



The Effect of grain size on the complex permittivity of Oil Palm Empty Fruit Bunch Fiber for Microwave Application

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Abstract

Oil palm empty fruit bunch (OPEFB) fiber, a waste product from oil palm mill is 100% biodegradable, environmentally friendly, and cheap was prepared and characterized for possible microwave absorbing material by determining its permittivity for fiber size and frequency. The dielectric properties were investigated by the use of open-ended coaxial (OEC) probe at microwave frequency 8-12 GHz range. The results showed that the dielectric properties of the OPEFB fiber material can be influenced by changing its particle size (100, 200, 300, 400, and 500 μm). The dielectric constant (ϵ') and loss factor (ϵ'') increased as the particle size of the fiber decreased. The ϵ' values for the lowest and highest fiber size (100 and 500 μm) were found to be 3.13 and 2.81 while ϵ'' values were 0.38 and 0.26 respectively. Improved complex permittivity with reduced particle size demonstrated their suitability for making composites that could attenuate microwaves within the X-band frequency range.

Keywords: Oil palm fiber; Permittivity; Microwave absorption; X-band frequency

1. Introduction

Given the massive increase in radio frequency (RF) sources and fast development in electronic devices and communication, microwave absorber material characterization has gained significant attention (Stergiou and Litsardakis 2016; Xie et al., 2016). It is important to identify the appropriate material to meet the requirements in the production of materials for microwave applications. Several research studies centered on whether agricultural waste materials are suitable for these applications and whether they are readily available, biodegradable, inexpensive, and lightweight (Yaacoba et al., 2015). Microwave heating is a possible option for the treatment of biomass. It is therefore important to investigate the temperature dependence of the material's dielectric activity before it is exposed to microwave radiation. The material's interaction with microwave radiation depends on the dielectric properties of the material (Vassilef et al., 2015). Empty fruit bunch (EFB) properties are similar to other biomass materials. The moisture content was found to be high enough to minimize the caloric value, but the material's high volatility produced high reactivity. The amount of oxygen was found to be 50%, giving a higher heating value (HHV) (Omar et al., 2011).

Effects of microwave frequencies on oil palm fiber (OPF) and oil palm shell (OPS) dielectric properties with varying frequencies between 0.2 and 10 GHz were reported by Teppati et al. (2016) and Salema et al. (2013). The dielectric constant was found to decrease with increasing frequency, whereas the loss factor increased as the



frequency increases. Identifying the temperature dependence of a material's dielectric properties is critical in the design of a microwave processing system, as dielectric properties determine the interaction of the microwave

material and whether dielectric properties change with temperature. Based on the heating characteristics of oil palm biomass via microwave irradiation, the investigation of dielectric properties reported a low loss of dielectric results of OPF and oil palm shell OPS fibers. Dielectric properties of semi-solid, powdered materials are affected by structure, including solid particles, air-filled voids occupying a small space between them, and surface density; while permittivity is influenced by the material's wave absorption (Baharudin et al., 2013). Also, the air constituent filling the space distance between the solid particles of the powdered material tends to reduce the permittivity values to the permittivity of the air. Therefore, a permittivity value corresponding to the solid particle can be achieved by eliminating the air constituent. Microwave absorbers may help to attenuate external reflections and remove unwanted radiation that may temper with device operations. It, therefore, requires high-performance microwave absorbing materials of reduced thickness and low density (Abdalahdi et al., 2017). Appropriate materials are needed to enhance microwave absorbers to meet these needs. Numerous magnetic materials have been used in microwave absorption applications, the most common of which are ferrites because of their outstanding electrical and magnetic properties. However, Ferrites are expensive, heavy, and have higher complex permittivity (Mensah et al., 2019); this implies more reflection; the reflecting characteristic is not good for military defense, as this reflection can be easily tracked by radar. Nonetheless, carbon-based materials (carbon black (CB), activated carbon (AC), carbon nanotubes (CNTs), and recently graphene) were chosen to replace ferrites due to low density, resistance to corrosion, strengthening potential and strong electrical/thermal conductivity [2]. Agricultural waste is regarded as a very significant precursor since it is inexpensive, reusable, safe abundant, and biodegradable; moreover, it has a high carbon and less ash content (Ahmed 2016, Chayid and Ahmed 2015).

Oil palm empty fruit bunch (OPEFB) can be investigated as a possible natural fiber. Recent studies investigate the reinforced polymer composite OPEFB, which has been found to achieve even better characteristics (Roslan et al., 2014 & Nasution et al., 2015). OPEFB is known as waste from the oil extraction process in the palm oil industry. Malaysian oil palm mills generate about 15 million tons of empty fruit bunch (OPEFB) of oil palm every year (Abdul et al., 2017). OPEFB fibers are cost-effective with improved rigidity, biodegradable, mechanical, and electrical characteristics of any composite. Abdalahdi et al. (2017) studied the effect of particle size on dielectric properties of OPEFB fiber using a frequency range of 1 to 4 GHz. It was discovered that the highest real and imaginary values of the complex permittivity were recorded for the lowest OPEFB fiber particle size. In this study, OPEFB fibers were crushed into powder using a crusher machine into different particle size (100 to 500 μm) to determine the effect of particle size on dielectric properties of OPEFB fiber using open-ended coaxial probe technique at X-band frequency (8 to 12 GHz).

2. Materials and Methodologies

The following materials were used to prepare the specimens used in this study; OPEFB, acetone, distilled water, and polyvinyl alcohol (PVA), 86.89% purity (Alfa Aesar). The OPEFB fibers were soaked in deionized water for 24 h to remove wax fiber coating. To minimize moisture, the fibers were rinsed with acetone and dried for 5 h in an oven at 90 °C. Using a crusher device (Mainland Hunan, China), the dried fibers were crushed into a powder which was then sifted by a laboratory sample sieve (Endecotts, London, England) to different fiber particle size (100, 200, 300, 400 and 500 μm). 25 g of each of the different particle sizes were mixed with PVC to make the powders easy to compress into rectangular shapes via hot press machine (Yangzhou Hi-tech, Jiangsu, China). The compression was performed with the hydraulic hot press at 90 °C lower and upper plate temperature, 150 kg/cm² pressure, then cooled for 10 min at 30 °C. Figure 1 shows the preparation stages of the compressed OPEFB fiber.



Figure 1. (a) Unwashed, (b) washed, (c) pulverized and (d) compressed fibers

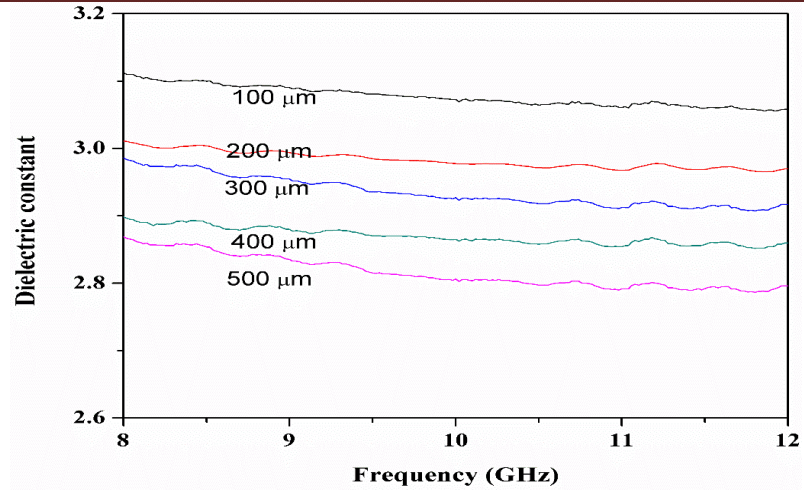
The complex permittivity measurements were performed in the 8-12 GHz range at room temperature via Agilent 85070B open-ended coaxial (OEC) probe connected to the Agilent N5230A PNA-L Network Analyzer (Agilent Technologies, Santa Clara, CA, USA). The calibration was performed using a standard one-port, short-air-water calibration and a reference standard material polytetrafluoroethylene (PTFE) was characterized to confirm the accuracy of the calibration. The coaxial probe was mounted on the flat surface of the compressed fibers with dimensions (6 x 3.5 x 0.8) cm³ ensuring that there was no air gap between the OEC probe and the sample throughout the process.

3. Results and Discussions

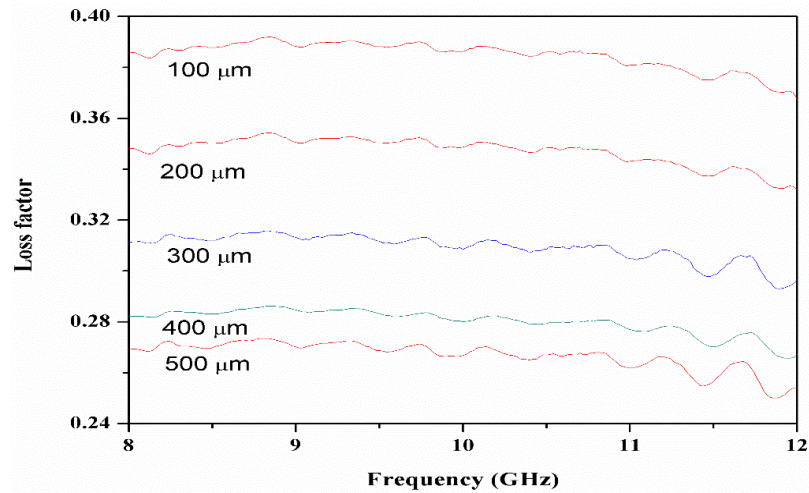
To study the dielectric properties of the OPEFB fiber, compressed substrates were characterized for their real (ϵ') and imaginary (ϵ'') parts of the relative complex permittivity (Eq. 1)

$$\epsilon^* = \epsilon' - j\epsilon'' \quad (1)$$

Compressing the samples reduced the vacuum and removed the air gaps that could affect the results. The dielectric properties of compacted OPEFB fiber were characterized for different particle size dependency and the variation in ϵ' and ϵ'' values in the 8 – 12 GHz range are depicted in Figure 2. The ϵ' and ϵ'' values in their profiles showed fluctuations due to impedance mismatch between the OEC probe's input impedance and the surface impedance of compressed samples resulting from surface imperfections. A reduction in the orientation polarization at high frequencies resulted in a decrease in the ϵ' corresponding to the frequency (Abdalahdi et al., 2017). The conductive grains are isolated at lower frequencies by thin insulating grain borders, which induces concentration of charges under the effects of the electric field thereby increasing the polarization of the interfaces at low frequencies in a high ϵ' . At higher frequencies, the charge carrier cannot align itself in the direction of the electric field, resulting in reduced interface polarization. The ϵ' and ϵ'' of the samples were observed to be increasing with a decrease in fiber particle size as shown in Table 1. The significantly higher ϵ' and ϵ'' values of the 100 μm OPEFB fiber size could be due to larger specific surface area which leads to an increased density (Mensah et al., 2019).



(a)



(b)

Figure 2. Plots of (a) Dielectric constant (ϵ') and (b) Loss factor (ϵ'') against frequency

Table 1. Variations of dielectric constant (ϵ') and loss factor (ϵ'') for all particle sizes of OPEFB fiber at X-band frequency.

Fiber size	ϵ'	ϵ''
100 μm	3.13	0.38
200 μm	2.97	0.34
300 μm	2.93	0.31
400 μm	2.86	0.27
500 μm	2.81	0.26



4. Conclusion

The OPEFB fiber was effectively pulverized into different particle sizes. The samples were characterized for dielectric properties using open-ended coaxial probe at 8-12 GHz frequency range. The ϵ' and ϵ'' decreased with increased fiber size. The highest values of ϵ' and ϵ'' are measured for the 100 μm with the lowest values measured for the 500 μm . The ϵ' and ϵ'' values of the 100 μm fiber are higher due to particle adhesion and minimal space between particles, which led to the reduction of air gaps between fibers. The significant improved dielectric properties linked to the reduced particle size can be used in potential applications needing controllable suppression of electromagnetic radiation.

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