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Coconut shell, coconut shell activated carbon and beta-silicon carbide reinforced polymer composite: An alternative dielectric material for wireless communication application

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ABSTRACT

The effect of coconut shell (CS), coconut shell activated carbon (CSAC) and beta-silicon carbide (β-SiC) in polymer composites was investigated. Elemental composition, surface morphologies and structural analyses of the fillers were performed using carbon, hydrogen, nitrogen and sulfur (CHNS) analyser, scanning electron microscope (SEM) and X-ray Diffractometer (XRD). The dielectric properties of the composites were measured using open-ended coaxial line method. CS and CSAC fillers had positive influence on the dielectric properties (ε', ε" and σ) of the polymer composites, contributed by the orientation polarizations arises from polar nature of the amorphous CS and CSAC fillers. β-SiC filler had insignificant influence on the dielectric properties of the polymer composites due to its single polarization of the crystalline structure filler. This finding is in agreement with XRD patterns of CS and CSAC fillers that revealed the presence of amorphous structure with broad diffraction peaks that were detected at 2Θ=22.236°, 34.8604° and 2Θ=23.985° and 44.015°, respectively. The amorphization structure in the polymer composites allows the displacement and conduction currents that were induced from electric field to flow through the polymer composites when subjected to electromagnetic energy, thus increased the dielectric properties of the composites.

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1. INTRODUCTION

Dielectric materials that were made from lightweight polymers are widely used over wireless communication applications as electromagnetic interference (EMI) suppression material. EMI is unwanted microwave energy that propagates through electronic device that is caused by another electronic device induced by electromagnetic field. It is crucial to reduce or eliminate EMI in wireless communication systems, especially in military and stealth technology, as it can interfere with the sensitivity of the wireless receiver. The properties of dielectric materials are represented dielectric constant (ε'), dielectric loss factor (ε"), and the electrical conductivity (σ). ε' presents the ability of the dielectric material to absorb and store the electromagnetic (EM) energy whereas ε" presents the ability of the material to dissipate the stored EM energy to heat whereas σ is a measure of how well the heat is dissipated from the dielectric material [1].

The dielectric properties of a material are greatly influenced by the interfacial polarization of the molecules within the material. Polymer molecules are poor dielectric material due to its non-polar nature. Therefore, the polymer is normally incorporated with different type of fillers to improve the dielectric properties as well as to improve the thermal stability and strength of the polymer [2-5]. Synthetic filler such as ceramic is normally used due its good thermal stability and strength but its single polarization nature limits the dielectric properties of the polymer composites [6-8]. To improve the dielectric properties of the polymer, carbon conductive filler is used to induce orientation polarization by incorporating polar molecules in the non-polar nature polymer [9-12]. The addition of different type of fillers leads to multiple interfacial polarizability, thus improved the dielectric properties of the polymer.

The conductive filler which is mainly obtained from the natural fiber has become a great interest of study in order to explore newer types of constituent used in conducting polymer [13]. Lignocellulosic natural fiber contains highly polar hydroxyl (OH) groups that contributes to the orientation or dipole polarization which greatly influence the dielectric behavior of the conducting polymer. In addition, the usage of the natural fiber will greatly reduce the dominant dependency on conventional conducting polymer as well as replacing the synthetic conductive filler as they possess various advantages such as low cost, low density, comparable mechanical strength and environmental friendly.

In this work, an attempt had been made by using the two different types of conductive fillers, namely coconut shell (CS) and coconut shell activated carbon (CSAC) with beta-silicon carbide (β-SiC) prepared in epoxy resin to form dielectric based polymer composites. CS and CSAC were used to boost the dielectric properties of the polymer and whereas β-SiC nanoparticle was used to improve the physical bonding or physical adhesion between the fillers and polymeric matrix. This work investigates the physical characterization and dielectric properties of the polymer composites with the insertion of CS, CSAC and β-SiC fillers. This is the continuous improvement work reported elsewhere [14, 15].

2. RESEARCH METHOD

2.1. Raw material preparation

Raw coconut shells were collected, cleaned from the coir and dried under sunshades before pulverised into fine powder by using Disk Mill and sieved using 75μm test sieve. Commercially available coconut shell activated carbon was purchased from Tan Meng Keong Sdn. Bhd, Perak Malaysia with mesh size 200. Commercially available β-SiC (99+% pure, 45-65nm, cubic) were purchased from US Research Nanomaterials, Inc., USA. Thermoset Epocast PT100 based epoxy resin and Epoharden PT100S amine based epoxy hardener, were supplied by Portal Trading, Penang, Malaysia. It took 1~2 hours under room temperature 30~35°C for curing.

2.2. Composite preparation

The Composite preparation was conducted at room temperature according to the composition indicated in Table 1. The ratio of the fillers to matrix for all the composition is set to ratio of 1:1 whereas the ratio of the epoxy resin to epoxy hardener is set to ratio 2:1. The composites mixture was fabricated with dimension of length (40 mm) x width (40mm) x thickness (5mm) and were cured at room temperature until completely harden.

Table 1. Composition weight percentage (wt%)

Composite	Filler (wt%)		
	β-SiC	CS	CSAC
β-SiC Polymer	100	0	0
CS Polymer	0	100	0
CSAC Polymer	0	0	100
CS/ β-SiC Polymer	50	50	0
CSAC/β-SiC Polymer	50	0	50

2.3. Elemental composition analysis

The elemental composition analysis of the CS and CSAC fillers were examined using Vario MICRO cube carbon, hydrogen, nitrogen and sulphur analyser at room temperature (23 °C) with relative humidity 50 ±5%.

2.4. Scanning electron microscopy (SEM) analysis

The morphologies of the CS, CSAC, and β-SiC fillers were examined using ZEISS Supra55 scanning electron microscope (SEM). Pior to the SEM examination, the sample under test were mounted on the SEM stub and sputter coated with a layer of platinum to avoid electrostatic charges.

2.5. X-ray diffraction (XRD) analysis

The crystallographic structure of the fillers and composites was examined by using Rigaku, Miniflex II Benchtop X-ray Diffractometer.

2.6. Dielectric properties

Open-ended coaxial probe method using high temperature dielectric probe, Agilent E8362B PNA series network analyzer and Agilent 85070E measurement software was used to determine the dielectric properties of the prepared composites over broadband frequency from 200MHz-20 GHz.

3. RESULTS AND ANALYSIS

3.1. Elemental composition analysis

The purpose of performing the elemental compostion analaysis on CS and CSAC fillers was to examine the composition of the carbon (C) in both of the fillers. Carbon is responsible to suppress the unwanted microwave energy or EMI. This is because carbon is a conductive element that is easily heated by microwave energy, thus it has excellent tendency to convert and dissipate the unwanted microwave energy that propagates through it into heat [16-17]. Table 2 shows the elemental composition of CS and CSAC particle. It was found that the carbon element in CSAC is significant higher compared to CS, 47% and 84%, respectively, indicating that the CSAC particle is more conductive compared to CS particle, thus having higher tendency in terms dissipating the unwanted microwave energy via heat loss, as evidenced by the dielectric loss factor and electrical conductivity results in section 3.4 [18].

Table 2. Elemental composition

Filler	Element			
	Carbon (C%)	Hydrogen (H%)	Nitrogen(N%)	Sulfur(S%)
Coconut shell (CS)	47	3.2	0.2	1.0
Coconut shell activated carbon (CSAC)	84	1.3	0.9	0.2

3.2. Filler morphologies analysis

Figure 1 shows the SEM morphology of CS, CSAC and β-SiC fillers at 5KX magnifications. It was noticed that the presence of irregular size and macroporous structure was detected in both CS and CSAC fillers. The irregular sized CS and CSAC fillers, which were considered to be large particle sizes, might leads to aggregation of filler particles and field distortion in the polymeric matrix that might resulted in breakdown field strength. Therefore, for this purpose, β-SiC nanoparticles were incorporated to increase the filler-polymer interfacial area and reduces breakdown that affect the dielectric behavior of the conducting polymer composites [19-21].

3.3. X-ray diffraction (XRD) analysis

Figure 2 shows the XRD pattern of the fillers. The XRD pattern of CS and CSAC fillers revealed the presence of amorphous region with broad diffraction peaks that were detected at 2Θ= 22.236°, 34.8604°, and 2Θ= 23.985°, 44.015°, respectively, attributed by the lignocellulosic structure in CS and CSAC fillers. It can be observed that CSAC filler has lower peak intensities compared to CS filler, indicating that the crystallinity structure in synthesized coconut shell activated carbon is lower than CS filler. In other words, CSAC possesses higher amorphous structure compared to CS. Presence of crystalline region with sharp peaks were detected in β-SiC filler at 2Θ=35.574°, 41.336°, 59.908°, 71.628°, 75.403°, attributed to (111), (200), (220), (311) and (222) planes respectively. Figure 3 shows the XRD pattern of polymer composites with the addition of the different type of fillers. In can be observed that only broad diffraction peaks were detected in the CS and CSAC polymer composites due to the amorphous region contributed by the both of the fillers and the polymer structure. In β-SiC polymer composites, hybrid amorphous/crystalline structures were detected with the broad diffraction peaks contributed by the amorphous polymer structure whereas the sharp peaks contributed by the crystalline β-SiC filler. Similarly, the addition of CS/β-SiC and CSAC/β-SiC lead to hybrid amorphous/crystalline structure in the polymer

composites. It can be observed that the peak intensities of the amorphous structure in the polymer composites increased accordingly with the increase in the amount of CS and CSAC fillers that were loaded in the composites, as presented in Figure 3. The presence of amorphous region in the polymer composites allows the induced current from electromagnetic field to flow through it and increased the dielectric properties of the polymer composites, as evidenced by the dielectric properties results in section 3.4.

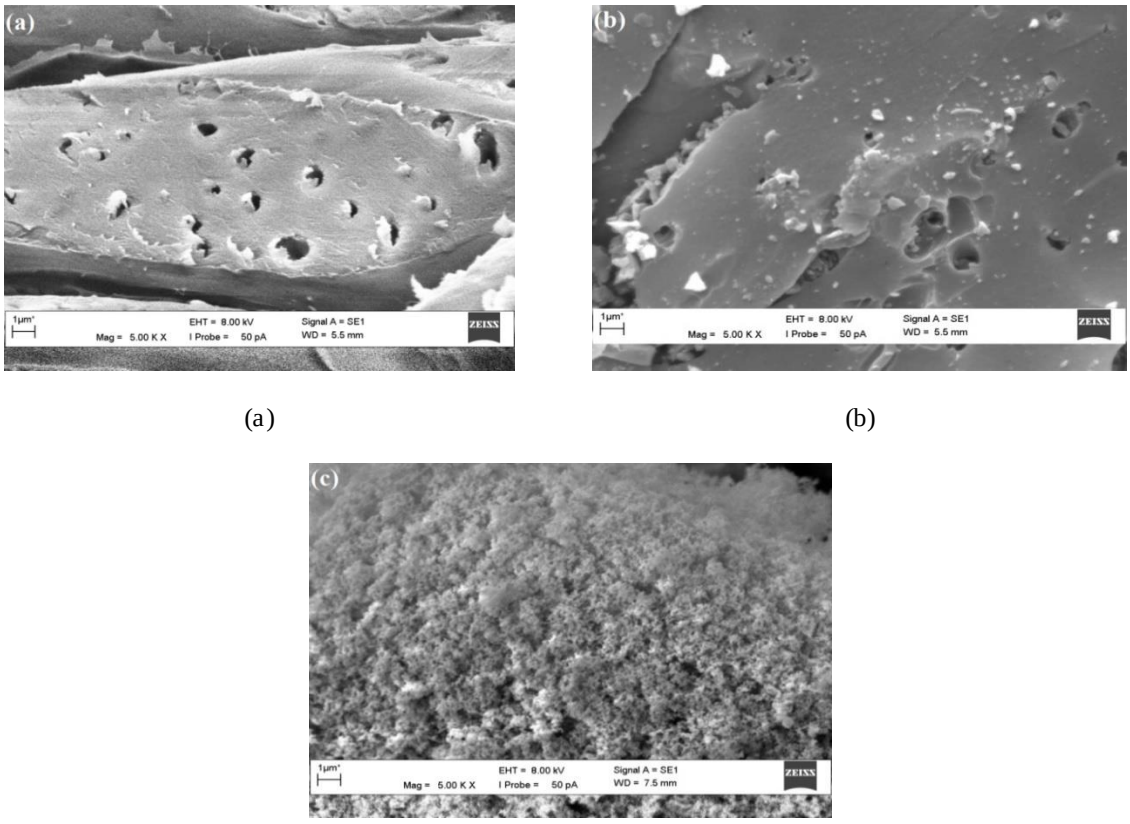


Figure 1. SEM morphologies at magnification of 5KX, (a) CS, (b) CSAC, (c) β-SiC

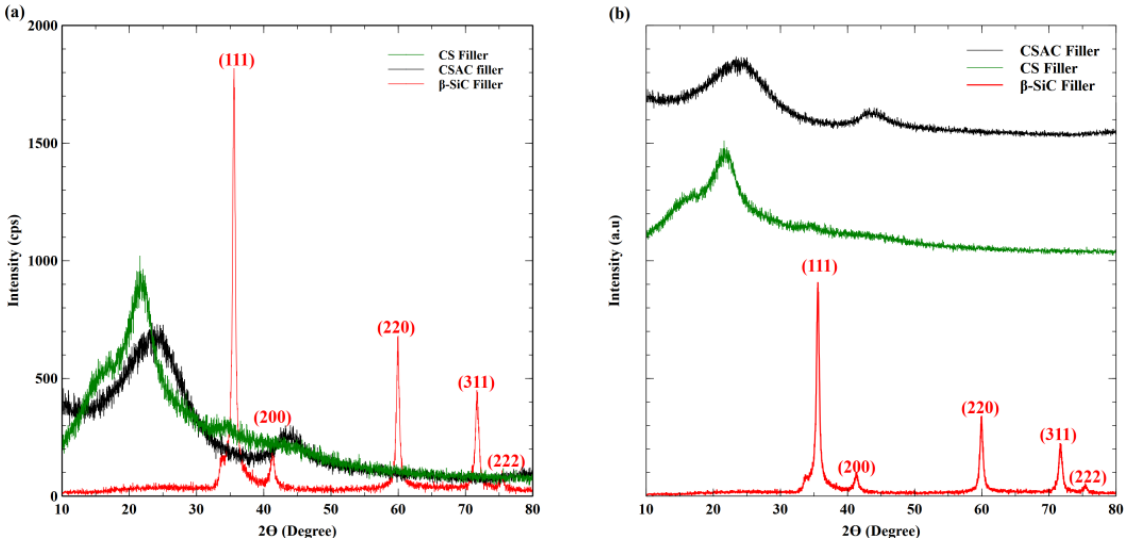
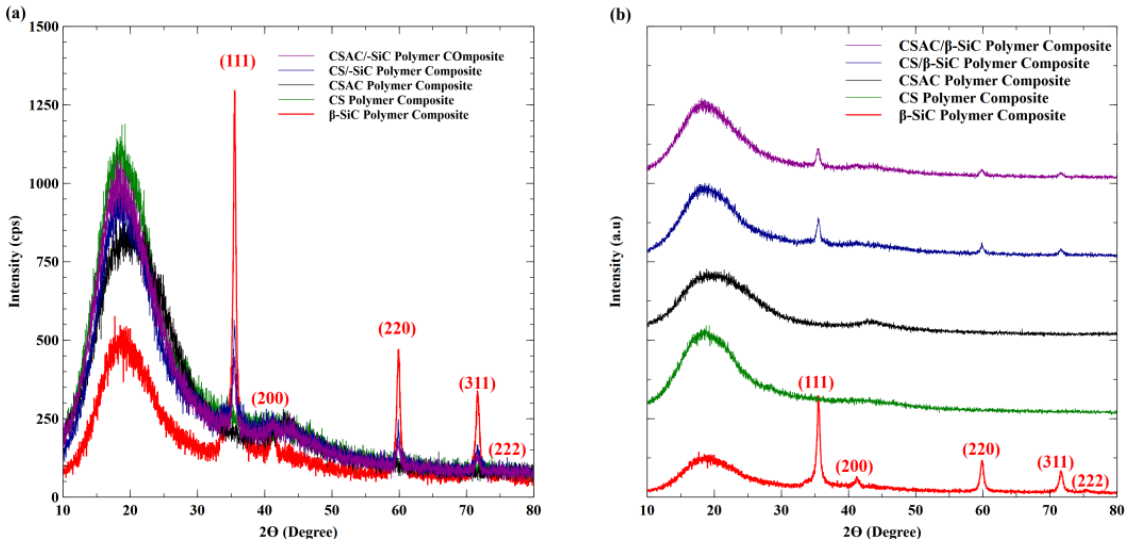


Figure 2. XRD pattern of the fillers, (a) Intensity, (b) Normalized intensity



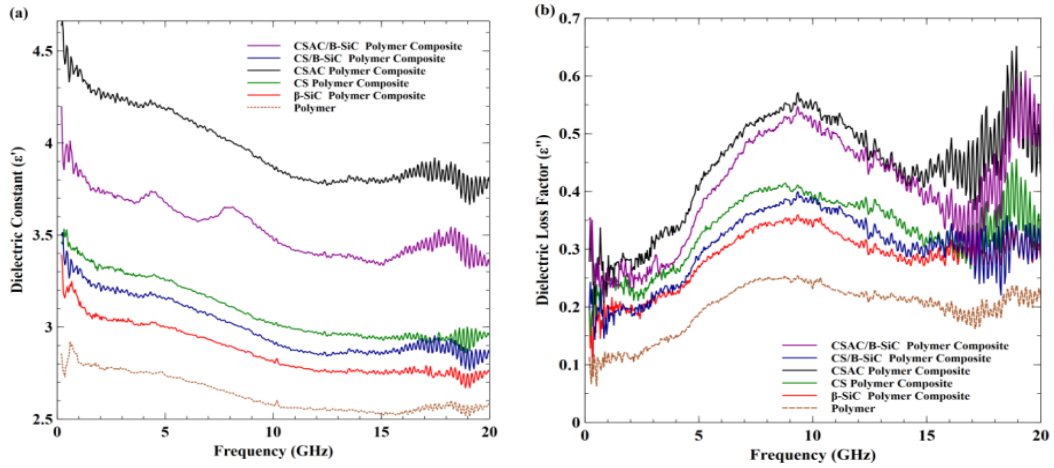
(a) (b)

Figure 3. XRD pattern of the polymer composites, (a) Intensity, (b) Normalized intensity

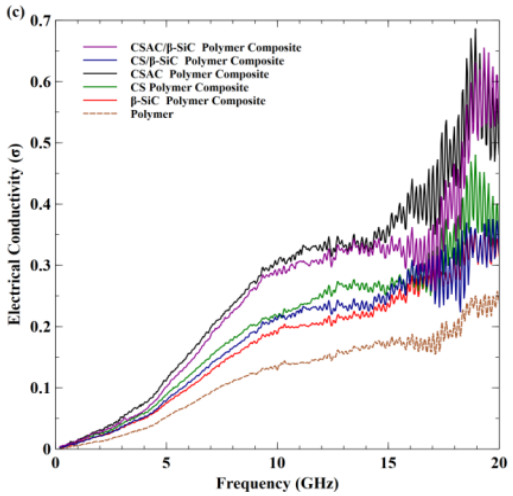
3.4. Dielectric properties

When electromagnetic energy propagates through dielectric material, displacement and conduction currents were induced in the electric field. The displacement current led to polarizations which influenced the dielectric constant (ε'); whereas the conduction current led to the dissipation of conduction or heat losses which influenced the dielectric loss factor (ε") and electrical conductivity (σ) [22-24]. Figure 4(a) presents the dielectric constant (ε') of the composites plotted over the broadband frequency range from 200 MHz to 20 GHz. It was observed that ε' decreased with increasing frequency at room temperature. Pure polymer shows the lowest ε' values due to the single polarization orientation in the polymer molecules, followed by the β-SiC polymer composite. High intensity of crystallinity structure attributed by the β-SiC filler restricted the interaction of the induced displacement current when electromagnetic energy flows through it. The addition of the CS and CSAC filler in polymer composite allows the induced displacement currents to flow through the amorphous region in the polymer composites. The polar molecules nature of the lignocellulosic CS and CSAC fillers were able to capture and attract charges due to the interaction of displacement current in the electric field, which led to the orientation polarization in the composites and contributed to an increase in ε' [22]. Moreover, ε' was higher or more prominent at lower frequencies compared to higher frequencies. This is because complete dipoles orientation due to the accumulation of free charges are possible at lower frequencies but not at higher frequency as molecular vibrations reduce the possibility to achieve complete orientation of dipoles, which leads to decreased of ε' [25].

Figure 4(b) presents the dielectric loss factor (ε") of the polymer composites whereas Figure 4(c) shows the electrical conductivity (σ) of the polymer composites plotted over the broadband frequency range from 200 MHz to 20 GHz, respectively. Similar trends were observed in the ε" and σ. Movement of free electrons were restricted due to single polarization that occurred in pure polymer and β-SiC composites, thus decreased its ε" and σ. On the other hand, the addition of the CS and CSAC fillers provides orientation polarization that was contributed by the polar molecules in the hydroxyl group presence in lignocellulosic fillers. The polar nature of the CS and CSAC fillers in the polymer composites allows the movement of free electrons, thus induced the conduction current in the electric field when electromagnetic waves propagates through it, which in turns leads to the dissipation of conduction or heat losses and contributes to an increase in ε" and σ. Furthermore, it can be observed that the insertion of CSAC in the polymer composites shows significant increased in ε', ε" and σ at all frequencies compared to the insertion of CS, contributed by the higher carbon content and higher amorphous structure in CSAC, as evidenced by elemental composition and XRD analyses.



(a) (b)



(c)

Figure 4. (a) Dielectric constant, (b) Dielectric loss factor, (c) Electrical conductivity

4. CONCLUSION

The addition of the CS and CSAC fillers increased the dielectric properties of the polymer composites, attributed by the amorphous nature of the CS and CSAC fillers which allows orientation polarization to take place when the electromagnetic energy propagates through the polymer composites. However, the addition of β-SiC filler has insignificant contribution on the dielectric properties of the polymer composites as only single polarization takes place within the crystalline structure β-SiC filler. Thus, it can be concluded that with the presence of the amorphous filler in the polymer composites, this type of polymer composites can be used as an alternative dielectric materials with the purpose to weaken electromagnetic energy, especially to suppress electromagnetic interference (EMI) in various electronic equipment and systems used over wide range of wireless communications Application up to 20 GHz.

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