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P. Savi and M. Yasir

Composites based on biochar derived from sewage sludge as filler in epoxy resin are fabricated and measured in a waveguide in C-band. Biochar is cheap, readily available and environmentally friendly and thus is a very good contender among other carbon-based materials for use in shielding applications. Biochar provide promising results in term of transmission of less than -10dB for a composite with 20wt.% biochar filler. The dissipation loss, calculated from the scattering parameters show that a significant portion of the losses are due to dissipation.

Introduction: There has been an increasing amount of work performed on electromagnetic interference (EMI) shielding materials due to increased use of electronic and communication equipment in the recent years [1],[2]. A number of novel materials including graphene and carbon nanotubes have been used as fillers to produce highly conductive composites [3]-[8]. The conductivity values need to be considered in combination with a number of other factors including mechanical robustness, ease of fabrication, cost and environmental impact.

Conventional fillers used in composites are metals, which are heavy and expensive. Carbon based fillers like graphene and carbon nanotubes are expensive and involve chemical processing including the use of harsh chemicals and petroleum based materials that are not sustainable [9]. Biochar is a good contender for use as composite filler as it is very cheap and abundantly available unlike most fillers [9]-[11]. One of the most important aspect of using biochar is that it is carbon negative meaning that it seizes the carbon produced and its use over time can result in a positive impact on the environment. This is very useful in this era where carbon emissions are ever increasing. Biochar however, is less conductive as compared to its competitors. It has been demonstrated that the activation of biochar by thermal pyrolysis makes it more conductive and thus suitable for use as filler in composites [11],[12].

There are a number of methods to characterize composites at microwave frequencies for the retrieval of shielding effectiveness (SE) values [13-14]. For accurate analysis of the shielding effectiveness, the two most common methods are measurement of transmitted and reflected signal in an anechoic chamber by the help of antennas and the measurement of the scattering parameters in a waveguide structure. The measurement of transmitted and reflected signal in an anechoic chamber is technologically complicated. The use of a waveguide structure for the measurement of shielding effectiveness is more convenient in terms of technological complexity and cost. However, it requires accurate dimensions of samples to fit in a waveguide.

In this letter, biochar made from sewage sludge is used as a filler to fabricate composites and measurements of the scattering parameters are performed in a rectangular waveguide structure in the C-band. Specific reusable moulds based on silicone are fabricated from a 3D printed master mould. The use of silicone mould ensures easy extraction of the samples. Fabricated composite samples are fit in a designated spacer placed between waveguide ends. The SE values measured are based on the transmitted signal inside the waveguide structure. Composites based on a 20wt.% biochar filler provides a SE value greater than 10 dB.

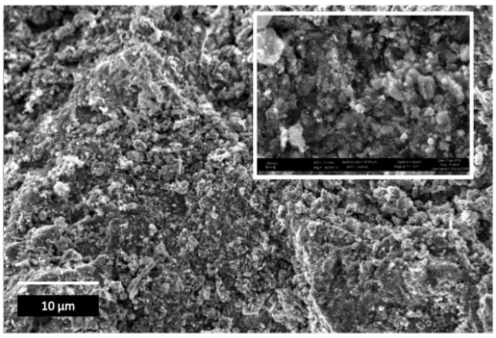

Fig. 1 *FESEM photograph of the Biochar.*

Materials and Methods: The biochar used as a filler in making the composites was derived from sewage. The fabrication of this biochar involves drying and pyrolysis. The pyrolysis is performed in an environment where the gases produced are burnt without flames. Both the drying and pyrolysis methods are performed by Bioforcetech Corporation.

For a morphological characterization of the biochar, Field Emission Scanning Electron Microscope (FESEM) analysis is performed. A photograph of the FESEM analysis is shown in Fig. 1. Agglomerates of less than 5 µm can be seen in the inset of the figure. This aids in easy fabrication of the composites.

A spacer is used for placement of the biochar composites in a rectangular waveguide in order to perform the scattering parameters measurements. For the samples to fit the specified dimensions of the spacer, first a rigid plastic mould is fabricated by 3D printing as shown in Fig. 2, hereby referred to as a master mould. The thickness of the mould is 4 mm. Liquid silicone GLS50 Prochima® is used to fabricated several moulds by using the master mould. Silicone is chosen for the fabrication of the composites for ease of extraction of the composites once they have polymerized. The silicone mould can be utilized for multiple fabrications.

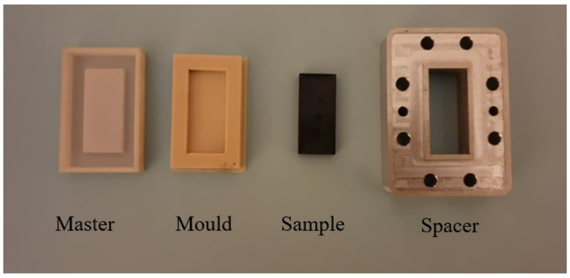

Fig. 2 *Master, mould, sample and spacer used in the waveguide measurements (left to right).*

For the fabrication of biochar composites (see Fig. 3), the biochar is first mixed in epoxy resin by a mechanical mixer. A hardener is subsequently added and further mixing continues. Finally, the mixture is poured in the moulds and left to polymerize. Biochar composites with 10 wt.% and 20 wt.% are fabricated.

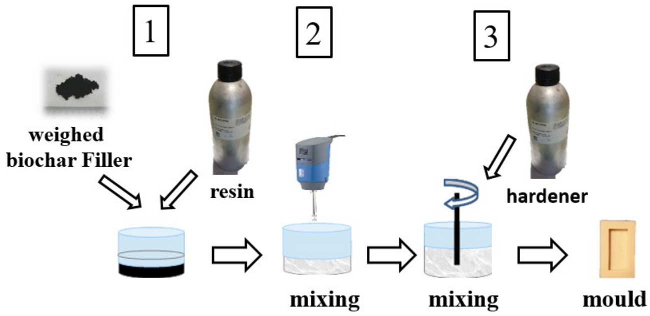

Fig. 3 *Fabrication process flow.*

The measurements of scattering parameters are performed with a vector network analyser (VNA) as shown in Fig. 4. The VNA is connected to standard WR137 waveguides by the help of coaxial to waveguide adapters. A standard calibration procedure is adopted to calibrate the VNA by a waveguide calibration kit. The reference planes for the calibration are at the ends of the waveguide, where the spacer is to be connected. Scattering parameter measurements are first performed with the empty waveguide spacer. Samples of pristine epoxy resin composites are then measured to be used as a reference. Several biochar composites of 10 wt.% and 20 wt.% are subsequently measured. The transmission scattering measurements of empty waveguide, epoxy resin and epoxy resin with biochar filler are shown in Fig. 5. It can be seen that the increase in weight percentage of biochar filler results in a reduced transmission in the waveguide.

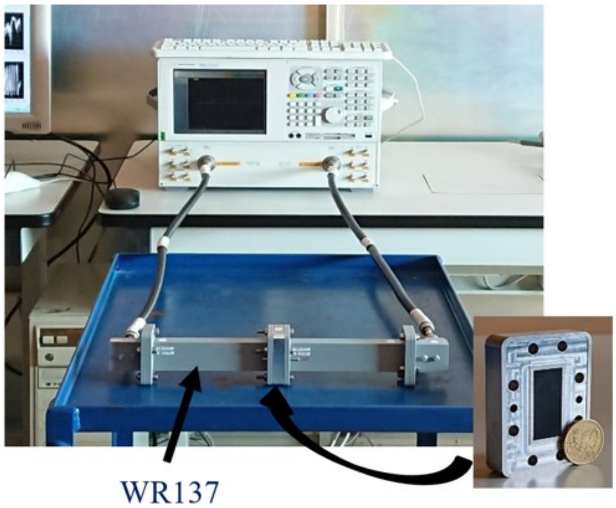

Fig. 4 *Waveguide measurements with VNA. See the waveguide spacer in the inset*

For a 10 wt.% biochar filler, the transmission is almost -7 dB, which reduces to almost -10 dB for 20 wt.% of biochar filler. Lower values of transmission can be achieved by a further increase in the percentage of biochar in the composite or increasing the thickness of the sample, which in this case is 4mm.

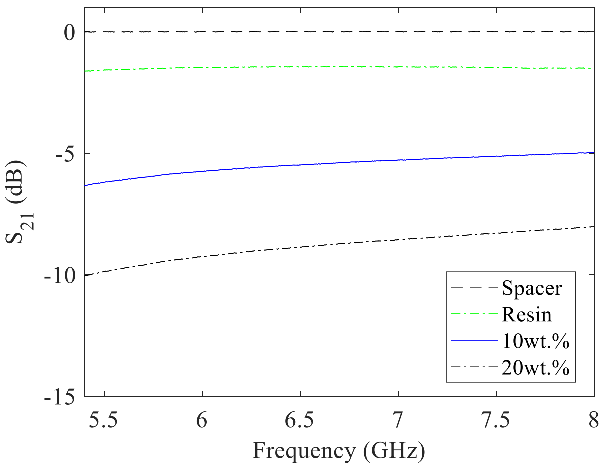

Fig. 5 *Transmission of spacer and composites in the waveguide setup.*

The shielding effectiveness of a material can be attributed to dissipation loss, L_D and mismatch loss, L_M [15],[16]:

$$SE = L_D + L_M \tag{1}$$

where, L_M can be calculated from the reflection scattering parameter, S_{11}, by:

$$L_M = -10\ log_{10}(1 - |S_{11}|^2) \tag{2}$$

The dissipation loss, L_D can be expressed in terms of reflection scattering parameter, S_{11} and transmission scattering parameter, S_{21} as:

$$L_D = -10log_{10}\left(\frac{|S_{21}|^2}{1-|S_{11}|^2}\right) \tag{3}$$

The insertion loss and dissipation loss for the samples with 10 wt. % and 20 wt.% biochar filler are compared in Fig. 6. It can be seen that a significant portion of the shielding effectiveness is dissipative.

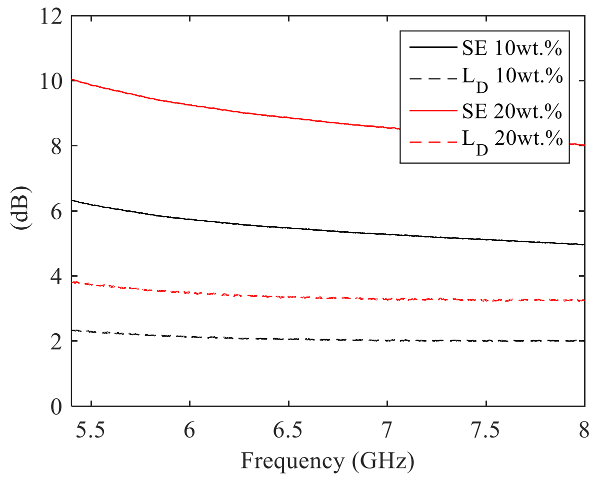

Fig. 6 *Insertion and dissipation loss for the 10 wt.% and 20 wt.% samples.*

Conclusion: The use of biochar as a filler in composites is analysed. Biochar is a carbon negative material that is abundantly available and very cost effective. A convenient method of the fabrication of biochar composites is devised. In order to evaluate the shielding effectiveness of the samples, measurement of scattering parameters in a waveguide are performed. Addition of biochar in composites results in increased transmission loss. A total of -10dB of transmission is achieved with a filler percentage of 20 weight percent. The shielding effectiveness and dissipation are calculated and it is observed that a significant portion of the loss is due to the dissipation loss in the material.

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