International Journal of Applied Electromagnetics and Mechanics 73 (2023) 73–80
DOI 10.3233/JAE-220295
IOS Press

Study of electrical volume-conductivity, tensile strength, and electromagnetic shielding effectiveness of coconut fiber composite

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Abstract. Natural fiber composite becomes a necessity encountering the issue of eco-friendly materials. The application of natural fiber composite as electromagnetic interference (EMI) shielding enclosures has not been studied extensively. This study aims to investigate the performance of the coconut fiber composite as EMI shielding enclosure material. Enhancement of the electrical volume-conductivity of the composite was made by polymerization of coconut fiber with polyaniline and doping the multiwall carbon nanotubes to epoxy resin. Three types of composites were made with different weight percentages of coconut fiber: 5, 10, and 15 wt%. The highest volume-conductivity and shielding effectiveness of coconut fiber composite are 0,0458 S/m and −7.69 dB from the highest weight percentage of coconut fiber (15 wt%). While the highest tensile strength (26.78 MPa) resulted from the lowest weight percentage (5 wt%). This study shows the coconut fiber composite could potentially be the material of EMI shielding enclosure though their electrical conductivity and tensile strength should be increased.

Keywords: Coconut fiber, natural composite, enclosure, conductivity, shielding effectiveness

1. Introduction

The widespread usage of wireless technology and high-speed electronic equipment brings serious electromagnetic interference (EMI) to the environment. On the other hand, the electronic equipment should perform satisfactorily in its electromagnetic environment as well as maintain low EMI emissions to the neighborhood. EMI shielding is one of the methods to prevent electronic equipment from EMI disturbance. The composite-based polymer is the most common EMI shielding material in the last decade. Jiang et al. [1] reviewed that intrinsically conducting polymers (ICP) and conductive polymer composites (CPC) (insulating polymers filled with conducting fillers) are mostly reported by researchers. CPC

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and IPC-based EMI shielding materials have desirable electrical conductivity and excellent properties to absorb or reflect the electromagnetic wave over a wide frequency. Among intrinsically conducting polymers, Polyaniline (PANI) and polypyrrole (PPy) are widely used in developing EMI shielding material. Soares et al. [2] discussed in detail the application of PANI and PPy in EMI shielding materials as coating of fabrics and as fillers for insulating thermoset matrix. Another conducting polymer that is attractive to researchers is PEDOT: PSS. Bora et al. [3] studied 9 ± 1 μm thick cross-linked PEDOT:PSS has an EMI shielding effectiveness (SE) of 40 dB. Whereas, nano-conducting fillers such as metal nanoparticles, carbon nanostructures, and nanocarbons are effectively used for insulating polymers [1]. Carbon nanotubes, carbon black, graphene, graphite, and silver nanowire have attracted attention due to their advantages of low density, high electrical conductivity, corrosion resistance, and easy processing [4]. Recently, $Ti_3C_2T_x$MXene has been extensively developed as a filler to obtain high-performance EMI shielding material. Zhou et al. [5] reported that double-layered aramid nanofiber (ANF)/MXene films doped with PEDOT:PSS has EMI SE of 48,1 dB. Wang et al. [6] examined $Ti_3C_2T_x$ and Fe_3O_4 combined with cellulose nanofibers (CNF) then laminated with epoxy resin has an excellent EMI SE of 79 dB. Besides, the ICP and CPC, conventional carbon fiber reinforced polymer (CFRP) also show good shielding properties. Munalli et al. [7] investigated fabric prepregs-carbon fiber with epoxy resin as the matrix, the highest average SE is 81.6 ± 5.3 dB resulting from a sample consists of 8 layers of fabric prepregs carbon fiber. Recently, the important issue of materials that are environmental-friendly resulted in the use of natural fibers composited as an EMI shielding material. Natural fiber composites generally consist of natural fiber as reinforced and polymer as a matrix. The application of natural fiber composites has been widely used in the automobile industry [8], and aerospace [9]. Natural fibers which are popular to use as reinforced composites are abaca, banana, bamboo, coconut fibers, cotton, flax, hemp, jute, kenaf, pineapple, ramie, and sisal [10,11]. Among those natural fibers, coconut (coir) fibers are abundant in tropical countries like Indonesia. The coconut fibers have good mechanical properties, i.e., tensile strength was 500 MPa. Coconut fibers can be laminated with a variety of polymer matrices such as polypropylene, polyester, polyurethane, and epoxy [12]. However, coconut fiber is not conductive as reported by [13]. To enhance the conductivity (1/resistivity), ICP such as PANI has been used as a coating of coconut fibers as described in [14,15]. The electrical conductivity of PANI-coated coconut fibers with polyurethane (PU) composite is $(1.5 \pm 0.39) \times 10^{-2}$ S/cm to $(1.5 \pm 0.39) \times 10^{-1}$ S/cm depending on the composite oxidant type [14]. And the electrical conductivity of PANI-coconut fibers is 4.93×10^{-2} S/m and 3.18×10^{-2} S/m depending on the chemical process of the coir fibers [15]. The electrical conductivity which was measured by the authors shows the coconut fiber composites potentially used as EMI shielding material. Yah et al. [16] reported the electromagnetic wave absorption properties of coconut fibers mixed with charcoal and epoxy resin are <-25 dB. Lin et al. [13] investigated the electromagnetic shielding effectiveness (EMSE) of wood plastic composite made from coir, carbon fibers, and polypropylene. At a ratio of coir and carbon fibers of 12:3, the EMSE is close to 0, which means the coir has no EMSE. Whereas increasing the carbon fibers to a ratio of 3:12 the EMSE is −25 dB.

This study developed a coconut fiber composite using both ICP and CPC. First, coconut fibers as reinforced were coated with polyaniline (PANI) using in-situ polymerization. Second, epoxy resin as an insulating polymer matrix was doped with multiwall carbon nanotubes (MWCNTs) as a conductive filler. The composite is composed of the coconut coir coated with PANI as reinforced and the MWCNTs doped epoxy resin as a matrix. The percentage of coconut fibers contained was varied to the weight of epoxy resin: 5, 10, and 15 wt%. Then, the coconut fiber composite (CCFC) underwent electrical volume resistivity, tensile strength, shielding effectiveness measurement, and scanning electron microscopy (SEM). The electrical volume-conductivity is indirectly taken from electrical volume-resistivity measurement.

2. Materials and method

2.1. Materials

Coconut fibers were supplied by rural plantations in Lampung. Aniline was supplied by Merck. All solution used in this study was in analytical grade. Multiwall carbon nanotubes (MWCNTs) were supplied by US Research Nanomaterial, Inc. The polymer matrix was butyl glycidyl ether of bisphenol-A epoxy resin supplied by Local Enterprise Co., Hongkong.

2.2. Preparation of composite samples

Coconut fibers were treated with 2 wt% NaOH solution for 2 hours at room temperature, followed by washing with distilled water several times to leach out the absorbed alkali and dried in an oven at 70 °C for several hours. The coconut fibers were cut to a length of 10 mm. The polyaniline-coated coconut fibers were prepared by in-situ polymerization using aniline as a monomer, HCl as a dopant, and ammonium persulfate (APS) as an oxidant. The polymerization is carried out based on the method proposed by Merlini et al. [14]. While the amount of 0.5 wt% MWCNTs was poured into epoxy resin and stirred for 10 minutes. The composites were made on three types of weight percentages of coconut fibers to epoxy resin: 5 wt%, 10 wt%, and 15 wt%. The coconut fibers were placed in the mold, then the MWCNTs-doped epoxy resin was poured into a mold and subjected to compression molding. The composite was left cured at room temperature for 8 hours. Then, the CCFC was cut into some samples. There are 15 disc-shaped specimens, 3 dog-bone specimens, and 3 rectangular boxes for electrical volume-resistivity, tensile strength, and shielding effectiveness measurements, respectively.

2.3. Method of tensile strength testing

The specification of dog-bone specimens is in accordance with ASTM D 638-1. A tensile test was performed using MTS Landmark 100 kN.

2.4. Method of electrical volume-resistivity measurement

The electrical volume-conductivity was indirectly determined by measuring volume-resistivity. Volume-resistivity measurements were obtained for the disc-shaped specimens with a diameter of 105 mm using the four-point-probe method proposed by Tobing [17] as shown in Fig. 1. The volume-resistivity for each type of coconut fiber composite is taken from the average results of five measurements. Those were used to calculate the electrical volume-conductivity.

2.5. Method of shielding effectiveness measurement

The samples of EMI shielding enclosure were rectangular box-shaped sized 120 mm × 80 mm × 50 mm. The shielding effectiveness (SE) measurement of the EMI shielding enclosure was carried out using the modified method of IEEE Std. 299 for small enclosures proposed by Ustuner et al. [18]. One monopole antenna is placed located outside of the enclosure as a transmitter, and the second monopole antenna is used inside the enclosure as a receiver. Both antennas were aligned at a distance of 20 mm. The first antenna is connected to a function generator, and the second antenna is connected to an oscilloscope. A BNC female connector was attached to the second monopole and inserted into the enclosure through a

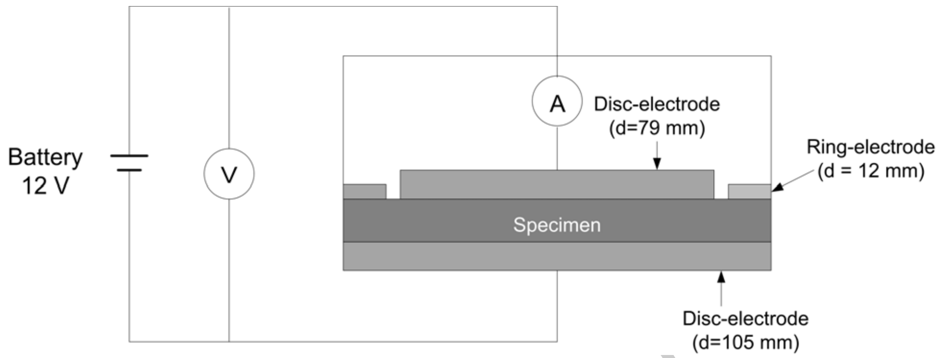


Fig. 1. The schematic diagram of volume-resistivity measurement using the 4-point-probe method.

hole to provide a connection to the oscilloscope using a coaxial cable. The schematic diagram of the SE measurement set-up is shown in Fig. 2. The SE test was carried out in a regular room without an anechoic chamber and was performed in two steps. The first step is to obtain the voltage received by the receiver antenna with the enclosure (V_1), and the second is to measure that voltage without the enclosure (V_2). Those measurements were conducted in the frequency range between 1 MHz–20 MHz. The shielding effectiveness was calculated using a ratio of amplitude with and without enclosure as shown in (1).

$$\mathrm{SE} = 20 \log \left(\frac{V_1}{V_2} \right) \tag{1}$$

3. Results and discussion

3.1. Morphologies of coconut fiber composites (CCFC)

Figure 3a and b shows SEM images on the fracture surfaces of CCFC 5 wt% and 15 wt%. It can be seen a good fibers and epoxy resin matrix adhesion is achieved in the composites CCFC 5 wt% than that in 15 wt%. In contrast, as the content of conducting fibers is increased, the presence of voids in the matrix and at the fiber/matrix interface can be observed. These results are similar to the study reported by Merlini et al. [14]. The dispersion of carbon nanotubes can be illustrated in Fig. 3c, the MWCNTs which indicated as bright spots were fairly distributed in the polymer matrix.

3.2. Tensile strength of coconut fiber composites

The effect of coconut fiber weight content on the tensile strength of these composites is shown in Fig. 4. The tensile strength of coconut fiber composites decreased as the coconut fiber weight percentage increased. These results are similar to a previous study reported by Gelfuso et al. [19]. Composite with fiber weight content higher than 10 wt% leads to agglomeration. The matrix has lower tensile strength than fiber, so in the composite 5 wt% the tensile load can easily transfer to the fiber and the tension increase to break up the fiber. Whereas, for composite 10 wt% and 15 wt% the agglomeration of fiber blocks the load transfer, so the load path tends to occur in a resin matrix. Hence, the tensile strength decreased, and the curve of composite 10 wt% and 15 wt% was smoother than that of composite 5 wt%. The SEM images of composite 15 wt% shown in Fig. 3c display the fracture that occurs in the polymer matrix.

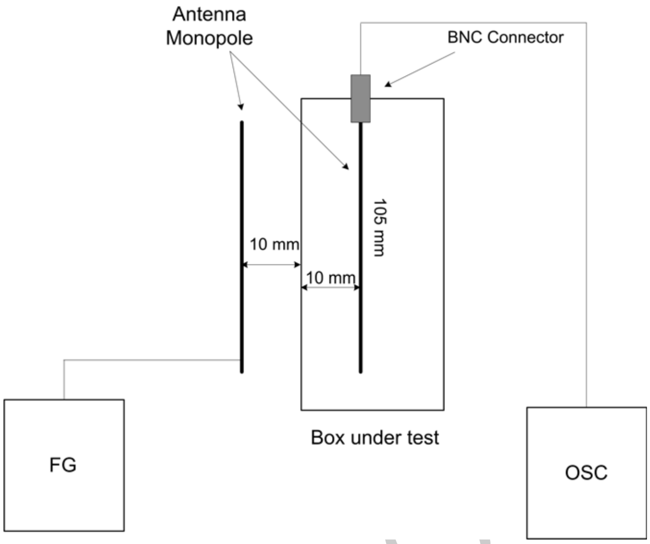
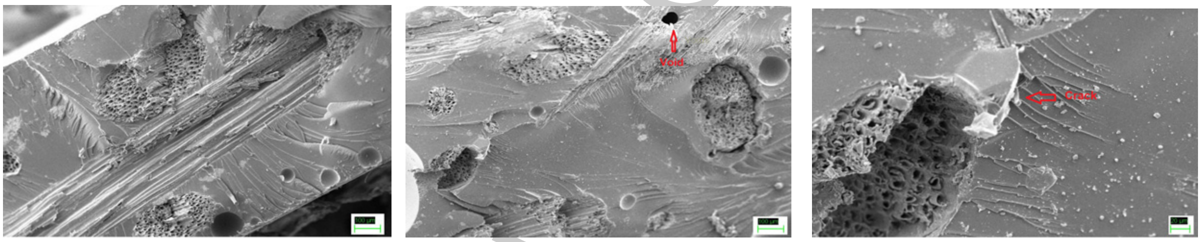


Fig. 2. The schematic diagram of shielding effectiveness measurement.



(a) (b) (c)

Fig. 3. SEM images of coconut fiber composites a. 5 wt%, b. and c. 15 wt%.

3.3. Electrical volume-conductivity and shielding effectiveness of coconut fiber composites

The results of average volume-resistivity measurement for three types of CCFC are shown in Table 1. The electrical volume-conductivity and shielding effectiveness are shown in Figs 5 and 6. The electrical volume-conductivity of CCFC: 5 wt%, 10 wt%, and 15 wt% are 0.0142 S/m, 0.0368 S/m, and 0.0458 S/m. Pure epoxy resin is an insulating material with electrical conductivity of 2×10^{-10} S/m. The increment of electrical conductivity of CCFC mainly resulted from the addition of PANI-coated coconut fiber. The electrical conductivity of PANI-coated coir fiber by insitu process is 4.93×10^{-2} S/m reported by Karthikeyan et al. [15]. Therefore, the addition of the coconut fiber weight content develops more electrically conductive networks in an epoxy resin matrix and it provides more path for current to flow. The MWCNTs are attributed to improving the conductive network in an epoxy resin matrix. PANI-coated coconut fibers and MWCNTs can both enhance the electrical conductivities of CCFC. Huangfu et al. [20] investigated the effect of PANI and MWCNT to improve the electrical conductivity of epoxy nanocomposites, the results suggest that MWCNT and PANI can enhance the electrical conductivities of PANI/MWCNT/TAGA/epoxy (PCGE composites).

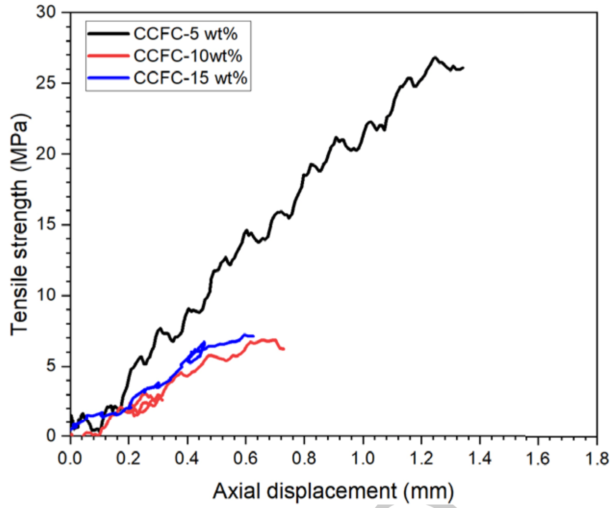


Fig. 4. Typical tensile strength-axial displacement behavior of coconut fiber composite: 5, 10, and 15 wt%.

Table 1
Volume-resistivity measured result

Sample type	Current (A)	Voltage (V)	Resistance (Ω)	Thickness (mm)	Volume-resistivity (Ω-mm)
CCFC-5 wt%	0.760	11.118	14.456	1.020	70.606×10^3
CCFC-10 wt%	1.124	11.078	9.893	1.100	44.999×10^3
CCFC-15 wt%	1.314	10.692	8.255	1.840	23.916×10^3

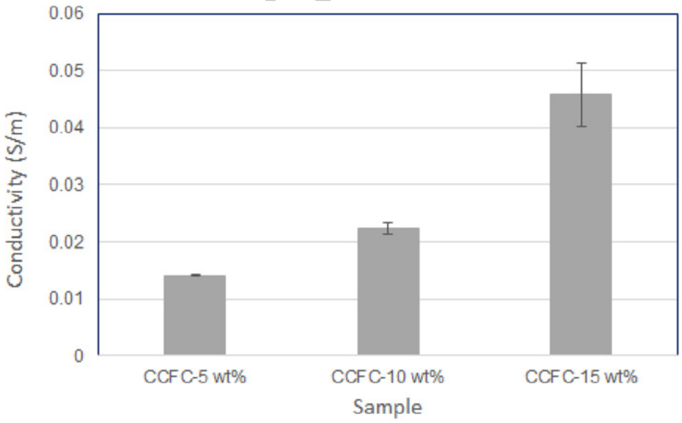


Fig. 5. The electrical volume-conductivity of coconut fiber composite: 5, 10, and 15 wt%.

Figure 6 shows the shielding effectiveness of three enclosures made from CCFC: 5 wt%, 10 wt%, and 15 wt % were −4.9 dB, −7.18 dB, and −7.69 dB, respectively. The SE of three enclosures in the frequency range of 1–20 MHz were below 10 dB which can be related to the low conductivity of the CCFC. The

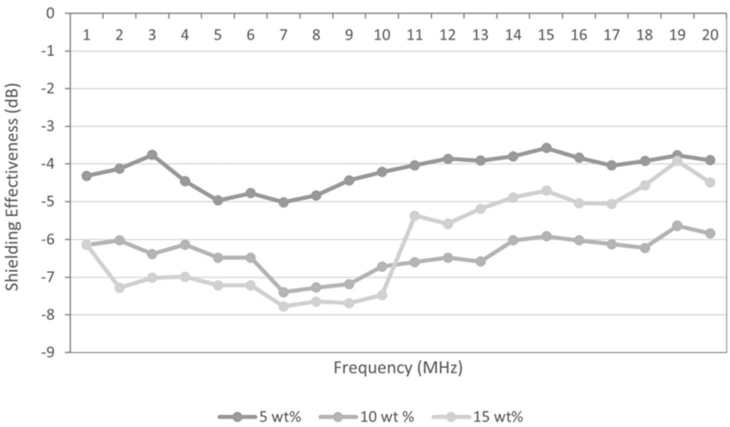


Fig. 6. Shielding effectiveness of coconut fiber composite-enclosures: 5, 10, and 15 wt%.

SE of enclosures was increased as the weight percentage of coconut fiber increased. The addition of PANI-coated coconut fiber and MWCNT improve the absorption of electromagnetic wave of coconut fiber composites. The SE results in this study are lower than that reported by other works, particularly for epoxy EMI composites [4,6,21]. The reason is related to the usage of natural fiber, though the coconut fiber has been coated with PANI the electrical conductivity is lower than metallic or inorganic nonmetallic filler such as $Ti_3C_2T_x$/Fe3O4/cellulose nanofibers [6], graphene/FeNi [4], and copper nanowires/ thermally annealed graphene aerogel (TAGA) [21]. The other reason is the weight content of inorganic nonmetallic filler. Huangfu et al. [20] reported that epoxy nanocomposites with 2.58 wt% PANI + 0.83 wt% MWCNT + 1.2 wt% TAGA as the filler have electrical conductivity 52.1 S/m and EMI shielding effectiveness 42 dB. The amount of MWCNT and TAGA in that research is 2.03 wt% higher than the quantity of MWCNTs in this study (0.5 wt%). On the other hand, the lower SE of the enclosure is due to the poor response of a monopole antenna at the lower frequencies [18] and the SE measurement conducted in a non-anechoic environment. Generally, measurement of EMI shielding effectiveness using waveguide transmission line [20] or coaxial transmission line [7] as a specimen holder with a sample made from planar material. These measurements are less severe to the disturbance of electromagnetic interference from nearby environments. In general, this study shows that coconut fiber composites properties can be potentially used as EMI shielding material, though it requires a treatment to increase their electrical conductivity and mechanical properties.

4. Conclusion

This research has investigated the application of polyaniline-coated coconut fibers and MWCNTs-doped epoxy resin to compose coconut fiber composites. The electrical volume-conductivity of the coconut fiber composite has a strong relationship with its shielding effectiveness. The highest weight percentage of coconut fiber resulted in the highest volume-conductivity and shielding effectiveness. The highest shielding effectiveness of EMI shielding enclosure made of coconut fiber composite 15 wt% was −7.69 dB which is related to volume-conductivity of 0.0458 S/m. Whereas, tensile strength decreased as the coconut fibers increased. The highest tensile strength was 26.78 MPa.

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