

# The Potential of Agricultural Waste Fibres as Bio-Conductive Filler in Epoxy Based Polymer

Been Seok Yew<sup>1\*</sup>, Fwen Hoon Wee<sup>2</sup>, Martini Muhamad<sup>1</sup>,  
and Saiful Bahri Mohamed<sup>1</sup>

<sup>1</sup> Faculty of Innovative Design and Technology, Universiti Sultan Zainal Abidin, Malaysia.

<sup>2</sup> School of Computer and Communication Engineering,  
Universiti Malaysia Perlis (UniMAP), Malaysia

\*Corresponding Author: bseokyew@unisza.edu.my

Received: February 3, 2022; Revised: March 8, 2022; Accepted: March 30, 2022

## Abstract

This work investigates on the potential of coconut shell (CS), coir, sugarcane bagasse (SGB) as bio-conductive fillers in epoxy composites. The elemental composition of the fillers was examined using Carbon, Hydrogen, Nitrogen and Sulphur (CHNS) elemental analysis whereas the morphology of the fillers was observed using scanning electron microscope (SEM). Fourier Transform Infrared (FTIR) Spectroscopy Analysis was performed to examine on the chemical structure of the fillers. The performance of the fillers in epoxy composites was evaluated in term of dielectric properties using open-ended coaxial probe technique. CHNS elemental analysis revealed that the fillers contain up to 48.37% of carbon, and presence of macroporous structure was detected. The polar nature of the fillers was confirmed from FTIR analysis with the presence of hydroxyl (OH) groups. For the dielectric properties measurement, it was found that the fillers increase the dielectric constant ( $\epsilon'$ ), dielectric loss factor ( $\epsilon''$ ), dissipation factor ( $\tan \delta$ ) and electrical conductivity ( $\sigma$ ) of pure epoxy up to 15%, 42%, 32% and 42%, respectively. With enhancement that is  $< 50\%$ , the performance of raw natural fibres as bio-conductive fillers is considered as not prominent for microwave heating application and activation process is necessary to improve their conductive behaviour.

**Keywords:** Bio-conductive filler; Epoxy; Dielectric properties; Electrical conductivity; Microwave heating.

## 1. Introduction

The electromagnetic interference radiated by communication devices and electronic instruments is becoming a cause of concern and it is important to recognize how to weaken the electromagnetic energy (EM). In general, a lossy dielectric material is used for this purpose. Carbon black and carbon nanotube are commercially available highly conductive material that are commonly used as conductive element in lightweight shielding material such as polymer, but these materials are expensive.

In dielectric material, conductive element is the factor that contributes to polarization,

which will enhance the dielectric properties and the microwave heating ability. A poor dielectric material such as polymer is commonly filled with conductive elements to improve its dielectric properties. The dielectric properties of dielectric material are presented in term of complex permittivity ( $\epsilon$ ), as presented in equation (1).

$$\text{Dielectric Properties, } \epsilon = \epsilon' + j\epsilon'' \quad (1)$$

The ability of a material to absorb and store EM energy is represented by the dielectric constant ( $\epsilon'$ ) whereas dielectric loss factor ( $\epsilon''$ ) is responsible convert and release

the stored EM energy into ohmic loss (heat dissipation). The dissipation factor (tangent delta) is presented in equation (2), which is ratio of the dielectric constant (ohmic loss) to the dielectric loss factor (energy stored), as.

$$\text{Dissipation Factor, } \tan \delta = \varepsilon'' / \varepsilon' \quad (2)$$

The ability of a material to dissipate the ohmic loss is represented by the electrical conductivity, as shown in equation (3). The ohmic losses are proportional to the electrical conductivity, i.e. dielectric materials with high electrical conductivity dissipate more heat.

$$\text{Electrical conductivity, } \sigma = 2\pi f \varepsilon_0 \varepsilon'' \quad (3)$$

Where free space permittivity ( $\varepsilon_0$ ) is equal to  $8.854 \times 10^{-12}$  F/m,  $f$  is the frequency in hertz (Hz) (Mittal et al., 2016).

In recent years, conductive elements derived from natural fibres have been a topic of interest to explore as bio-conductive filler in dielectric-based polymer (Choh et al., 2016; Huang et al., 2019; Elloumi et al., 2021; Zwawi, 2021). Although the effectiveness of the natural fibres is expected to be poorer compared to commercially highly conductive material, it is worth to investigate how far these bio-conductive fillers can perform. Natural fibres are rich in hydroxyls (OH) group compound which are responsible to induce orientation/dipole polarization when a dielectric material is subjected to EM field (Dungani et al., 2016; Camargo et al., 2020; Yew et al., 2020; Belgacem et al., 2021; Zwawi 2021). The examples of the natural fibres that can be abundantly found in Malaysia are from coconut waste, sugarcane bagasse, rice

husk, banana waste and oil palm waste. In this work, three types of locally found raw natural fibres in Gong Badak, Terengganu, which are coconut shell (CS), coir and sugarcane bagasse (SGB) Malaysia were selected as bio-conductive fillers. This is the continuous improvement work reported elsewhere (Ab. Jabal et al., 2016; Yew et al., 2016).

## 2. Material and Methods

### 2.1 Raw Materials

Locally found raw CS, coir and SGB were collected, cleaned, and dried under sunshades until completely dried. The raw materials were pulverised into fine powder by using Disk Mill. Epoxy resin (Epocast PT100) and amine-based epoxy hardener (Epoharden PT100S) were used as the matrix.

### 2.2 Composites Preparation

The epoxy composites filled with CS, coir and SGB were prepared with the composition presented in Table 1. The ratio of the epoxy resin to hardener is 2:1. The curing process of the epoxy composites took about 1 to 2 hours to completely curing at room temperature. Disposable plastic petri dish with diameter of 55 mm was used as mould. In this work, the composites were fabricated with thickness of 5 mm. The diameter of the fabricated composites must be wider than the diameter high temperature probe (diameter = 19 mm) that is used for dielectric properties measurement and the samples surface must be smooth to minimize fringing field effect that may results in dielectric measurement inaccuracy (Wang and Chung 2017).

**Table 1.** Bio-filler/epoxy weight percentage composition

Material	Weight Percentage (wt%)			
	Pure Epoxy	CS/Epoxy	Coir/Epoxy	SGB/Epoxy
Epocast PT100	100	100	100	100
Epoharden PT100s	50	50	50	50
Coconut Shell (CS)	0	45	0	0
Coir	0	0	45	0
Sugarcane Bagasse (SGB)	0	0	0	45

2.3 Carbon, hydrogen, nitrogen, and sulphur (CHNS) elemental analysis

The CHNS elemental analysis was performed to investigate the carbon elemental composition in coconut shell, coir and sugarcane filler. Carbon is the element that can suppress and weaken the EM wave by converting and dissipating the EM wave into heat. The CHNS elemental analysis was performed through Elementar Germany vario MICRO cube CHNS Analyser, which was carried out at 23°C and relative humidity of 50% room condition.

2.4 Particle morphology

ZEISS Supra55 and JEOL JSM-6360LA scanning electron microscopes were used to observe the morphologies of the coconut shell, coir, and sugarcane bagasse particles. For specimen under test preparation, a small amount of filler powder is dispersed on a carbon adhesive tape that was placed on the specimen stub. Rubber hand blower was used to remove excess powder before the specimen is coated with conductive layer (thin layer of gold) by using sputter coater machine. The particles morphology was observed at magnification up to 2.0 KX with acceleration voltage of 5-15kV.

2.5 Fourier transform infrared (FTIR) spectroscopy analysis

The chemical structure of CS, coir and SGB were analysed using Shimadzu/IRTracer - 100 and PerkinElmer - Spectrum 100. The FTIR spectra with percentage transmittance (%T) versus wavelength (cm<sup>-1</sup>) were recorded within the scanning range of 650-4000 cm<sup>-1</sup>.

2.6 Dielectric properties and electrical conductivity

Open-ended coaxial probe technique was used to determine the dielectric properties of the epoxy composites at room temperature over 200 MHz - 20 GHz. The apparatus of the measurement method consists of high temperature probe kit, Agilent E8362B PNA series network analyser and Agilent 85070E measurement software. The measurement of the dielectric properties and electrical conductivity was made by contacting the high temperature probe kit on the flat surface of the epoxy composites. Open-ended coaxial probe technique is a simple, convenient, and non-destructive testing method that most applicable technique for dielectric measurements over wide range of frequency (La Gioia et al., 2018; Keysight Technologies 2019; Saeidi et al., 2019; Maenhout et al., 2020).

3 Results and Discussion

3.1 Carbon, hydrogen, nitrogen and sulphur (CHNS) elemental analysis of CS, coir, and SGB fibres

The elemental composition of CS, coir and SGB fillers is presented in Table 2. It was examined that CS, coir and SGB fillers contains 48.37%, 46.73% and 43.69% carbon element, respectively. With up to 48% of carbon element, these agricultural waste fillers are potentially useful as conductive element for microwave heating purpose (Vashisth et al., 2021). Microwave heating is the ability of a conductive material to suppress and attenuate the EM energy. When the conductive material is subjected to EM fields, the material is capable to absorb the EM energy, convert and dissipate the energy into heat loss.

Table 2. Elemental composition of CS, coir, and SGB fillers

Filler	Elemental Percentage (%)			
	Carbon (C)	Hydrogen (H)	Nitrogen (N)	Sulphur (S)
Coconut Shell (CS)	48.37	6.313	1.62	0.306
Coir	46.73	6.232	1.57	0.378
Sugarcane Bagasse (SGB)	43.69	6.355	1.83	0.448

3.2 SEM morphology of CS, coir and SGB particles.

Figure 1 presents the SEM particle morphologies of the CS, coir and SGB. It can be observed that macropores with irregular size in micrometer (SEM scale) were found on in CS, coir and SGB particles. Macropores referred to pores size that is greater to 50 nm (McCusker et al., 2001; Azman et al., 2020). Material with porous structures is capable to provide multiple paths for the incident electromagnetic waves and greatly decrease the reflectivity the electromagnetic waves. With the porous structure, the contact probability of the material and the incident electromagnetic waves increase, which increase the electromagnetic waves absorbing bandwidth. Thus enhance the attenuation ability of electromagnetic waves (Cheng et al., 2020; Wei et al., 2020).

3.3 Fourier transform infrared (FTIR) analysis of CS, coir and SGB fibres

Figure 2 presents CS, Coir and SGB filler FTIR spectra of over the wavelength of 650 – 4000  $\text{cm}^{-1}$ . The absorption bands at 3367.85, 3340.71 and 3320.61  $\text{cm}^{-1}$  correspond to the hydroxyl group (OH) in CS, coir and SGB fibres respectively (Nascimento et al., 2018; Ismail et al., 2021). The presence of the highly polar nature of OH groups of the CS, coir and SGB fibres attract charges resulted from the interaction of displacement current in the electric field, which induced orientation polarization (Vilchevskaya and Müller 2021). In general, they are five types of polarization, namely ionic, atomic, electronic, orientation (or dipole), and interfacial (space charge). The ionic, orientation and interfacial polarizations interact strongly over microwave frequency, which greatly increase the dielectric behaviour of the material (Abdel-karim et al., 2018; Elloumi et al., 2021). On the other hand, the atomic and electronic polarizations are almost lossless (Zangina et al., 2016; Yew et al., 2020).

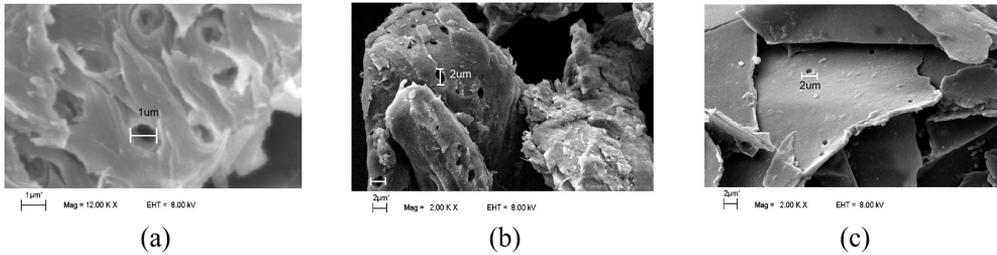


Figure 1. SEM particles morphologies (a) Coconut Shell (b) Coir (c) Sugarcane Bagasse.

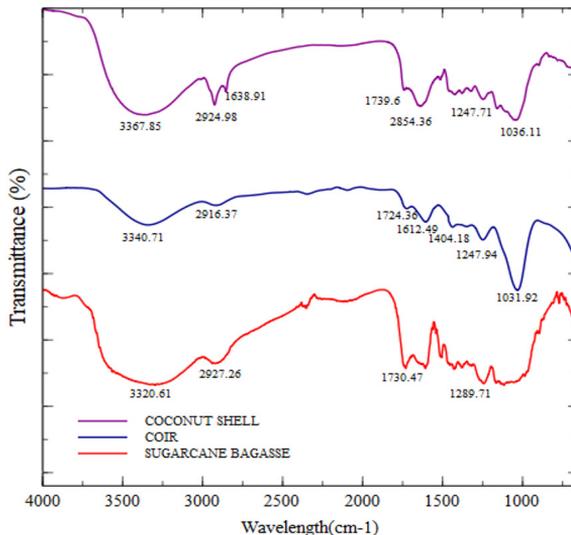


Figure 2. FTIR spectra of coconut shell, coir, and sugarcane bagasse fillers.

### 3.4 Dielectric properties and electrical conductivity of epoxy composites with CS, coir and SGB fillers.

As EM energy propagates through a dielectric material, displacement and conduction currents will be induced. The dielectric constant ( $\epsilon'$ ) is dependent on the induced displacement current, which is responsible for polarization whereas dielectric loss factor ( $\epsilon''$ ) is dependent on the induced conduction currents that arises due to free electrons movement, which is responsible for heat loss (Zangina *et al.*, 2016).

The dielectric properties of the epoxy composites with CS, coir and SGB fillers were measured over wide range of frequency to observe the dielectric behaviour at lower and higher frequency range. The dielectric constant ( $\epsilon'$ ) of the epoxy composites versus the frequency range from 200 MHz to 20 GHz is presented in Figure 3 (a). It can be observed that there was a decreasing trend of the  $\epsilon'$  against increasing frequency of all the epoxy composites due to conductive impact of microwave heating (Saeidi *et al.*, 2019). With the absence of conductive filler, the pure epoxy molecules exhibit single polarization orientation, which resulted in lowest average  $\epsilon'$ . With the presence of CS, coir and SGB fillers, the dielectric constant ( $\epsilon'$ ) of the epoxy composites were increased up to 14% to 15%. According to Rayssi *et al.*, the dielectric properties depend on chemical composition. The presence of the CS, coir and SGB act as conductive elements in the epoxy composites contributes to an increase in dielectric constant ( $\epsilon'$ ). CS, coir and SGB fillers interact with the incident electromagnetic waves and induced displacement current in the epoxy composites. Orientation and interfacial polarizations took place due to the alignment of hydroxyl group dipole in the direction of applied electric field and localized accumulation of charges (Rayssi *et al.*, 2018). Moreover, it can be observed that at lower frequency, it is more prominent to achieve complete dipole orientation that was resulted from free charges accumulation and contributes to the increased of dielectric constant ( $\epsilon'$ ). However, at higher frequency, the dielectric constant ( $\epsilon'$ ) decreased rapidly with the increase in frequency that is resulted

from vigorous molecular vibrations, which restricted the complete dipoles orientation, thus decreased the dielectric constant ( $\epsilon'$ ) (Hassan *et al.*, 2019). There is also possibility of random fluctuation that occurred during the measurement which caused inconsistency on the beginning and ending of each frequency dependent permittivity graph.

Similarly for dielectric loss factor ( $\epsilon''$ ) that is presented in Figure 3 (b), it can be observed that the dielectric loss factor ( $\epsilon''$ ) show up to 43% improvement with the presence of CS, coir and SGB fillers in the epoxy composites. The dielectric loss factor ( $\epsilon''$ ) for all the epoxy composites show increasing trend with the increase in lower frequency range from 200 MHz to 10 GHz. This indicates that the ohmic loss within the epoxy composites were more prominent at lower frequency range. The ohmic loss or the heat dissipation is depended on the movement of positive and negative charges within a lossy dielectric material which causes the polarization to switch direction or moves in opposite directions (Jambaladinni and Bhat 2021). However, from frequency that is higher than 10 GHz up to 20 MHz, the dielectric constant ( $\epsilon'$ ) decreased with increasing frequency. Similarly, this is resulted by vigorous molecular vibrations that restricted movement of charges in the epoxy composites.

The dissipation factor ( $\tan \delta$ ) is dependent of both  $\epsilon'$  and  $\epsilon''$ , which is often used to determine how lossy a material is for microwave heating. In general, dielectric material with high dissipation loss indicates high heat loss, which reflects to high electromagnetic waves attenuation or microwave heating ability. Figure 3 (c) presents the dissipation factor ( $\tan \delta$ ) over the frequency. It can be observed that the CS, coir and SGB fillers enhanced the microwave heating ability of the epoxy composites up to 32%, owing to the presence of carbon elements in the agricultural waste filler. The polar nature of the CS, coir and SGB also enhanced the electrical conductivity ( $\sigma$ ) up to 42% compared to pure epoxy, as shown in Figure 3(d).

CS filler possess higher dielectric properties (dielectric constant and dielectric loss factor) and electrical conductivity

compared to coir and SGB fillers. As confirmed by CHNS elemental analysis, the elemental composition of carbon in CS (48.37%) is slightly higher compared to coir (46.73%) and SGB (43.69%) fillers. As the percentage

of carbon composition is higher compared to coir and SGB fillers, the tendency of CS filler to dissipate EM wave to heat energy is better than coir and SGB fillers (Menéndez *et al.*, 2010; Micheli *et al.*, 2011; Cheng *et al.*, 2020)

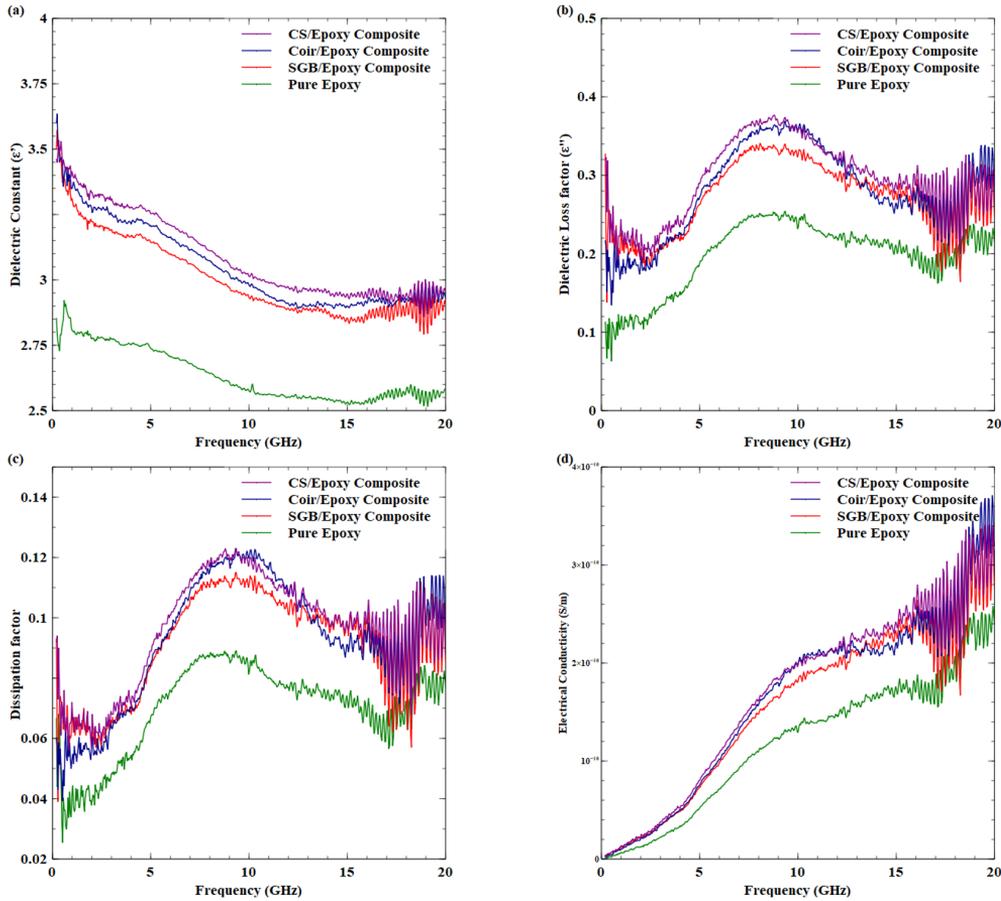


Figure 3. (a) Dielectric constant (b) Dielectric loss factor (c) Dissipation factor (d) Electrical Conductivity over 200 MHz to 20 GHz.

Table 3. Elemental composition of CS, coir, and SGB fillers

Composite	Dielectric properties			Electrical conductivity x 10 <sup>-10</sup> (S/m)	Average value (Enhancement with respect to pure epoxy,%)			
	ε'	ε''	tan δ		ε'	ε''	tan δ	x 10 <sup>-10</sup> (S/m)
Pure Epoxy	2.516-2.922	0.063-0.254	0.025-0.089	0.0103-2.58	2.635	0.197	0.070	1.19
CS/Epoxy	2.839-3.533	0.168-0.369	0.050-0.123	0.0356-3.41	3.050 (15%)	0.282 (43%)	0.093 (33%)	1.69 (42%)
Coir/Epoxy	2.827-3.564	0.129-0.353	0.038-0.120	0.0235-3.71	2.994 (14%)	0.269 (37%)	0.091 (30%)	1.64 (38%)
SGB/Epoxy	2.816-3.587	0.184-0.352	0.052-0.118	0.0214-3.40	3.043 (15%)	0.280 (42%)	0.092 (31%)	1.57 (32%)

## 4. Conclusion

The findings of this work indicated that presence of the bio-based CS, coir and SGB conductive fillers enhanced the dielectric properties and electrical conductivity of the epoxy composites. However, the enhancement is considered as insignificant, which is < 50%. These bio-conductive fillers can be converted into activated carbon to improve their conductive behaviour, in which through the activation process where the carbon element of raw natural fibres is potentially increase up to 85%. On the other hand, chemical modification such as alkaline treatment on natural fibres is not favourable for conductive filler purpose as this process tends to remove the hydroxyl groups in the natural fibres, which affected the polarization ability of the natural fibres when subjected to electromagnetic field.

## Acknowledgement

The authors are grateful for the financial support provided by UniSZA; for the measurement facilities provided by UniMAP, UMT and UMP.

## References

- Ab. Jabal SN, Yew BS, Wee FH. 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* 2016; 20(2): 444–51.
- Abdel-karim AM, Salama AH, Hassan ML. Electrical conductivity and dielectric properties of nanofibrillated cellulose thin films from bagasse. *Journal of Physical Organic Chemistry* 2018;31(9):1–9.
- Azman NHN, Sulaiman Y. Hierarchical Porous Materials for Supercapacitors. In: *Reference Module in Earth Systems and Environmental Sciences* [Internet]. Elsevier; 2020. Available from: <https://www.sciencedirect.com/science/article/pii/B9780128197233000226>
- Belgacem C, Serra-Parareda F, Tarrés Q, Mutjé P, Delgado-Aguilar M, Boufi S. Valorization of date palm waste for plastic reinforcement: Macro and micromechanics of flexural strength. *Polymers (Basel)* 2021;13(11).
- Camargo MM, Taye EA, Roether JA, Redda DT, Boccaccini AR. A review on natural fiber-reinforced geopolymer and cement-based composites. *Materials (Basel)* 2020;13(20):1–29.
- Cheng JB, Shi HG, Cao M, Wang T, Zhao HB, Wang YZ. Porous carbon materials for microwave absorption. *Materials Advances* 2020;1(8): 2631–45.
- Choh JL, Ching YC, Gan SN, Rozali S, Julai S. Effects of Oil Palm Empty Fruit Bunch Fiber on Electrical and Mechanical Properties of Conductive. *BioResources* 2016;11: 913–28.
- Dungani R, Karina M, Subyakto, Sulaeman A, Hermawan D, Hadiyane A. Agricultural waste fibers towards sustainability and advanced utilization: A review. *Asian Journal of Plant Sciences* 2016; 15(1–2): 42–55. Available from: <http://dx.doi.org/10.3923/ajps.2016.42.55>
- Elloumi I, Koubaa A, Kharrat W, Bradai C, Elloumi A. Dielectric properties of wood-polymer composites: Effects of frequency, fiber nature, proportion, and chemical composition *Journal of Composites Science* 2021; 5(6).
- La Gioia A, Porter E, Merunka I, Shahzad A, Salahuddin S, Jones M, *et al.* Open-Ended Coaxial Probe Technique for Dielectric Measurement of Biological Tissues: Challenges and Common Practices *Diagnostics* 2018; 8(2): 40.
- Hassan D, Ah-yasari AH, Ah-yasari AH. Fabrication and studying the dielectric properties of ( polystyrene-copper oxide ) nanocomposites for piezoelectric application. *Bulletin of Electrical Engineering and Informatics* 2019; 8(1): 52–7.
- Huang Y, Kormakov S, He X, Gao X, Zheng X, Liu Y, *et al.* Conductive Polymer Composites from Renewable Resources: An Overview of Preparation, Properties, and Applications. *Polymers (Basel)* 2019;11(2):1–32.

- Ismail NF, Mohd Radzuan NA, Sulong AB, Muhamad N, Che Haron CH. The effect of alkali treatment on physical, mechanical and thermal properties of kenaf fiber and polymer epoxy composites. *Polymers (Basel)* 2021; 13(12).
- Jambaladinni S, Bhat JS. Enrichment a study of structural, optical and dielectric properties of mowiol 4-88 (Pva) filled zno nanocomposites. *Walailak Journal of Science and Technology* 2021; 18(14).
- Keysight Technologies. Dielectric Properties of Materials Industry Applications/ Products. 2019; Available from: [www.keysight.com](http://www.keysight.com)
- Maenhout G, Markovic T, Ocket I, Nauwelaers B. Effect of open-ended coaxial probe-to-tissue contact pressure on dielectric measurements. *Sensors (Switzerland)*. 2020; 20(7): 1–13.
- McCusker L, Liebau F, Engelhardt G. Nomenclature of structural and compositional characteristics of ordered microporous and mesoporous materials with inorganic hosts(IUPAC Recommendations 2001). *Pure and Applied Chemistry* 2001; 73(2): 381-394. <https://doi.org/10.1351/pac200173020381>
- Menéndez JA, Arenillas A, Fidalgo B, Fernández Y, Zubizarreta L, Calvo EG, Bermúdez JM. Microwave Heating Processes involving Carbon Materials. *Fuel Processing Technology* 2010; 91(1): 1-8.
- Micheli D, Apollo C, Gradoni G, Marchetti M, Morles R.B, Pastore R. Electromagnetic Characterization of Composite Materials and Microwave Absorbing Modeling. *Advances in nanocomposites-synthesis, characterization and industrial applications* (Ed: Reddy B). 2011; 359-84.
- Mittal G, Rhee YK, Park JS. The Effects of Cryomilling CNTs on the Thermal and Electrical Properties of CNT/PMMA Composites. *Polymers* . 2016. 8(5):169.
- Nascimento LFC, Monteiro SN, Louro LHL, Luz FS Da, Santos JL Dos, Braga FDO, et al. Charpy impact test of epoxy composites reinforced with untreated and mercerized mallow fibers. *Journal of Materials Research and Technology* 2018; 7(4): 520–7.
- Rayssi C, El Kossi S, Dhahri J, Khirouni K. Frequency and temperature-dependence of dielectric permittivity and electric modulus studies of the solid solution  $\text{Ca}_{0.85}\text{Er}_{0.1}\text{Ti}_{1-x}\text{XCo}_4\text{x}/3\text{O}_3$  ( $0 \leq x \leq 0.1$ ). *RSC Advances*. 2018;8(31):17139–50.
- Saeidi T, Ismail I, Wen WP, Alhawari ARH. Dielectric properties of complete oil palm trunk sample (healthy and unhealthy). *AIP Advances*. 2019;9(7): 1–13. Available from: <https://doi.org/10.1063/1.5094459>
- Vashisth A, Upama ST, Anas M, Oh JH, Patil N, Green MJ. Radio frequency heating and material processing using carbon susceptors. *Nanoscale Advances* 2021; 3(18): 5255–64.
- Vilchevskaya EN, Müller WH. Modeling of orientational polarization within the framework of extended micropolar theory. *Continuum Mechanics and Thermodynamics [Internet]*. 2021;33(4):1263–79. Available from: <https://doi.org/10.1007/s00161-021-00972-x>
- Wang Y, Chung DDL. Effect of the fringing electric field on the apparent electric permittivity of cement-based materials. *Composites Part B: Engineering [Internet]*. 2017;126:192–201. Available from: <http://dx.doi.org/10.1016/j.compositesb.2017.05.080>
- Wei H, Cheng L, Shchukin D. Effect of porous structure on the microwave absorption capacity of soft magnetic connecting network Ni/Al<sub>2</sub>O<sub>3</sub>/Ni film. *Material*. 2020;13(7).
- Yew BS, Muhamad M, Mohamed SB, Wee FH. Coconut shell, coconut shell activated carbon and beta-silicon carbide reinforced polymer composite: An alternative dielectric material for wireless communication application. *Bulletin of Electrical Engineering and Informatics* 2020; 9(1): 311–8.
- Yew BS, Wee FH, Muhamad M. Effect of biomass waste filler on the dielectric properties of polymer composites. *EnvironmentAsia* 2016; 9(2): 134–9.

Zangina T, Hassan J, Amin K, Azis S, Ahmadu U, See A. Sintering behaviour, ac conductivity and dielectric relaxation of  $\text{Li}_{1.3}\text{Ti}_{1.7}\text{Al}_{0.3}(\text{PO}_4)_3$  NASICON compound. Results in Physics [Internet]. 2016;6:719–25. Available from: <http://dx.doi.org/10.1016/j.rinp.2016.10.003>

Zwawi M. A review on natural fiber bio-composites, surface modifications and applications. Molecules 2021; 26(2).