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Biochar-iron composites as electromagnetic interference shielding material

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Abstract

Electromagnetic waves emitted by electrical and electronic devices constitute interference with each other, which becomes a problem for security devices, space vehicles, ships, electronics or even human beings. Electromagnetic interference (EMI) protective materials are being developed to eliminate such negative effects of electromagnetic waves. Especially carbon-based ones are becoming increasingly important. The carbonized material biochar, derived from biomass, emerges as a sustainable, renewable, environmentally friendly and inexpensive EMI material. In this study EMI protective effect of biochar derived from industrial tea waste biomass and its iron composite was investigated. The effect values of the samples were found to be greater than 10 dB.

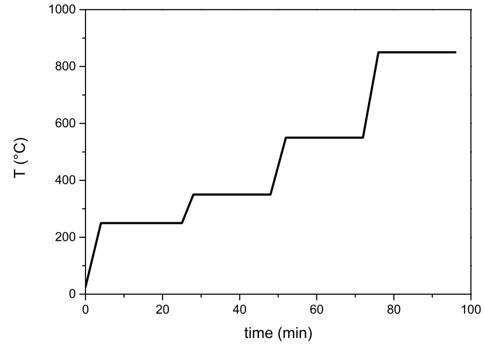
1. Introduction

Electromagnetic wave is the sum of the fields of electric and magnetic fields of electricity that are at the right angles to each other at the same frequency. These fields result of the potential and movement of electrons, have a radiative energy and a momentum. The waves or fields are called as 'Electromagnetic Field (EMF)'. Electromagnetic waves emitted by electrical and electronic devices create interference with each other, called as 'Electromagnetic Interference (EMI)'. EMI occurs via the emission of EMF by various sources such as base stations, mobile telephones, electrical appliances, wireless communication devices etc. The interference of waves causes such problems as malfunctioning of electronic devices or other electronic systems by blurring the signals and results the shortening the life of electronic devices [1–3]. Furthermore, the electromagnetic pollution threatens the human health that headache, nervousness, insomnia, drowsiness may be seen in those exposed to EMI [4].

The extent of EMI damages varies depending on the power and frequency of the radiation energy. Since the energy of radiation emitted from nuclear sources is very high, it can cause enormous damage in a short time. Here, the interference of low energy waves such as radio waves emitted by electronic devices should be considered. Although, the energy of radio waves is very low, the folded energy generated by the interference of these low frequency waves is much more effective than the effect of a single low frequency wave. In order to eliminate this pollution, electromagnetic interference filtering or shielding (EMI-S) applications should be realized [3].

EMI-S is performed by blockage of electromagnetic radiation by reflection or absorption. The shielding effectiveness (SE) of materials is expressed in units of 'decibel'(dB). Many different materials are used for EMI-S such as; silver, gold, copper; bronze, high magnetic permeable iron and nickel alloys, ferromagnetic alloys and coatings, polymers, cement, composites and carbon materials [3, 5]. The common feature of the materials used is that they are electrically conductive and act as a Faraday cage to reflect electromagnetic waves and show magnetic features in the absorption mechanism.

The low corrosion resistance of metals and composites makes them difficult to use as EMI-S materials. On the other hand, carbon materials such as carbon fibers, carbon nanotubes or graphene have been being



(a) Heating program

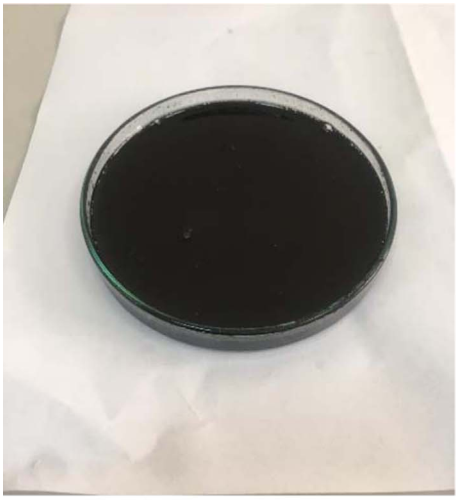
(b) Tea waste sample in a glass flask (14 cm diameter)

(c) BC-Fe sample on a A4 paper (around 6 cm length)

Figure 1. Pyrolysis heating program (a), tea waste (b) and BC-Fe sample (c).

remarkable materials due to their thermal stability, oxidation resistance and cheapness [3, 6]. Aal *et al* [7] have shown that the graphene paper as a carbon material can be a good microwave protector for industrial or military use. Cao *et al* [8] reported that EMI-S properties of composites of graphene and metal oxides are effective over a wide band ranges. Ou *et al* [9] realized that the SE value of GaInSn doped carbon nanotube films increased in the X-band range (8.2–12.4 GHz) with a reflection mechanism from 20 dB to 55 dB. Moreover, composites of carbon and iron are investigated as effective materials for EMI protection. Especially, Fe-oxide-carbon composites have been reported to be effective in the absorption mechanism [10–12]. These composites also reduce the reflection.

Recently, carbonizing material 'biochar', which is produced by pyrolysis of biomass in inert environment, has been investigated as a novel EMI-S carbon material. Farhan *et al* [13] showed that biochar, produced from plane tree seeds, having porous structure, rich in surface functional groups and composed with iron, is an effective EMI-S material in the X-band range.



(a) Wet manner of BC-Fe-PMMA composite

(b) Dry manner of BC-Fe-PMMA composite

Figure 2. Wet (a) and dry (b) manners of BC-Fe-PMMA composite.

In this work, EMI-S properties of composite of iron oxide and biochar derived from industrial tea wastes were investigated. Tea waste biomass can be evaluated as a sustainable, renewable, environmentally and cheap carbon resource in EMI protection issues.

2. Experimental

The EMI-S material was developed in two stages; (1) production of Fe-biochar composite (BC-Fe) from industrial tea waste biomass by pyrolysis and (2) encapsulation of BC-Fe into polymethyl methacrylate (PMMA) polymer.

Industrial tea waste collected from a local tea factory was milled and sieved through a 500 μm sieve (figure 1(b)). The sample was dried in an oven at 80 °C for 24 h and impregnated with $FeCl_3$ with the ratio of 3:1 (w/w) as biomass:iron, respectively. At first step of impregnation, $FeCl_3$ was solved homogenously with a proper amount water (saturated solution). This solution was impregnated into the biochar drop by drop and then mixed well for 30 min. The wet sample was dried once again.

The impregnated sample was pyrolyzed in a rotary oven (Protherm RTR 11/100/500) at nitrogen atmosphere to 850 °C for 20 min. The heating program and samples are shown in figure 1(a). The torrefaction was realized at first 50 min that volatile materials were removed until 350 °C with slower heating rate. The heating rate was increased after 350 °C and pyrolysis started effectively [14].

Figure 3. EMI analyzing experimental setup.

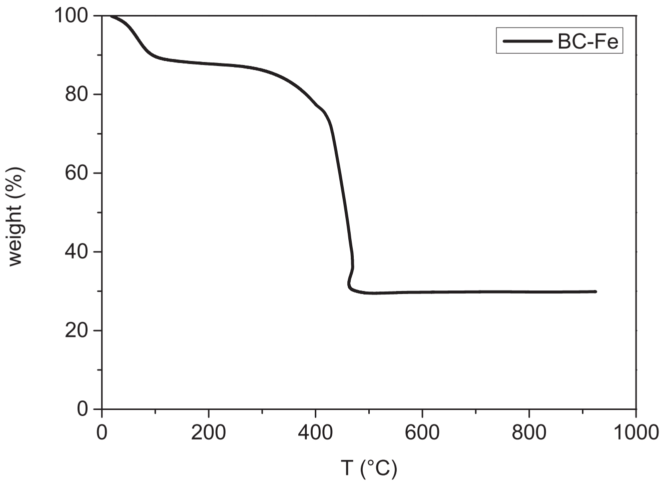


Figure 4. TGA analysis of BC-Fe.

Characterizations of the BC-Fe were performed by thermogravimetric analyzer (Shimadzu, TGA 50) and scanning electron microscopy (Jeol JSM-6610 SEM).

The derived BC-Fe (figure 1(c)) sample was encapsulated into PMMA. For this purpose, 0.27 M solutions of PMMA (TCI M0088) were prepared in toluene solvent. After crushing the BC-Fe in a mortar, 5, 10, 20, 30 and 40% (w/w) mixtures were prepared with PMMA solution. The mixture was transferred into the 9 cm diameter glass petri dishes to allow the solvent evaporate at room temperature (figure 2(a)). The thicknesses of the obtained films (figure 2(b)) are in the range of 0.5–0.9 mm. The samples were nomenclature as BC-Fe-PMMA-5, BC-Fe-PMMA-10, BC-Fe-PMMA-20, BC-Fe-PMMA-30 and BC-Fe-PMMA-40.

SE measurements were carried out with Anritsu MS4644A model Vector Network Analyzer between 7.5–15 GHz measurement range and the probe's open area is 2.34 cm^2 (2.29 $\times$ 1.02 cm) (figure 3). The samples were placed on a metal sheet, 20 dB signals were sent and the reflected signals were detected. The wave coming out of the measuring probe passes through the material, reflects from the metal and again passes through the material then reaches the probe. The ratio between the given power and the received power is determined graphically on the decibell scale (figure 7).

3. Results and discussion

The thermogravimmetric analysis at air atmosphere of BC-Fe is shown in figure 4. The humidity or further volatiles starts to remove at the first stage until ~100 °C and sample stays stable til around 500 °C. The mineral content of the BC including iron was determined around 30% which confirms the impregnation ratio. The

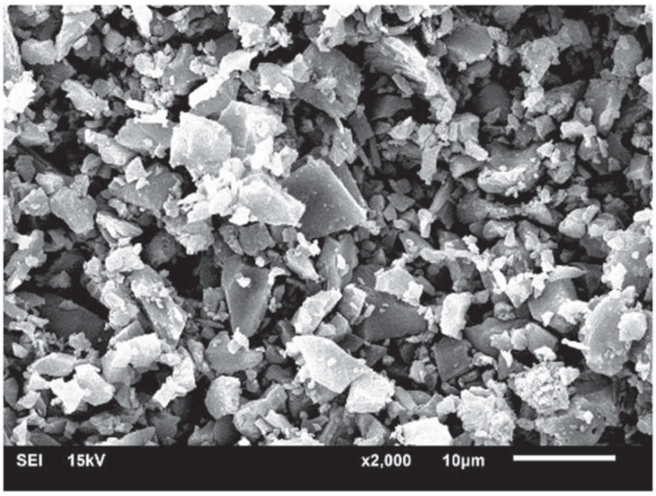


Figure 5. SEM picture of BC-Fe.

(a) BC-Fe's response to the magnet in line direction on a A4 paper

(b) BC-Fe's response to the magnet in circular direction on a A4 paper

Figure 6. BC-Fe's response to the magnet (1 cm diameter) in line (a) and circular (b) directions.

material particles are in μm size (figure 5). Further characterizations for similar materials can be found elsewhere [15].

The $FeCl_3$ in the impregnated biomass turns into the its oxide form of Fe_2O_3 and Fe_3O_4 during the pyrolysis at the high temperature of 850 °C by taking out the oxygen from the biomass. Iron helps both the ordering-graphitization of the amorphous carbon structure of biomass and stabilizes on the biochar surface [15]. The formed iron oxides show magnetic dipole properties as shown in figure 6.

Electromagnetic wave absorber materials are generally used to prevent the reflection of the electromagnetic waves coming to a surface. The reflection magnitudes of the samples were determined given in figure 7. The significant magnitudes are given in table 1.

The reflectivity of the materials is around −10 dB at certain frequencies, but slightly above −10 dB. The reflection is diminishing around 60% when the BC-Fe amount arises to 40% (figure 8).

The contribution of carbon material to EMI shielding effectiveness was reported Dang *et al* [16]. The carbon fiber intensified the shielding effectiveness of polyacrylamide/wood fiber composite from 0.41 to 41 dB in the X-band frequency range (8–12 GHz).

There are very limited works on the EMI shielding properties of biochar obtained from biomass. Tolvanen *et al* [17] determined the shielding effectiveness of poly(lactic acid)/biochar/graphite three phase composites beyond 30 dB at K-band frequency range (18–26.5 GHz). It is reported that biochar obtained from pine as a hybrid filler in the composite improved the shielding effectiveness due to the increased number of wave

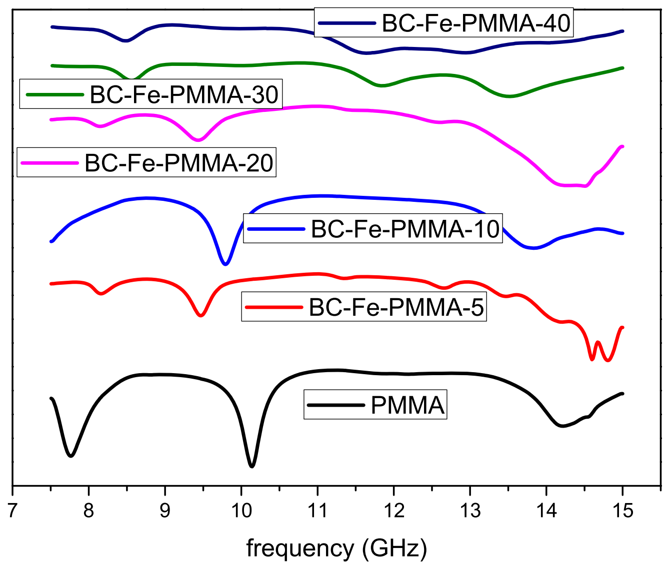


Figure 7. Reflection results of the samples.

Table 1. Reflection peaks of the samples.

Sample	Reflection max (-dB)	Frequency (GHz)
PMMA	9.4	7.8
	10.5	10.1
	6.3	14.2
BC-Fe-PMMA-5	2.0	8.2
	4.4	9.5
	2.4	13.5
	9.0	14.6
	9.1	14.8
BC-Fe-PMMA-10	7.7	9.8
	6.0	13.8
BC-Fe-PMMA-20	2.5	8.1
	4.1	9.4
	2.1	12.6
	8.8	14.3
	8.8	14.5
BC-Fe-PMMA-30	2.3	8.5
	2.9	11.8
	4.1	13.5
BC-Fe-PMMA-40	2.4	8.5
	3.7	11.6
	3.2	12.3
	3.6	12.9

scattering centers. Biochar is also an advantageous material in controlling the conductivity of composites. Li *et al* [18] presented that bamboo biochar as an ingredient in polyethylene composite provides high EMI-SE of 48.7 dB at 1500 MHz with its improved crystalline structure and electrical conductivity. Despite the biochar derived from tea waste in this study does not a well conductivity or developed carbon structure like nanofibers or graphene, the EMI-SE values are comparable with literature [17, 18].

4. Conclusions

EMI is important for military or other security applications, industrial and commercial applications, aerospace, consumer electronics, automobile manufacturing and other manufacturing industries. Shielding materials can be developed from sustainable, renewable, environmental friendly and cheap carbon resources such as biochar derived from tea waste. In this work, EMI shielding material derived by converting industrial tea waste biomass

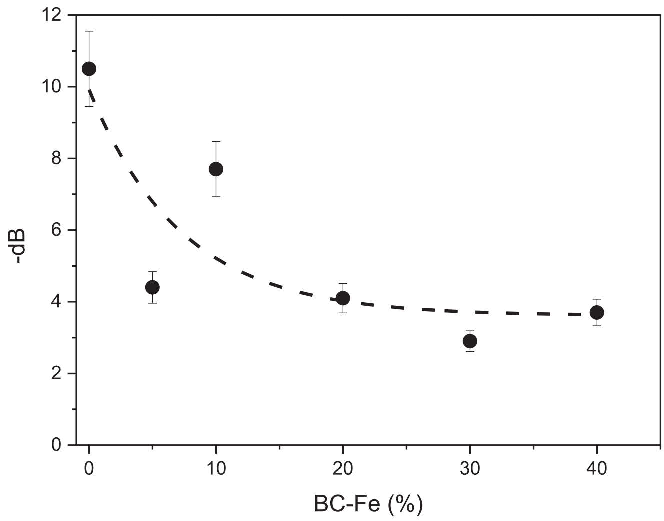


Figure 8. Reflection of the samples in the range of 0 to 40% and at around 10 GHz with 10% errors.

into biochar and prepared as iron composite and the effect values were found to be greater than 10 dB. Industrial tea waste biomass can be evaluated as a sustainable, renewable, alternative, green and cheap EMI protection material.

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