_{10}\left(\frac{P_i}{P_t}\right) = SE_A + SE_R + SE_{MR}$$

where Pi and Pt are the incident and transmitted power, SE_A, SE_R, and SE_{MR} are the absorption, reflection, and multiple-reflection contributions to the shielding efficiency, respectively.

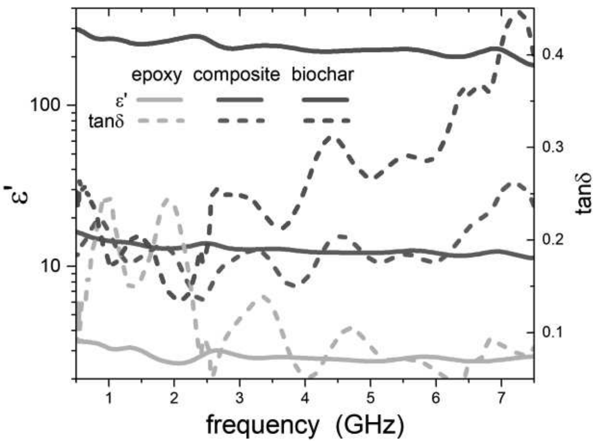

Figure 1: Real part of the permittivity (logarithmic scale, on the left) and loss tangent (linear scale, on the right) for analyzed epoxy, epoxy composite containing 25 wt.% of biochar (measured), and for biochar inclusions alone (calculated with a proper mixing rule).

Figure 2 shows the contribution of absorption, reflection, and multiple reflections to the shielding efficiency SE, for biochar-epoxy shielding layers 10 or 30 mm thick, calculated starting from the experimental data shown in Figure 1.

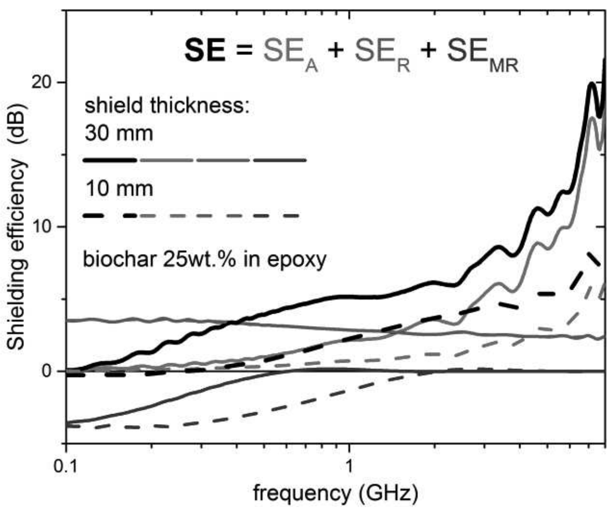

Figure 2: Absorption (A, shown in red), reflection (R, shown in green), and multiple reflections (MR, shown in blue) components of the overall shielding efficiency SE (shown in black), for biochar-epoxy layers of thickness 10 mm and 30 mm. SE was calculated from experimental data shown in Figure 1.

Figure 3a–d show the calculated SE for various materials and biochar composites, of potential interest as building materials [5]: undoubtedly, the increase of both thickness and biochar content significantly enhances the SE of the composites, hence demonstrating the feasibility of the proposed approach for practical applications in building construction sector.

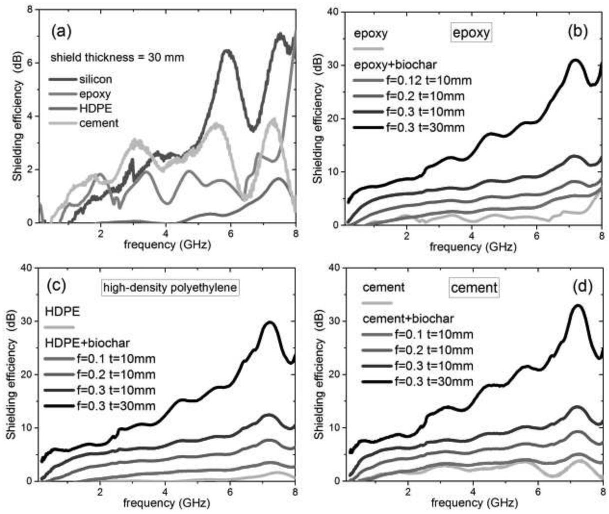

Figure 3: (a) Shielding efficiency of a 30-mm-thick uniform layer of different materials: silicon, epoxy, HDPE, and cement. (b) Shielding efficiency of a 30-mm-thick uniform layer of epoxy (light gray), of 10-mm-thick epoxy-biochar layers, with different biochar volume fractions f (from f = 0.12, red, to f = 0.3, blue), and of a shield with thickness 30 mm and f = 0.3 (black). (c,d): same as (b), but for HDPE and cement.

Conclusions

We investigated the microwave SE of composites, where biochar inclusions are dispersed in materials of interest for building construction. We directly measured raw materials and some biochar composites, obtaining their complex permittivity in the range from 100 MHz to 8 GHz. Then, we extracted the biochar contribution and calculated the properties of other composite combinations by using a suitable permittivity mixing formula. From complex permittivity, finally, we calculated the shielding efficiency, showing that tailoring the content of biochar—a cost-effective and ecofriendly material—and layer thickness allows obtaining a desired value of EM shielding, among those significant for applications.

References

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