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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Article Info

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.

Keywords:
Beta silicon carbide
Coconut shell
Coconut shell activated carbon
Dielectric properties
Polymer

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].

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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                      | 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). Prior 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 composition analysis 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].

| Filler                                | 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= 22.36°, 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
Coconut shell, coconut shell activated carbon and beta-silicon carbide reinforced... (Been Seok Yew)
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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REFERENCES

[1] P. Saini and M. Arora, “Chapter 3: Microwave absorption and em shielding behavior of nanocomposites based on intrinsically conducting polymers, graphene and carbon nanotubes,” New polymers for special Applications, pp. 71-112, 2012.

[2] F. Wan, F. Luo, H. Wang, Z. Huang, W. Zhou, D. Zhu, “Effects of Carbon Black (Cb) And Alumina Oxide on The Electromagnetic-Induced Microwave-Absorption Properties of Sic Fiber/Aluminum Phosphate Matrix Composites,” Ceramic International, vol. 10, no. 10, pp. 15849-15855, 2014.

[3] A. Kumar, V. Agarwala, D. Singh, “Effect of Milling on Dielectric and Microwave Absorption Properties of Sic Based Composites,” Ceramics International, vol. 40, no. 1, pp. 1797-1806, 2012.

[4] J. Wang, R. Xu, Y. Sun, B. Zhang, W. Chen, T. Wang, S. Yang, “Enhanced Microwave Absorption Properties of Epoxy Composites Reinforced with Fe50Ni50-Functionalized Graphene,” Journal of Alloys and Compounds, vol. 653, pp. 14-21, 2015.

[5] T. Liu, X. Xiubo, Y. Pang, S. Kobayashi, “Co/C Nanoparticles with Low Graphitization Degree: A High-Performance Microwave Absorbing Material,” Journal of Materials Chemistry, vol. 4, pp. 1727-1735, 2016.

[6] X. Su, J. Xu, Z. Li, J. Wang, X. He, C. Fu, W. Zhou, “A Method to Adjust Dielectric Property of SiC Powder in the GHz Range,” Journal of Materials Science and Technology, vol. 27, no. 5, pp. 421-425, 2011.

[7] H. J. Yang, J. Yuan, Y. Li, Z. L. Hou, H. B. Jin, X. Y. Fang, M. S. Cao, “Carbon Carbidc Powders: Temperature-Dependent Dielectric Properties and Enhanced Microwave Absorption at Gigahertz Range,” Solid State Communications, vol. 163, pp. 1-6, 2013.

[8] H. Yang, M. Cao, Y. Li, H. Shi, Z. Hou, X. Fang, H. Jin, W. Wang, J. Yuan, “Enhanced Dielectric Properties and Excellent Microwave Absorption of SiC Powders Driven with Nio Nanorings,” Advanced Optical Material, vol. 2, no. 3, pp. 214-219, 2014.

[9] A. Saib et al., “Carbon nanotube composites for broadband microwave absorbing materials,” in IEEE Transactions on Microwave Theory and Techniques, vol. 54, no. 6, pp. 2745-2754, June 2006.

[10] X. Liu, Z. Zhang, Y. Wu, “Absorption Properties of Carbon Black/Silicon Carbide Microwave Absorbers,” Composites Part B: Engineering, vol. 42, no. 2, pp. 326-329, 2011.

[11] H. Zhu, Y. Bai, R. Liu, N. Lun, Y. Qi, F. Han, J. Bi, “In Situ Synthesis of One-Dimensional MWCNT/SiC Porous Nanocomposites with Excellent Microwave Absorption Properties,” Journal of Materials Chemistry, vol. 21, no. 35, pp. 15385-15387, 2011.

[12] S. Bi, L. Ma, B. Mei, Q. Tian, C. H. Liu, C. R. Zhong, Y. D. Xiao, "Silicon Carbide/Carbon Nanotube Heterostructures: Controllable Synthesis, Dielectric Properties and Microwave Absorption," Advanced Powder Technology, vol. 25, no. 4, pp. 1273-1279, 2014.

[13] A. Shaaban, S. M. Se, I. M. Ibrahim, Q. Ahsan, “Preparation of Rubber Wood Sawdust-Based Activated Carbon and Its Use as a Filler of Polyurethane Matrix Composites for Microwave Absorption,” Xinxing Tan Calliow/New Carbon Mater., vol. 30, no. 2, pp. 167-175, 2015.

[14] B. S. Yew, F. H. Wee, S. Nurbazilah, S. B. Mohamed, A. Humaizi, M. R. Juhari, “The Investigation on The Potential of Coconut Shell Powder Composite in term Of Carbon Composition, Surface Porosity and Dielectric Properties as a Microwave Absorbing Material,” Environment Asia, vol. 9, no. 1, pp. 9-17, 2016.

[15] B. S. Yew, F. H. Wee, M. Muhammad, “Effect of Biomass Waste Filler on the Dielectric Properties of Polymer Composites,” Environment Asia, vol. 9, no. 2, pp. 134-136, 2016.

[16] J. A. Menéndez, A. Aremillas, B. Fidalgo, Y. Fernández, L. Zubizarreta, E. G. Calvo, J. M. Bermúdez, “Microwave Heating Processes involving Carbon Materials,” Fuel Processing Technology, vol. 91, no. 1, pp. 1-8, 2010.

[17] D. Micheli, C. Apollo, G. Gradoni, M. Marchetti, R. B. Morles, R. Pastore, “Electromagnetic Characterization of Composite Materials and Microwave Absorbing Modeling,” Advances in nanocomposites-synthesis, characterization and industrial applications (Ed: Reddy B), pp. 359-84, 2011.

[18] S. N. Ab. Jabal, SN, B. S. Yew, F. H. Wee, “The Potential of Coconut Shell Powder (CSP) and Coconut Shell Activated Carbon (CSAC) Composites as Electromagnetic Interference (Emi) Absorbing Material,” Malaysian Journal of Analytical Sciences, vol. 20, no. 2, pp. 444-451, 2016.

[19] G. Chen and A. E. Davies, “The influence of defects on the short-term breakdown characteristics and long-term dc performance of LDPE insulation,” in IEEE Transactions on Dielectrics and Electrical Insulation, vol. 7, no. 3, pp. 401-407, June 2000.

[20] Y. Shen, Y. Lin, M. Li, C. Nan, “High Dielectric Performance of Polymer Composite Films Induced by a Percolating Interparticle Barrier Layer,” Adv. Mater., vol. 19, no. 10, pp. 1418-1422, 2007.

[21] P. Barber, S. Baalasubramaniam, Y. Anguchmy, S. Gong, A. Wibowo, H. Gao, H. J. Ploehn, H. -.C. Zur Loye, “Polymer Composite and Nanocomposite Dielectric Materials for Pulse Power Energy Storage,” Materials (Basel), vol. 2, no. 4, pp. 1697-1733, 2009.

[22] D. Micheli, C. Apollo, R. Pastore, M. Marchetti, “X-Band Microwave Characterization of Carbon-Based Nanocomposite Material Absorption Capability Comparison And RAS Design Simulation,” Compos. Sci. Technol., vol. 70, no. 2, pp. 400-409, 2010.

[23] O. P. Nautiyal, S. C. Bhatt, R. C. Pant, B.S. Semwal, “Dielectric Properties of Silver Sodium Niobate Mixed Ceramic System,” Indian J. Pure Appl. Phys., vol. 48, no. 5, pp. 357-362, 2010.

[24] T. AI, P. O. Nasicon, T. Zangina, J. Hassan, K. Amin, S. Azis, U. Ahmady, A. See, “Sintering Behaviour, AC Consuctivity and Dielectric Relaxation of Li1.3Ti1.7A10.3(PO4)3 NASICON Compound,” Results Phys., vol. 6, pp. 719-725, 2016.
[25] D. Hassan, and A. H. Ah-Yasari, “Fabrication and studying the dielectric properties of (polystyrene-copper oxide) nanocomposites for piezoelectric Application,” *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 8, no. 1, pp. 52-57, 2019.

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