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Effect of Biomass Waste Filler on the Dielectric Properties of Polymer Composites

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Abstract

The effect of biomass waste fillers, namely coconut shell (CS) and sugarcane bagasse (SCB) on the dielectric properties of polymer composite was investigated. The aim of this study is to investigate the potential of CS and SCB to be used as conductive filler (natural source of carbon) in the polymer composite. The purpose of the conductive filler is to increase the dielectric properties of the polymer composite. The carbon composition the CS and SCB was determine through carbon, hydrogen, nitrogen and sulphur (CHNS) elemental analysis whereas the structural morphology of CS and SCB particles was examined by using scanning electron microscope (SEM). Room temperature open-ended coaxial line method was used to determine the dielectric constant and dielectric loss factor over broad band frequency range of 200 MHz-20 GHz. Based on this study, the results found that CS and SCB contain 48% and 44% of carbon, which is potentially useful to be used as conductive elements in the polymer composite. From SEM morphology, presence of irregular shape particles (size ≈ 200 μm) and macroporous structure (size ≈ 2.5 μm) were detected on CS and SCB. For dielectric properties measurement, it was measured that the average dielectric constant (ε') is 3.062 and 3.007 whereas the average dielectric loss factor (ε'') is 0.282 and 0.273 respectively for CS/polymer and SCB/polymer composites. The presence of the biomass waste fillers have improved the dielectric properties of the polymer based composite ($\varepsilon' = 2.920$, $\varepsilon'' = 0.231$). However, the increased in the dielectric properties is not highly significant, i.e. up to 4.86 % increase in ε' and 20% increase in ε''. The biomass waste filler reinforced polymer composites show typical dielectric relaxation characteristic at frequency of 10 GHz - 20 GHz and could be used as conducting polymer composite for suppressing EMI at high frequency range.

Keywords: coconut shell (CS); sugarcane bagasse (SCB); polymer; dielectric properties

1. Introduction

Abandoned agricultural biomass waste or simply biomass waste produced from daily human activities is not a new issue. Improper biomass waste management and lack of awareness has caused pollution due to illegal open burning and emission of harmful gases (methane) as well as the waste leachate produced from the rotten or biodegradation of the biomass waste. In Malaysia, improper disposal of agricultural biomass waste such as coconut shell and sugarcane bagasse from human activities can be easily found. Fig. 1 shows the snapshot of the agricultural biomass waste produced by human activities. These biomass wastes can be diverted into commercially-viable recovered materials and energy recovery instead of disposal. Utilization of agricultural biomass waste not only helps to reduce environmental pollution, this would also reduce the costs for waste disposal and would generate the revenue from the sale of the recovered materials and energy (Rahman *et al.,* 2013).

In recent years, researchers have actively focused on using biomass waste such as the coconut shell and sugarcane bagasse as reinforcing fillers in the polymer (thermoset or thermoplastic) composites. Polymers are well established lightweight materials used over variety of applications. However, these works tend to focus on the mechanical properties and thermal properties of the composites (Luz *et al.,* 2007; Ramaraj, 2007; Onésippe *et al.,* 2010; Khorami and Ganjian, 2011; Sarki *et al.,* 2011; Sareena *et al.,* 2012; Jang *et al.,* 2012; Kumar and Boopathy, 2014; Adeosun *et al.,* 2016) while few have reported over the dielectric properties (Lai *et al.,* 2005; Mishra and Aireddy, 2011; Aal *et al.,* 2011; Dhal and Mishra, 2012; Jayamani *et al.,* 2014).

In this study, an attempt has been made to investigate the effect of coconut shell and sugarcane bagasse fillers on the dielectric properties of the polymer composites over broad band frequency range of 200 MHz - 20 GHz. The coconut shell (CS) and sugarcane bagasse (SCB) were used as the conductive filler to enhance the dielectric properties of the polymer composites. The fabricated conducting polymer composites are an alternative for dielectric loss materials used in the absorption of electromagnetic interference (EMI) application over GHz range. This is the continuous improvement work reported elsewhere (Yew *et al.,* 2016a).

(a)

(b)

Figure 1. Snapshot of agricultural biomass waste ((a) coconut shell and (b) sugarcane bagasse) produced by human activities that can be easily found around Gong Badak, Kuala Nerus, Terengganu, Malaysia.

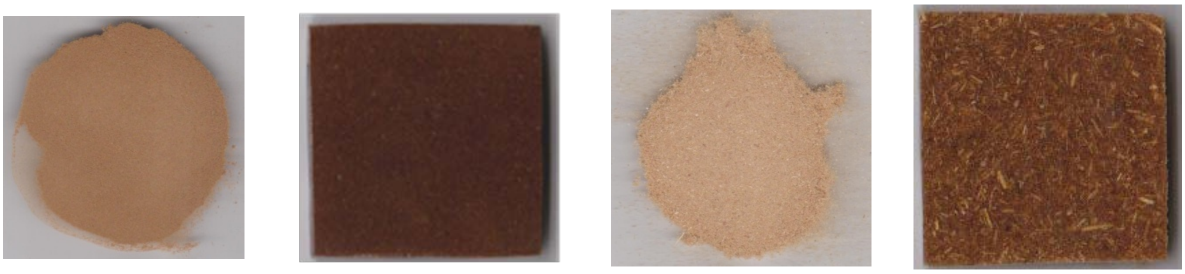
2. Materials and Methods

2.1 Composite preparation

Raw coconut shell and sugarcane bagasse were collected, cleaned, dried, grinded and sieved. Epoxy resin with amine hardener was used as the matrix and the composites were cured at room temperature. Fig. 2 shows the untreated CS (Fig. 2(a)) and SCB (Fig. 2(c)) in powder form. In order to insure a good dispersion of the CS and SCB powders and to provide homogeneous mixtures, the mixture were mechanically stirred using IKA RW20 Digital Stirrer for few minutes at room temperature. The mixtures were then fabricated in planar shape mould with dimension of 30 mm x 30 mm x 5 mm. The mixture was allowed to be completely cured at room temperature. Fig. 2 (b) and 2 (d) show the fabricated composites.

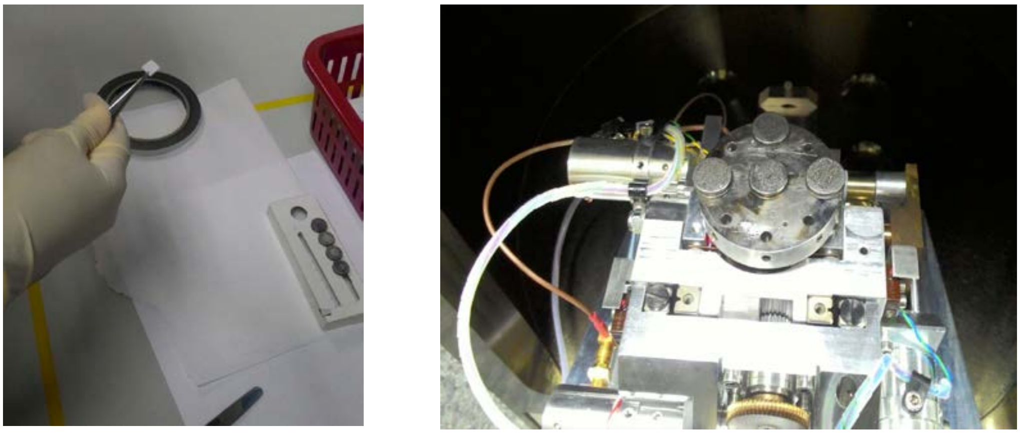
2.2 Elemental and structural characterization

The elemental analysis of CS and SCB was determined using Vario MICRO cube carbon, hydrogen, nitrogen and sulphur (CHNS) elemental analyser. The analysation was carried temperature at 23±3°C and relative humidity of 50±5% room condition. ZEISS Supra55 scanning electron microscope (SEM) was used to determine the structural morphology of CS and SCB powders. Powder specimens for SEM analysis were prepared by gently sprinkle and lightly pressed the CS and SCB powders on the carbon conductive adhesive tape that was mounted on a sample holder (cylindrical stubs). In order to ensure uniform conductivity and to prevent charge-up, the excessive powder on the carbon conductive adhesive tape was removed by using a hand blower. Then, the powder specimens were metallized with a thin layer of conductive platinum coating by using BAL-TEC SCD 005 Cool Sputter Coater. The coated powder specimens were placed into the scanning electron microscope and viewed at magnification of 50 X to 1.0 kX with acceleration voltage of 8kV (Refer Fig. 3).



(a) (b) (c) (d)

Figure 2. (a) CS filler, (b) CS reinforced polymer bio-composite, (c) SCB filler and (d) SCB reinforced polymer bio-composite



(a) (b)

Figure 3. (a) Powder specimens preparation using double coated carbon conductive adhesive tape and cylindrical stubs and (b) Placement of coated powder specimens in the scanning electron microscope

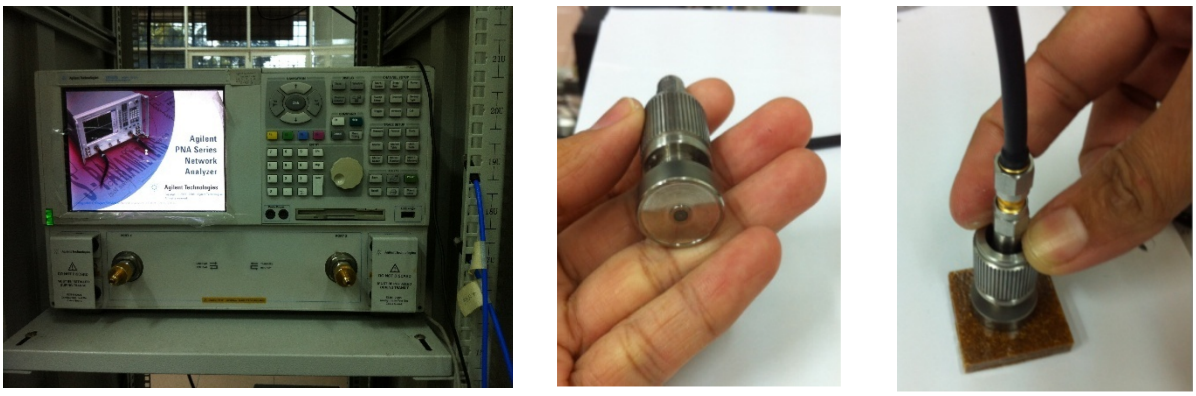
2.3 *Dielectric properties*

The dielectric properties of the fabricated composites were measured by using open-ended coaxial line method over broad band frequency range (200 MHz-20 GHz) at room temperature. The measurement apparatus include high temperature dielectric probe and Agilent 85070E measurement software, Agilent E8362B PNA series network analyser and coaxial cables. The high temperature dielectric probe transmits a signal into the material under test (MUT) and the dielectric properties of the MUT were measured based on the reflected signal. For solid MUT such as composite, the air gaps that exist between the surface of the composite and the dielectric probe can be a significant factor that influenced the measurement accuracy of the dielectric properties. It is crucial to ensure that the surface texture of the composite is flat in order to minimise the leakage of reflected signal though the air gaps that are formed from the uneven MUT's surface texture. Measurement is made by simply contacting the dielectric probe to the flat surface of the MUT. Fig. 4 shows the apparatus and dielectric properties measurement on the fabricated composite by using high temperature dielectric probe. Similar measuring method had been reported elsewhere (Wee *et al.,* 2011; Yew *et al.,* 2016a; 2016b).

3. Results and Discussion

3.1 *Elemental and structural characterisation*

From CHNS elemental analysis, it was found that the carbon composition (C %) was 46.700% and 44.690% for CS and SCB, respectively (Yew *et al.,* 2016b). This indicates that CS and SCB fillers are potentially useful to be used as conductive fillers in the dielectric loss material (Refer to Table 1). Fig. 5 shows the SEM morphologies of the CS and SCB. The presence of irregular particle shape with size approximately 200 μm and macroporous structure with porosity of approximately 2.5 μm was detected in both CS and SCB particles at 1kX magnification. The particles with irregular shape and minimized pores size have a relatively large surface area, which makes the particles possess larger conduction losses and affect the dielectric and microwave absorption properties (Liu *et al.,* 2011; Horikoshi and Serpone, 2015).



(a) (b) (c)

Figure 4. (a) Agilent E8362B PNA series network analyser, (b) High temperature dielectric probe and (c) Dielectric properties measurement

Table 1. Elemental analysis of the biomass waste filler

Filler	Elemental analysis (wt %)				
	Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen (by difference)
Coconut Shell (CS)	46.700	3.174	0.171	1.036	48.919
Sugarcane bagasse (SCB)	43.690	6.355	1.830	0.448	47.677

3.2 Dielectric properties measurement

For comparison purpose, the dielectric properties of the biomass waste filler reinforced polymer composites are compared to the pure polymer composite. The dielectric properties of the composite are presented in complex permittivity ($\varepsilon = \varepsilon' + j\varepsilon''$). The real part of permittivity (ε') represents the dielectric constant, i.e. the storage capability of electric energy. The imaginary part of the permittivity (ε'') represents the dielectric loss factor, i.e. the loss conversion capability of electric energy to heat (Kumar *et al.,* 2014). Table 2 presents the average dielectric properties over frequency range 200 MHz-20 GHz.

The graph of ε' and ε'' versus frequency is shown in Fig. 6. ε' of the composites decreased with the increase of frequency for the entire range of frequency whereas ε'' increase with increasing frequency from 200 MHz up to 9 GHz but shows decreasing trend from 10 GHz to 20 GHz. This indicates that the prepared composites show typical dielectric relaxation characteristic starting from 10 GHz - 20 GHz (Cao *et al.,* 2009). The prepared composites could be used as conducting polymer composites for EMI absorption applications for higher frequency range (i.e. > 10 GHz), such as application over Ku-band for satellite communication.

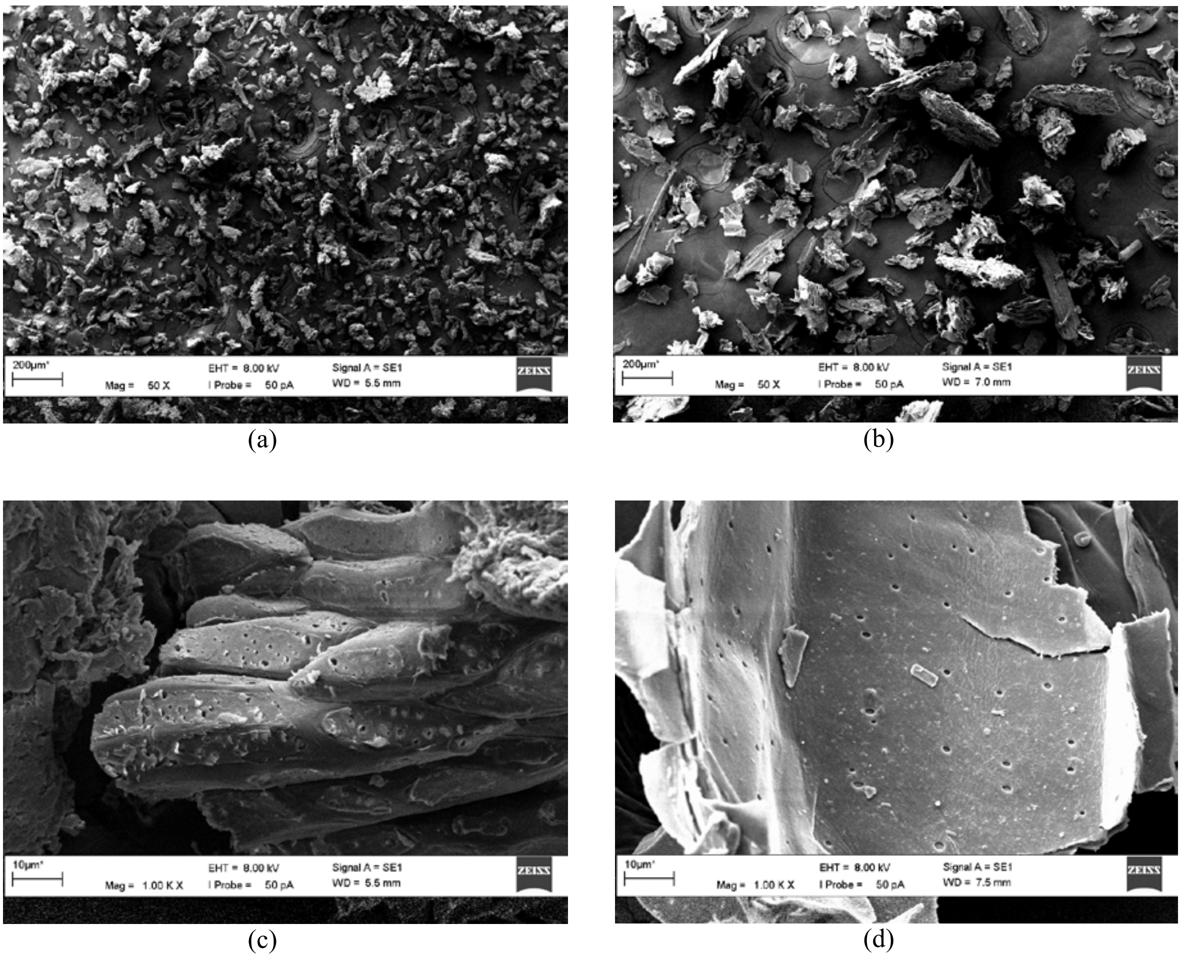


Figure 5. SEM images of (a) CS particles, (b) SCB particles, (c) CS particle porosity and (d) SCB particle porosity

Table 2. Average dielectric properties over frequency range 200 MHz-20 GHz

Composite	Real part of permittivity, *ε'*	Imaginary part of permittivity, *ε"*
Pure polymer	2.920	0.231
CS reinforced polymer	3.062	0.282
SCB reinforced polymer	3.007	0.273

Based on the measured dielectric properties, the biomass waste filler reinforced polymer composites show up to 4.86% increase in *ε'* and 22 % increase in *ε"* compared to the pure polymer composite at room temperature. It was found that the *ε'* of the CS reinforced polymer and SCB reinforced polymer composites have increased to 3.062 and 3.007, whereas *ε"* has increased to 0.282 and 0.273, respectively. The dielectric properties of the CS reinforced polymer composite were higher compared to SCB reinforced polymer composite. This is due to the higher carbon composition in the CS filler.

However, the increase in the dielectric properties of the biomass waste filler reinforced polymer composites compared to the pure polymer composite is not highly significant. One of the factors affecting the dielectric properties of the biomass waste filler reinforced polymer composites could be due to the molecular structure of the fillers dispersed in the matrix. As a material dielectric properties is determined by its physical molecular structure, any changes in the molecular structure will affect the dielectric properties. When talking about natural, it is not so much we can have maximum control on it. The same thing happens to the biomass waste fillers or fibres such as coconut shell and sugarcane bagasse. It is true that based on the literature reviews, the natural fibre reinforced polymer composites exhibits good mechanical properties, however the values were varied. The mechanical properties of the natural fibre with the same species may varies and strongly influenced by a few factors, such as climate change, the way it has been planted, the soil, the origin (where it comes from) and etc. These huge ranges of varieties are really not a solid result for scientific purposes and may have a lot of argumentations about it. Natural fibres are material that has complex and uneven components. Cellulose, hemicellulose, and lignin comprise the main composition of natural fibre (Chen, 2014). Non-cellulose constituents such as lignin and hemicelluloses are the main factors influencing the variety of physical properties inherited by the natural fibre.

4. Conclusions

An investigation to explore the effect of biomass waste filler on the dielectric properties of polymer composite was performed. The biomass waste fillers were used as the natural based conductive filler to improve the dielectric properties of polymer composite. Comparison was made with the pure polymer composite. Based from the study, it can be concluded that the biomass waste filler reinforced polymer composites show increased in dielectric properties. This indicates that the biomass waste filler has the potential to be used as alternative conductive filler for polymer based composite even though the increase in dielectric properties is not highly significant. In future, considerations should be made on the molecular structure of the biomass waste filler by removing all unwanted non-cellulose constituents such as lignin and hemi-cellulose from the natural fibres through the combination of physical and chemical treatments. The effect of the treated fibres on the dielectric properties of the biomass waste filler reinforced polymer composites will be investigated.

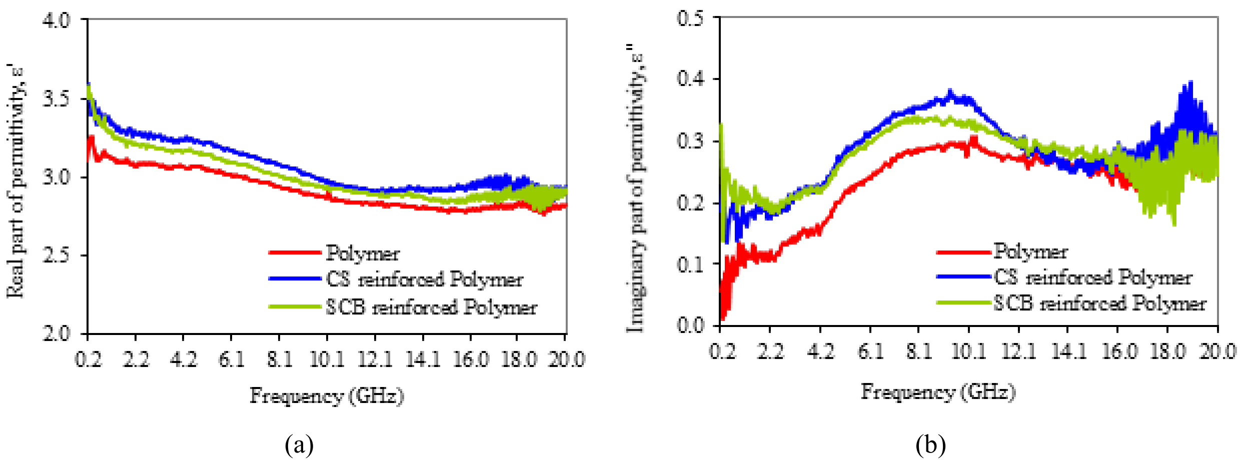


Figure 6. Complex permittivity in the function of frequency range 200 MHz-20 GHz (a) Frequency dependent of real part, *ε'*, of complex permittivity and (b) Frequency dependent of imaginary part, *ε"*, of complex permittivity

Acknowledgements

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