**UNIVERSITI PUTRA MALAYSIA**

***FABRICATION AND CHARACTERISTICS OF OIL PALM FIBRE-REINFORCED POLYLACTIC ACID COMPOSITE FILLED WITH IRON OXIDE FOR MICROWAVE APPLICATION***

**DAW MOHAMMAD ABDALHADI**

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By

**DAW MOHAMMAD ABDALHADI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy**

**May 2018**

## DEDICATION

I dedicate this work to my late father (May Allah be merciful to him), my mother and members of my beloved family.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**Chairman : Associate Professor Zulkifly Abbas, PhD**
**Faculty : Science**

Microwave absorbers generally consist of a filler material inside a polymer matrix. The filler contains one or more elements that do most of the absorbing. Absorbers are used in a wide range of applications to eliminate stray or unwanted radiation that could interfere with a system's operation. Ferrites is the most common shielding material in the development of absorbing composites. However, ferrites are heavy, corrosive, non-biodegradable and expensive. This project investigates the application of oil palm empty fruit bunch fibres (OPEFB) as an alternative to ferrite fillers for microwave absorbing applications with PLA as the host matrix. OPEFB offer various advantages such as low cost, low density, better thermal, insulating properties and biodegradability. Also PLA has significant advantages including ease of fabrication, zero toxicity, biodegradability, high mechanical strength and thermal plasticity. Different compositions of filler were doped and blended to produce OPEFB-PLA and OPEFB-PLA-$Fe_2O_3$ composites via Brabender Plastograph EC blending machine operating at 170°C with rotor speed of 50 rpm for 20 minutes. The total mass of each blended composite was 45g and contained 200 μm size OPEFB fibres. The crystalline structure of the composites was analyzed using X-ray diffraction (XRD) machine. The elemental compositions were examined using Scanning Electron Microscopy (SEM), energy dispersive X-ray analysis (EDX) and Fourier transform infrared (FTIR) techniques. Thermal analyses were carried out using TGA and DTG. The dielectric properties and S-Parameters, were measured using a PNA (N5227) Network Analyzer from 8GHz to 12 GHz for rectangular waveguide and 0.01 GHz to 12 GHz for microstrip at room temperature. The theoretical calculations of the S-Parameters coefficients of the samples were computed using Finite Element Method (FEM) in conjunction with the COMSOL software. The comparison between the measured and calculated

scattering parameters was also investigated. The permittivity of the composites was found to be dependent on the mixing ratio between OPEFB, PLA, and $Fe_2O_3$. At 10 GHz in the X-band frequencies, the dielectric constants of OPEFB-PLA and OPEFB-PLA-$Fe_2O_3$ composites were found to be between 3.04 to 3.36 and 3.14 to 3.7 respectively while the loss factor values were from 0.3 to 0.4 and 0.3 to 0. 346. Both the dielectric constant and loss factor of the OPEFB-PLA OPEFB-PLA-$Fe_2O_3$ composites increased with increasing percentages of OPEFB and $Fe_2O_3$ fillers. Furthermore, the results obtained from the scattering parameters $|S_{11}|$ and $|S_{21}|$ were used to determine the absorption loss of the different percentages of OPEFB-PLA and OPEFB-PLA-$Fe_2O_3$ composites samples, the absorption loss were found at 10 GHz to be from 0.049 to 0.105 and 0.045 to 0.062 respectively. Finally, the effect of the different percentages of OPEFB and $Fe_2O_3$ filler on the electric field was investigated by visualizing the electric field distribution pattern of the OPEFB-PLA and OPEFBPLA-$Fe_2O_3$ composites samples placed in the rectangular waveguide and placed on the top of microstrip using finite element method.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**FABRIKASI DAN CIRI-CIRI KOMPOSIT ASID POLILAKTIK DIPERKUATKAN DENGAN FIBER KELAPA SAWIT DAN FERUM OKSIDA UNTUK KEGUNAAN MIKROGELOMBANG**

Oleh

**DAW MOHAMMAD ABDALHADI**

**Mei 2018**

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Penyerap mikrogelombang kebiasaanya mempunyai bahan pengisi di dalam polimer matrik. Pengisi mempunyai satu atau lebih elemen yang melakukan penyerapan. Penyerap digunakan dalam banyak aplikasi untuk menghilangkan radiasi sesat atau yang tidak diperlukan daripada menganggu operasi sistem. Besi oksida ($Fe_2O_3$) adalah bahan pelindung yang biasa digunakan di dalam perkembangan komposit penyerap. Walau bagaimanapun besi oksida adalah berat, menghakis, tidak biodegrasi dan mahal. Projek ini membincangkan aplikasi komposit serat tandan kosong (OPEFB) sebagai alternatif pengisi besi oksida untuk aplikasi penyerapan mikrogelombang dengan asid polilaktik (PLA) sebagai hos matrik. OPEFB mempunyai banyak kelebihan seperti murah, densiti yang rendah, terma yang baik, berciri penebat dan boleh biodegradasi. PLA juga mempunyai banyak kelebihan termasuk mudah untuk difabrikasi, tiada toksik, boleh biodegrasi, kekuatan mekanikal yang tinggi dan terma keplastikan. Pengisi dengan komposisi yang berbeza telah di didopkan dan digaul untuk menghasilkan komposit OPEFB-PLA dan OPEFB-PLA-$Fe_2O_3$ menggunakan mesin penggaul *Brabender Plastograph EC* pada 170°C dengan kelajuan rotor 50rpm selama 20 minit. Kesemua jisim komposit adalah 45g dan mengandungi serat OPEFB sebesar 200 µm. Struktur Kristal komposit telah diperiksa menggunakan mesin pembelahan sinar-X (XRD). Komposisi elemental telah diperiksa menggunakan Pencarian Elektron Mikroskopi (SEM), analisis tenaga larian sinar-X (EDX) dan teknik pengubah Fourier inframerah (FTIR). Analisis terma dilakukan menggunakan TGA dan DTG. Pemalar dielektrik dan Parameter-S diukur menggunakan PNA (N5227) *Network Analyzer* dari 8GHz hingga 12 GHz untuk pandu gelombang bersegi empat dan 0.01 GHz hingga 12 GHz untuk mikrostrip suhu bilik. Teori pengiraan untuk Parameter-S pekali di kira melalui Finite Element Method (FEM) dengan perisian COMSOL.

Perbandingan diantara pengukuran dan pengiraan parameter penyerakan juga diperiksa. Kadar ketulusan komposit juga dijumpai berhubung kait dengan nisbah diantara OPEFB, PLA dan $Fe_2O_3$. Di frekuensi X pada 10GHz, dielektrik pemalar OPEFB-PLA dan OPEFB-PLA-$Fe_2O_3$ komposit dijumpai diantara 3.04 hingga 3.36 dan 3.14 hingga 3.7 masing-masing manakala faktor hilang untuk adalah dari 0.3 hingga 0.4 dan 0.3 hingga 0.346. Kedua-dua pemalar dielektrik dan faktor hilang untuk OPEFB-PLA dan OPEFB-PLA-$Fe_2O_3$ komposit bertambah dengan pertambahan nilai OPEFB dan $Fe_2O_3$ pengisi. Tambahan lagi, keputusan yang didapati dari parameter penyerakan $|S_{11}|$ dan $|S_{21}|$ telah digunakan untuk mengira penyerapan yang hilang dalam perbezaan peratusan OPEFB-PLA dan OPEFB-PLA-$Fe_2O_3$ sampel komposit, nilai penyerapan yang hilang di 10 GHz adalah dari 0.049 hingga 0.105 dan 0.045 hingga 0.062 masing-masing. Akhir sekali, kesan perbezaan peratusan OPEFB dan $Fe_2O_3$ pengisi dalam medan elektrik telah diperiksa dengan mereka medan elektrik corak pengedaran untuk OPEFB-PLA dan OPEFB-PLA-$Fe_2O_3$ komposit sampel yang diletakkan di dalam pandu gelombang segi empat dan yang diletakkan di atas microstrip menggunakan *finite element method.*

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Finally, I wish to thank the Embassy of Libya in Malaysia (Academic Affairs and Consular) and The Ministry of Education in Libya for granting me the scholarship to pursue my PhD studies in Malaysia.

I certify that a Thesis Examination Committee has met on 21 May 2018 to conduct the final examination of Daw Mohammad Abdalhadi on his thesis entitled "Fabrication and Characteristics of Oil Palm Fibre-Reinforced Polylactic Acid Composite Filled with Iron Oxide for Microwave Application" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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**Declaration by graduate student**

I hereby confirm that:

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| | |
|---|---|
| PLA | Polylactic acids |
| OPEFB | Oil palm empty fruit bunch |
| $Fe_2O_3$ | Iron Oxide |
| OECP | Open Ended Coaxial Probe |
| RWG | Rectangular waveguide |
| c | Velocity of light |
| $\varepsilon^*$ | Complex permittivity |
| $\varepsilon'$ | Dielectric constant |
| $\varepsilon''$ | Loss factor |
| EM | Electromagnetic |
| EMI | Electromagnetic interference shielding |
| $\sigma$ | Electrical conductivity |
| $\varepsilon$ | Permittivity |
| $\mu$ | Permeability |
| SE | Shielding effectiveness |
| dB | Decibels |
| FEM | Finite Element Method |
| XRD | X-ray diffraction |
| TGA | Thermogravimetric analysis |
| DTG | Differential thermal |
| FTIR | Fourier transforms infrared |
| SEM | Scanning electron microscopy |
| EDX | Energy Dispersive X-ray |

| | |
|---|---|
| T/R | Reflection/Transmission |
| RFI | Radio frequency interference |
| J | The current density |
| D | The electric displacement |
| B | The magnetic flux density |
| $\gamma$ | Propagation constant |
| $\rho_q$ | The electric charge density |
| β | Phase constant |
| $\nabla$ | Laplacian vector |
| d | Sample thickness |
| $\eta$ | Impedance |
| $\eta_0$ | Impedance in free space |
| $\omega$ | Angular frequency |
| f | Frequency |
| fr | Critical frequency |
| $\varepsilon_r$ | Relative dielectric of the substrate |
| $H_z$ | Longitudinal magnetic field |
| $E_z$ | Longitudinal electric field |
| $P_1$ | Power measured with the material inserted |
| $P_2$ | Power measured without material inserted |
| $Z_O$ | Impedance of free space |
| $Z_{in}$ | Impedance of the absorbing material |
| $S_{11}$ | Input reflection coefficient of port one |

| | |
|---|---|
| $S_{12}$ | Transmission coefficient port one |
| $S_{22}$ | Input reflection coefficient of port two |
| $S_{21}$ | Transmission coefficient port two |
| TE | Transverse Electric |
| TM | Transverse Magnetic |
| $k_0$ | Free-space wave number |
| TEM | Transverse electromagnetic modes |
| MoM | Method of Moment |
| MUT | Materials under test, |
| PNA | Professional network analyzer |
| FDTD | Finite difference time domain |

# CHAPTER 1

# INTRODUCTION

The extensive development of electronic equipment and telecommunications has led to major concerns about electromagnetic pollution which has risen to a level never attained before. This situation has necessitated the continuous development of materials which are highly efficient in the inhibition or shielding of this undesirable radiation. Electromagnetic shielding is defined as the prevention of the propagation of electric and magnetic waves from one medium to another by using conducting or magnetic materials (Mu et al. 2015). The shielding can be carried out by minimizing the electromagnetic waves passing through a system either by reflection of the wave or by absorption and dissipation of the radiation power in the material. Theoretically, shielding reduces the coupling of electromagnetic waves, electromagnetic fields, and electrostatic fields and its effectiveness depends on the type of the material used, its thickness, the size of the shielded volume and operating frequency. In the industry of aerospace, for example, innovative solutions are needed to shield effectively sensitive electronic equipment such antennas from EMI without adding much of weight to aircraft. In the past, the problem of EMI was solved by isolating the electronic device through some metallic housing. Common metals like silver, iron, and aluminum were seen in most of the shields composed of metals used at that time. The high strength and conductivity of metals and alloys like mu-metal made them an interesting choice for applications such as shielding materials especially for shielding from low magnetic fields. The main parts of mu-metal were copper (5%), iron (14%), nickel (79.5%) and chromium (1.5%). It had sufficient ductility and could simply be made into sheets necessary for magnetic shields. Also, high permeability in mu-metal provided an avenue for the magnetic line of flux around the shielded area. Nonetheless, the disadvantage was that the metals were easily susceptible to oxidation or corrosion and so could not be utilized for outside applications. The heavyweight and price of the metal shields also limit the use of metals as shielding materials (Jagatheesan et al. 2015). Nowadays, the most common method of shielding by reflection is the use of metallic plates or adsorption by conductive polymers. Polymeric materials have also acquired popularity due to their flexibility, light weight, corrosion resistance, and lower cost than metals. Currently, metallic materials and polymer composites are by far the most commonly used materials. Research has also been carried out on the applications of polymer composites loaded with conductive fillers, fibres, nanotubes and dispersing particles (X. Chen, Liu, Liu, & Pan, 2015). Metals such as copper, gold, and silver have also been widely used in shielding. The problems of metal plates mainly focused on the discomfort of poor mechanical flexibility owing to the high stiffness, high weight density, and high cost. For a typical EM absorbing material, low density, high conductivity, strong broadband absorption and excellent thermal stability are the key parameters. The mechanism of microwave absorption categorizes the materials into two major sections; dielectric loss materials and magnetically lossy materials (Arief, Biswas, & Bose, 2017).

Ferrites have been used as absorbing materials in various forms for many years due to their large magnetic loss and large resistivity. Since the imaginary part of the complex permittivity of ferrites is very small, the dielectric loss is almost negligible and therefore their absorbing performance mainly depends on the magnetic loss (Li et al. 2017)

The design of an EMI shielding material with some degree of attenuation while meeting a set of environmental criteria, maintaining economics and regulating shielding have been proposed. The main motivation behind the proper design of the shield is to make a product that can conform to International Electromagnetic Interference Regulatory Standards. Investigation of new active materials applicable as microwave absorbers for electromagnetic interference (EMI) shielding of various electronic devices ranks among significant present-day activities (Paligova et al., 2004). Several studies have also been carried out to develop new microwave absorbing materials with high complex permeability and low reflection loss (Luo et al., 2015).

## 1.1 Absorbing Composites

Most conventional composites are supported by polymer as the matrix while fillers are the reinforcement's materials. The fillers are selected according to their properties which are based on what is needed from the composite. Many commercially produced composites utilize polymer matrix material often called a resin solution. There are a lot of different polymers with several broad categories and many variations available depending upon the preliminary raw ingredients. The most commonly used polymers are polyester, polylactic acid (PLA), polycaprolactone (PCL), ester, epoxy, phenol, polyimide, polyamide, polypropylene, and others (Pawar et al. 2016). Polymers have a very low concentricity of free charge carriers, and thus are non-conductive and transparent to electromagnetic radiation. Therefore, they are not appropriate for use as shielding for electronic equipment because they cannot protect it from external radiation. Also, they cannot prevent the flight of radiation from the component. Various fillers can be added to the isolating polymeric matrix to obtain different conductivity ranges. Therefore, the type or nature of fillers determines the dielectric characteristics of the polymer compound. A polymer that is conductive has evolved much interest in the recent past due to their excellent flexibility and easy preparation procedures as against conventional inorganic semiconductors. They are applied in areas of electronics as flexibility conductors and shielding devices, especially from electromagnetic radiation. (Gupta et al. 2015).The ceramic microwave absorbers lack flexibility and moldability into any desired shape. These difficulties can be overcome by incorporating the ferrites into the rubber matrix. Incorporation of ferrite powders in natural or synthetic rubbers produces flexible Rubber ferrite composites, which have many novel applications (Prema et al. 2008).

## 1.2 Interactions of Materials with Microwaves

The ability of the material to interact with electromagnetic energy is related to the material complex permittivity. A frequency characterizes this property in any homogeneous, isotropic and linear dielectric material. The dielectric constant is a measure of how much energy from an external electric field is stored in the material, while the loss factor accounts for the loss energy dissipative mechanisms in the material (Lamberti et al. 2015). Therefore, the material with a higher loss factor is readily heated by microwave (Satish et al. 2006). On the other hand, any material that has a very low loss factor is transparent to microwave effect. The microwave is only a small part of the electromagnetic spectrum (300 MHz to 300 GHz), which corresponds to wavelengths between 1m and 0.001m (Mudinepalli et al 2013). However, their uses have become more and more important in the study of material properties. The material characterization is essential for the correct selection and conversion of a substance for industrial, scientific and medical applications. The dielectric parameters over a wide temperature range are needed to assess their suitability for use in telecommunication, dielectric waveguides, lenses, dielectric resonators, and microwave integrated circuits (MICs). The electromagnetic spectrum consists of various types of electromagnetic signals. Microwave behaves similarly to light wave, which travels in straight lines, reflect, refract, diffract, scatter, and interfere in the same physical length. However, they differ in the behavior due to the difference in wavelength. Microwave wavelengths are typically $10^5$ greater than optical wavelengths. Thus microwaves tend to interact with materials and structures on a macroscopic scale. For example, microwaves can penetrate most non-metallic materials, reflect and scatter from internal boundaries, and interact with molecules (Bahr, 1982). Microwaves do not change or heat in any way the material due to the extremely low energy emitted (Yahaya et al., 2015). The signals can penetrate inside dielectric (electrically insulating) material easily. The depth of penetration is dictated by the loss factor of the dielectric material (ability to absorb microwave energy), the frequency of operation and the reflected or transmitted signal can then be related to the dielectric properties of the material (Zoughi et al. 1995).Many ideas have been tried to adapt these phenomena to microwave applications. The two critical applications that deal with the use of microwave properties are EMI shielding and radar absorbing materials.The uses of microwave technology can be found in various fields such as communications, radio, military, environmental remote sensing, weather monitoring and forecasting, soil settlement system, astronomy and medical system. Much of the success of today's microwave technology is due to decades of unremitting efforts, hard work and careful research by Andre-Marie Ampere, Carl Friedrich Gauß, Michael Faraday, Oliver Heaviside, Heinrich Hertz and James Clerk Maxwell (Pozar, 2009).

The interest of this work is in the interaction of microwaves with materials. These include parameters of absorption in materials, scattering, reflection, and transmission. These effects are utilized in various test setups to allow quantitative measurements in materials.

## 1.3 OPEFB Background

Natural fibres offer several advantages such as low density, low cost, biodegradability, acceptable specific properties, better thermal and insulating properties and low energy consumption during processing (Faizi et al., 2017).

The oil palm industries generate an abundant amount of biomass in millions of tons per year (Mohanty et al. 2005) which, if properly utilized, can solve the problem with disposal and build value-added products as well. OPEFB fibre is among the biomass that is currently utilized as fuel in the oil palm mills for the production of energy. There are ongoing attempts to transform OPEFB fibres into fertilizers by burning them into ash, which is abundant in potassium. However, this brings the issue about the environmental pollution created by the unrestrained burning of OPEFB fibres. The investigation of OPEFB fibre properties, such as their mechanical and physical characteristics, has resulted in their diverse applications in the field of composite materials.

Oil palm fibres are obtained from two parts of the oil palm tree, which are, the OPEFB and mesocarp. Among these two, OPEFB fibre is the most frequently used in composite materials and several other applications, because OPEFB is comprised of a cluster of fibres which is easily available and cheap. OPEFB fibres are extracted from the empty fruit bunch through the retting process while the mesocarp fibres are waste materials that remain after the oil extraction and requires cleaning before it is finally used (Hassan et al. 2010).

## 1.4 PLA Background

Biodegradable polymers are defined as those that undergo microbially induced chain scission leading to the mineralization. Biodegradable polymers may not be produced from bio source only, but it can be derived from the petroleum source. Polymers are also being produced from bio sources such as poly-hydroxybutyrate (PHB) and polyhydroxy valerate (PHV). On the other hand, the biodegradable polymer which is produced from the petroleum source is polylactic acid (Ray et al. 2005). PLA production has grown annually, and currently, it is estimated that worldwide production will reach at least 800,000 tons by 2020 with Japan and the USA the two major producers. PLA has gained importance due to its mechanical properties which are similar to the petrochemical-based plastics polyethylene terephthalate (PET) and polystyrene (PS). It has some favourable properties including ease of fabrication, zero toxicity, biocompatibility, high mechanical strength and thermal plasticity and is compostable. Most importantly its raw material, lactic acid, can be obtained from renewable resources, principally starch. As PLA is a polymer synthesized from renewable resources, it has been suggested that its use could help to lower greenhouse gas emissions and reduce fossil energy consumption compared to conventional petrochemical-based polymers. However, the ever-increasing diversion of starch feed-stocks such as maize to PLA production also brings pressures on land use and agriculture (Karamanlioglu et al. 2017). Polymers are usually used as housings or assemblies in the electronic and electrical industries. The desirable combination of characteristics like the low cost, a simplicity of fabrication, lightweight, and superior insulation characteristic make plastics one of the most useful materials for electronics and electrical applications. The function of plastics in the electronic and electrical applications was limited to general applications with no-load bearing uses. Plastic materials reinforced with fibre serve as effective insulators which enhance the mechanical properties of the field - carrying conductors (Jayamani et al. 2014). Nevertheless, different applications such as cable and wire sheathing and shielding from electromagnetic interference require the polymers be made conductive for the dispersal of electrostatic charges. This is achieved by incorporating conductive reinforcements in them. Combining fibrous reinforcements into polymer matrices results into high-performance matrix materials having excellent mechanical characteristics suitable for electronics and electrical applications. They can be utilized as terminals, connectors, household and industrial plugs, printed circuit boards and switches.

## 1.5 $Fe_2O_3$ Background

Ferrites can be defined as magnetic materials which are a composition of an oxide containing ferric ions as the essential constituent. There are two types of ferrites namely, soft and hard ferrites. The soft ferrite does not retain significant magnetization, while the hard ferrite has a rather permanent magnetization. The soft ferrite has a broad range of applications in electronics such as television refraction yokes and flyback transformers, revolving transformers in video players and recorders as well as switch-mode power supplies. Also, soft ferrite is used in electromagnetic interference and radio frequency interference absorbing materials, and a wide variety of transformer, filters, and inductors in electronic home appliances and industrial equipment (Mandal et al., 2016).

Iron oxides are among the most diffused chemical compounds in nature and are composed of Fe combined with O. Nowadays, they are used mainly as the raw in iron and steel industry and as pigments. Some can be achieved by thermal transformation; for example maghemite ($\gamma$- $Fe_2O_3$), which can be derived from the heating of some iron oxides associated with organic matters, or hematite ($\alpha$-

$Fe_2O_3$), that can be produced by heating goethite [α FeO(OH)] at a temperature between 250°C and 300°C (LEVATO, 2013). Hematite (α-$Fe_2O_3$) is the most stable form of iron oxide with uncommon magnetic behavior, such as anti-ferromagnetism and weak ferromagnetism. The Hematite has the same crystal structure of corundum in the rhombohedral lattice system (Xu et al. 2015).

## 1.6 Electrical properties

Electromagnetic wave entering into the materials can be almost entirely attenuated and absorbed within the finite thickness of the absorber (attenuation characteristic). However, when the fillers are made from dielectric and ferroelectric materials, permeability remains the same throughout the range of frequency, and their higher propagation constant allows wave absorber to be produced thinner. These absorbers being purely dielectric, polarization and conductive losses are the principal mechanisms for the absorption of the microwave, and the complex permittivity is an important parameter to be measured (Rui et al. 2011). The interaction of microwaves with materials can be determined from Maxwell's equations and the materials' properties. The relations define a range of properties including propagation mode, reflection, refraction, transmission, and impedance (Luo et al. 2015). Both the permittivity and permeability are complex numbers of which the imaginary part is associated with losses. This rich and complex system of properties allows a very wide range of measurement techniques at microwave frequencies. Some methods have been used in the measurements of electromagnetic properties at microwave frequencies. Amongst these methods are the transmission and reflection line technique, free space measurement technique, open-ended coaxial probe technique, and resonant method (Venkatesh, 2005). These techniques can be grouped into two methods depending on sample location, namely; coaxial line or waveguide and free space measurement. The details of the first group have been clearly expounded by Von Hippel (Baker,1990). The main disadvantage of these methods is the difficulty in placing the sample to fit into the waveguide or coaxial fixture with no air gap. The details of these techniques would be described in subsequent chapters.

## 1.7 Problem statement

Materials with good absorption are in demand to solve many EMI problems in industrial and commercial electronics. The most common shielding material is mu-metal; an alloy containing copper, chromium, iron, and nickel. Pure iron or scientifically known as Ferrites are commonly used in the development of absorbing composites. However, like any other metals, ferrites are heavy, corrosive, non-biodegradable and expensive. Usage of different metals such as ferrites for shielding could easily lead to galvanic corrosion which in turn increased the nonlinearity behavior and decreased its shielding effectiveness. In recent years, conventional plastic materials filled with conductive materials are gaining interests as alternatives to mu-metal. However, these conductive materials are mostly non-biodegradable. During the biodegradation process, biodegradable polymers are broken down into their simpler constituent components and redistributed through elemental cycles such as the carbon and nitrogen cycles.

This project investigates the application of oil palm empty fruit bunch fibres (OPEFB) as an alternative to ferrite fillers for microwave absorbing applications with PLA as the host matrix. OPEFB is categorized as a palm oil industry waste which is generated from the oil extraction mills process. OPEFB offer various advantages such as low cost, low density, better thermal and insulating properties, acceptable specific properties low energy consumption during processing and biodegradability. OPEFB can provide good flexural strength, tensile strength, stiffness, and elongation at break. It is expected that fibres with lower grain size will have a higher density which in turn will increase both the dielectric constant and loss factor of the OPEFB (Shinoj et al. 2010). However, to date, the effect of grain size of OPEFB on the value of dielectric constant and loss factor has not been investigated.

Polycaprolactone (PCL), an aliphatic polyester has been proposed as the host matrix for microwave absorber (Ahmad et al. 2017). PCL is a biodegradable polymer. However, electronics application of PCL is limited due to its low melting temperature (57–60 °C) and inferior mechanical properties. In contrast, many biopolymers have many superior qualities such as polylactide (PLA) with melting temperature 160°C and higher mechanical strength. PCL waste has a long decomposition time more than 24 month. Whilst PLA decomposed within 6 to 12 months (Pal et al. 2013) and (Meng et al. 2010). PLA also has other significant advantages including ease of fabrication, zero toxicity, biocompatibility, high mechanical strength and thermal plasticity. Most importantly its raw material, lactic acid, can be obtained from renewable resources, principally starch. As PLA is a polymer synthesized from renewable resources, it has been suggested that its use could help to lower greenhouse gas emissions and reduce fossil energy consumption compared to conventional petrochemical-based polymers. It is important to visualize the electric field distribution in a transmission line for microwave circuit designer. However, although the electric field distribution of a microwave substrate in a closed waveguide has been reported in the literature (Hotta et al. 2011). But none has been published for open transmission line system such as microstrip. The electrical properties of heterogeneous materials are closely related to the composition of its constituents. The effect of ferrites on the attenuation of biobased absorbers was not investigated by previous workers. It is important to clearly distinguish the attenuation contribution to the composite between the bio-based host matrix and ferrites for cost-effective production of bio-based ferrite absorbers.

## 1.8 Research Objectives

The main objectives of this work are:

1. To fabrication samples of pure OPEFB fibre with different fibre size and samples of OPEFB-PLA, OPEFB-PLA-$Fe_2O_3$ composites with various percentage of OPEFB and $Fe_2O_3$ fillers and then characterize their structural properties by using XRD, TGA, DTG, FTIR, SEM, and EDX.
2. To determine the effect of OPEFB fibre size on its dielectric constant and loss factor values and measure the relative permittivity of OPEFB-PLA and OPEFB-PLA-$Fe_2O_3$ composites using the open-ended coaxial probe and rectangular waveguide techniques. The latter technique is also used to measure the permeability of the OPEFB-PLA -$Fe_2O_3$ composites.
3. To study the effect of fillers on the on the scattering parameters and absorption values of OPEFB-PLA and $Fe_2O_3$-OPEFB-PLA composites using rectangular waveguide and microstrip technique. The scattering parameters results will be compared theoretically with Finite element method (FEM).
4. To visualize the electromagnetic field distribution of the composites using FEM for various filler percentage.

## 1.9 The scope of study

In this study, biodegradable composites would be fabricated using OPEFB and PLA with $Fe_2O_3$ added to improve their electrical and magnetic properties. The melt blending technique via Brabender machine would be carried out. The effect of the different percentage of OPEFB and $Fe_2O_3$ fillers on the dielectric properties would be measured using the open-ended coaxial probe and rectangular waveguide techniques. The effect of the OPEFB and $Fe_2O_3$ filler on the transmission and reflection coefficient of the OPEFB-PLA and OPEFB-PLA-$Fe_2O_3$ composites would also be studied. It also proposes to use FEM COMSOL software in calculating scattering parameters and for simulating electromagnetic wave excited through OPEFB-PLA and OPEFB-PLA-$Fe_2O_3$composites samples when placed inside a rectangular waveguide and on top a microstrip. The result obtained for scattering parameter through measurement, simulation and calculation will also be compared. Error analysis for the comparison is determined by both measurements and FEM techniques. The morphological characterization would be carried out using specific equipment like the XRD, FTIR, SEM, and EDX.

# REFERENCES


Abbas, S., Dixit, A., Chatterjee, R., & Goel, T. (2007). Complex permittivity, complex permeability and microwave absorption properties of ferrite–polymer composites. Journal of Magnetism and Magnetic Materials, 309(1), 20-24.

Abbas, Z., Pollard, R. D., & Kelsall, R. W. (2001). Complex permittivity measurements at Ka-band using rectangular dielectric waveguide. Instrumentation and Measurement, IEEE Transactions on, 50(5), 1334-1342.

Abdul Khalil, H., Siti Alwani, M., Ridzuan, R., Kamarudin, H., & Khairul, A. (2008). Chemical composition, morphological characteristics, and cell wall structure of Malaysian oil palm fibers. Polymer-Plastics Technology and Engineering, 47(3), 273-280.

Abiola, O., Kupolati, W., Sadiku, E., & Ndambuki, J. (2014). Utilisation of natural fibre as modifier in bituminous mixes: a review. Construction and Building Materials, 54, 305-312.

Absalyamov, S., & Mulyukov, K. Y. (2000). The stability of hematite in small-size particles. Paper presented at the Doklady Physics , Vol. 45, No. 12, 2000, pp. 657–658.

Ahmad, A. F., Abbas, Z., Obaiys, S. J., & Abdalhadi, D. M. (2017). Improvement of Dielectric, Magnetic and Thermal Properties of OPEFB Fibre–Polycaprolactone Composite by Adding Ni–Zn Ferrite. Polymers, 9(2), 12.

Ahmad, S. H., Abdullah, M. H., Hui, D., Yusoff, A. N., & Puryanti, D. (2010). Magnetic and microwave absorbing properties of magnetite–thermoplastic natural rubber nanocomposites. Journal of Magnetism and Magnetic Materials, 322(21), 3401-3409.

Al-Ghamdi, A. A., Al-Hartomy, O. A., Al-Solamy, F. R., Dishovsky, N., Mihaylov, M., Malinova, P., & Atanasov, N. (2016). Dielectric and microwave properties of elastomer composites loaded with carbon–silica hybrid fillers. Journal of Applied Polymer Science, 133(7).

Arief, I., Biswas, S., & Bose, S. (2017). FeCo-Anchored Reduced Graphene Oxide Framework-Based Soft Composites containing Carbon Nanotubes as Highly Efficient Microwave Absorbers with Excellent Heat Dissipation Ability. ACS Applied Materials & Interfaces.

Baharudin, E., Ismail, A., Alhawari, A., Zainudin, E., Majid, D. A. A., Seman, F. C., & Khamis, N. (2013). Determination of pulverized material permittivity for microwave absorber application. Paper presented at the Micro and Nanoelectronics (RSM), 2013 IEEE Regional Symposium, DOI: 10.1109/RSM.2013.6706479,pages 85-88.

Bahr, A. J. (1982). Microwave nondestructive testing methods (Vol. 1): CRC Press.

Bakare, A. A. (2017). Numerical, Solution Of Second Order Differntial, Equations By Method Of Finite Element. Departemnt Of Mathematic, Faculty Of Physical Sciences, University Of Ilorin.

Baker-Jarvis, J. (1990). Transmission/reflection and short-circuit line permittivity measurements: National Institute of Standards and Technology Colorado.

Baker, C. O., Huang, X., Nelson, W., & Kaner, R. B. (2017). Polyaniline nanofibers: broadening applications for conducting polymers. Chemical Society Reviews, 46(5), 1510-1525.

Barba, P. (2006). Numerical S-parameter extraction and characterization of inhomogeneously filled waveguides.

Bayrakdar, H. (2011). Complex permittivity, complex permeability and microwave absorption properties of ferrite–paraffin polymer composites. Journal of Magnetism and Magnetic Materials, 323(14), 1882-1885.

Bayrakdar, H. (2012). Electromagnetic propagation and absorbing property of ferrite-polymer nanocomposite structure. Progress in Electromagnetics Research M, 25, 269-281.

Belaabed, B., Lamouri, S., Naar, N., Bourson, P., & Hamady, S. O. S. (2010). Polyaniline-doped benzene sulfonic acid/epoxy resin composites: structural, morphological, thermal and dielectric behaviors. Polymer journal, 42(7), 546-554.

Belaabed, B., Wojkiewicz, J. L., Lamouri, S., El Kamchi, N., & Lasri, T. (2012). Synthesis and characterization of hybrid conducting composites based on polyaniline/magnetite fillers with improved microwave absorption properties. Journal of Alloys and Compounds, 527, 137-144.

Bikky, R., Badi, N., & Bensaoula, A. (2010). Effective Medium Theory of Nanodielectrics for Embedded Energy Storage Capacitors. Paper presented at the COMSOL Conf.

Cazacu, G., Darie-Nita, R. N., Chirila, O., Totolin, M., Asandulesa, M., Ciolacu, D. E.,Vasile, C. (2016). Environmentally Friendly Polylactic Acid/Modified Lignosulfonate Biocomposites. Journal of Polymers and the Environment, DOI 10.1007/s10924-016-0868-2, 1-19.

Chen, L.-F., Ong, C., Neo, C., Varadan, V., & Varadan, V. K. (2004). Microwave electronics: measurement and materials characterization: John Wiley & Sons.

Chen, X., Liu, L., Liu, J., & Pan, F. (2015). Microstructure, electromagnetic shielding effectiveness and mechanical properties of Mg–Zn–Y–Zr alloys. Materials & Design (1980-2015), 65, 360-369.

Ching, Y. C., & Ng, T. S. (2014). Effect of preparation conditions on cellulose from oil palm empty fruit bunch fiber. BioResources, 9(4), 6373-6385.

Choh, J. L., Ching, Y. C., Gan, S. N., Rozali, S., & Julai, S. (2015). Effects of oil palm empty fruit bunch fiber on electrical and mechanical properties of conductive filler reinforced polymer composite. BioResources, 11(1), 913-928.

Chowdhury, M., Beg, M. D. H., Khan, M. R., & Mina, M. (2013). Modification of oil palm empty fruit bunch fibers by nanoparticle impregnation and alkali treatment. Cellulose, 20(3), 1477-1490.

Dorgan, J., Braun, B., Wegner, J., & Knauss, D. (2006). Poly (lactic acids): a brief review: ACS Publications.

Edwards, T. C., & Steer, M. B. (2016). Foundations for microstrip circuit design: John Wiley & Sons.

Esa, F., Abbas, Z., Mohd Idris, F., & Hashim, M. (2015). Characterization of NixZn1− xFe2O4 and Permittivity of Solid Material of NiO, ZnO, Fe2O3, and NixZn1− xFe2O4 at Microwave Frequency Using Open Ended Coaxial Probe. International Journal of Microwave Science and Technology, 2015.Volume 2015, ID 219195,8 pages.

Ewulonu, C. M., & Igwe, I. O. (2012). Properties of oil palm empty fruit bunch fibre filled high density polyethylene. International journal of engineering and technology, 3(6), 2011-2012.

Faizi, M., Shahriman, A., Majid, M. A., Shamsul, B., Ng, Y., Basah, S., Wan, K. (2017). An overview of the Oil Palm Empty Fruit Bunch (OPEFB) potential as reinforcing fibre in polymer composite for energy absorption applications. Paper presented at the MATEC Web of Conferences.

Fan, Y., Huang, X., Wang, G., & Jiang, P. (2015). Core–Shell Structured Biopolymer@ BaTiO3 Nanoparticles for Biopolymer Nanocomposites with Significantly Enhanced Dielectric Properties and Energy Storage Capability. The Journal of Physical Chemistry C, 119(49), 27330-27339.

Gupta, A. K., Biswal, M., Mohanty, S., & Nayak, S. (2016). Eco-friendly lignocellulosic natural fibre reinforced recycled polymer composite with modified interface and reactive compatibilization: A micromechanical analysis with various model. Materials Focus, 5(2), 106-118.

Gupta, V., Rama, S., Jha, M. K., & Qureshi, M. (2015). Anfis Prediction of the Polymer and Polymer Composite Properties and Its Optimization Technique: Ijirset. Modelling A; Vol. 87; N° 2; pp 70-88.

Harmaen, A., Khalina, A., Faizal, A., & Jawaid, M. (2013). Effect of triacetin on tensile properties of oil palm empty fruit bunch fiber-reinforced polylactic acid composites. Polymer-Plastics Technology and Engineering, 52(4), 400-406.

Harrington, R. F. Time-Harmonic Electromagnetic Fields. (2001). IEEE press. New York.

Harris, V. G., Geiler, A., Chen, Y., Yoon, S. D., Wu, M., Yang, A., Zuo, X. (2009). Recent advances in processing and applications of microwave ferrites. Journal of Magnetism and Magnetic Materials, 321(14), 2035-2047.

Harun, N. A. F., Baharuddin, A. S., Zainudin, M. H. M., Bahrin, E. K., Naim, M. N., & Zakaria, R. (2012). Cellulase production from treated oil palm empty fruit bunch degradation by locally isolated Thermobifida fusca. BioResources, 8(1), 676-687.

Hasan, M. R., & Al Suman, A. (2012). Substrate Height and Dielectric Constant Dependent Performance of Circular Micro Strip Patch Array Antennas for Broadband Wireless Access. Journal of Emerging Trends in Computing and Information Sciences, 3(10), 1392-1397.

Hassan, A., Salema, A. A., Ani, F. N., & Bakar, A. A. (2010). A review on oil palm empty fruit bunch fiber-reinforced polymer composite materials. Polymer Composites, 31(12), 2079-2101.

Henton, D. E., Gruber, P., Lunt, J., & Randall, J. (2005). Polylactic acid technology. Natural fibers, biopolymers, and biocomposites, 16, 527-577.

Holbery, J., & Houston, D. (2006). Natural-fiber-reinforced polymer composites in automotive applications. JOM Journal of the Minerals, Metals and Materials Society, 58(11), 80-86.

Hotta, M., Hayashi, M., Lanagan, M. T., Agrawal, D. K., & Nagata, K. (2011). Complex permittivity of graphite, carbon black and coal powders in the ranges of X-band frequencies (8.2 to 12.4 GHz) and between 1 and 10 GHz. ISIJ international, 51(11), 1766-1772.

Ibrahim, N., Hashim, N., Rahman, M. A., & Yunus, W. Z. W. (2011). Mechanical properties and morphology of oil palm empty fruit bunch—polypropylene composites: effect of adding ENGAGETM 7467. Journal of Thermoplastic Composite Materials, 24(5), 713-732.

Idris, F. M., Hashim, M., Abbas, Z., Ismail, I., Nazlan, R., & Ibrahim, I. R. (2016). Recent developments of smart electromagnetic absorbers based polymer-composites at gigahertz frequencies. Journal of Magnetism and Magnetic Materials, 405, 197-208.

Iwamaru, T., Katsumata, H., Uekusa, S., Ooyagi, H., Ishimura, T., & Miyakoshi, T. (2012). Development of microwave absorbing materials prepared from a polymer binder including Japanese lacquer and epoxy resin. Physics Procedia, 23, 69-72.

Jacob, M., Varughese, K., & Thomas, S. (2006). Dielectric characteristics of sisal–oil palm hybrid biofibre reinforced natural rubber biocomposites. Journal of materials science, 41(17), 5538-5547.

Jagatheesan, K., Ramasamy, A., Das, A., & Basu, A. (2015). Fabrics and their composites for electromagnetic shielding applications. Textile Progress, 47(2), 87-161.

Jawaid, M., Alothman, O. Y., Paridah, M., & Khalil, H. S. A. (2014). Effect of oil palm and jute fiber treatment on mechanical performance of epoxy hybrid composites. International Journal of Polymer Analysis and Characterization, 19(1), 62-69.

Jawaid, M., & Khalil, H. A. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate Polymers, 86(1), 1-18.

Jayamani, E., Hamdan, S., Rahman, M. R., & Bakri, M. K. B. (2014). Comparative study of dielectric properties of hybrid natural fiber composites. Procedia Engineering, 97, 536-544.

Jayamol, G., Bhagawan, S., & Thomas, S. (1997). Electrical properties of pineapple fibre reinforced polyethylene composites. Journal of polymer engineering, 17(5), 383-404.

Jia, W., Gong, R. H., & Hogg, P. J. (2014). Poly (lactic acid) fibre reinforced biodegradable composites. Composites Part B: Engineering, 62, 104-112.

Jin, J.-M. (2015). The finite element method in electromagnetics: John Wiley & Sons.

Kabir, M., Wang, H., Lau, K., & Cardona, F. (2012). Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview. Composites Part B: Engineering, 43(7), 2883-2892.

Karamanlioglu, M., Preziosi, R., & Robson, G. D. (2017). Abiotic and biotic environmental degradation of the bioplastic polymer poly (lactic acid): A review. Polymer Degradation and Stability, 137 (2017) 122-130.

Khoon, T. F., Hassan, J., Mokhtar, N., Hashim, M., & Ibrahim, N. A. (2011). DIELECTRIC BEHAVIOR OF Ni0. 1Zn0. 9Fe2O4-POLYPROPYLENE COMPOSITES AT LOW MICROWAVE FREQUENCIES. Solid State Science and Technology, Vol. 19, No2 (2011) 207-213.

Kristiani, A., Effendi, N., Aristiawan, Y., Aulia, F., & Sudiyani, Y. (2015). Effect of combining chemical and irradiation pretreatment process to characteristic of oil palm's empty fruit bunches as raw material for second generation bioethanol. Energy Procedia, 68, 195-204.

Lamani, A., Jayanna, H., Naveen, C., Rajeeva, M., Prasanna, G., Chaturmukha, V, Avinash, B. (2016). Temperature-dependent dielectric properties and line profile analysis of zinc-substituted copper ferrites. Paper presented at the AIP Conference Proceedings. AIP Conf. Proc. 1731, 050136-1–050136-3; doi: 10.1063/1.4947790, 050136-1- 050136-3.

Lamberti, G. (2015). Microwave technology applied in post-harvest treatments of cereals and legumes. Chemical engineering transactions, 44, 13-18. doi: 10.3303/CET1544003

Latif, S. S., Nahar, S., & Hasan, M. (2015). Fabrication and electrical characterization of bamboo fiber-reinforced polypropylene composite. Journal of Reinforced Plastics and Composites, 34(3), 187-195.

Le Troedec, M., Sedan, D., Peyratout, C., Bonnet, J. P., Smith, A., Guinebretiere, R., . . . Krausz, P. (2008). Influence of various chemical treatments on the composition and structure of hemp fibres. Composites Part A: Applied Science and Manufacturing, 39(3), 514-522.

Levato, C. (2013). Iron Oxides Prehistoric Mines A European Overview. Anthropologica et Praehistorica, 126/2015 (2016), 9-23.

Li, L., Liu, S., & Lu, L. (2017). Synthesis and significantly enhanced microwave absorption properties of cobalt ferrite hollow microspheres with protrusions/polythiophene composites. Journal of Alloys and Compounds, 722 (2017) 158-165.

Luo, H., Gong, R., Wang, X., Nie, Y., Chen, Y., & Harris, V. G. (2015). Fe 3 O 4 cladding enhanced magnetic natural resonance and microwave absorption properties of Fe 0.65 Co 0.35 alloy flakes. Journal of Alloys and Compounds, 646, 345-350.

Ma, R., Wang, Y., Tian, Y., Zhang, C., & Li, X. (2008). Synthesis, characterization and electromagnetic studies on nanocrystalline nickel zinc ferrite by polyacrylamide gel. Journal of Materials Science & Technology, 24(3), 419-422.

Maloney, J. G., Smith, G. S., & Scott, W. R. (1990). Accurate computation of the radiation from simple antennas using the finite-difference time-domain method. IEEE Transactions on Antennas and Propagation, 38(7), 1059-1068.

Mandal, S. K., Singh, S., Dey, P., Roy, J. N., Mandal, P. R., & Nath, T. K. (2016). Frequency and temperature dependence of dielectric and electrical properties of TFe2O4 (T = Ni, Zn, Zn0.5Ni0.5) ferrite nanocrystals. Journal of Alloys and Compounds, 656, 887-896. doi: 10.1016/j.jallcom.2015.10.045

McAliley, J. H., O'Brien, C. P., & Bruce, D. A. (2008). Continuum electrostatics for electronic structure calculations in bulk amorphous polymers: Application to polylactide. The Journal of Physical Chemistry A, 112(31), 7244-7249.

Meng, Z., Zheng, W., Li, L., & Zheng, Y. (2010). Fabrication and characterization of three-dimensional nanofiber membrance of PCL–MWCNTs by electrospinning. Materials Science and Engineering: C, 30(7), 1014-1021.

Meriakri, V., Kalenov, D., Parkhomenko, M., Zhou, S., & Fedoseev, N. (2012). Dielectric Properties of Biocompatible and Biodegradable Polycaprolone and Polylactide and Their Nanocomposites in the Millimeter Wave Band. American Journal of Materials Science, 2(6), 171-175.

Mohanty, A. K., Misra, M., & Drzal, L. T. (2005). Natural fibers, biopolymers, and biocomposites: CRC press.

Mu, S., Xie, H., Wang, W., & Yu, D. (2015). Electroless silver plating on PET fabric initiated by in situ reduction of polyaniline. Applied Surface Science, 353, 608-614.

Mudinepalli, V. R., Song, S., Li, J., & Murty, B. (2013). A comparative study of structural and electrical properties of Ba 0.8 Pb 0.2 TiO 3 nanocrystalline ceramics prepared by microwave and spark plasma sintering. Materials Chemistry and Physics, 142(2), 686-691.

Murillo, J., Biernacki, J., Northrup, S., & Mohammad, A. (2017). BIOMASS PYROLYSIS KINETICS: A REVIEW OF MOLECULAR-SCALE MODELING CONTRIBUTIONS. Brazilian Journal of Chemical Engineering, 34(1), 1-18.

N.A. Ibrahim, N. H., M.Z.A. Rahman and W.M.Z.W. Yunus. (2011). Mechanical Properties andMorphology of Oil Palm EmptyFruit Bunch–Polypropylene Composites:Effect of Adding ENGAGETM 7467. Journal of Thermoplastic Composite Materials. doi: 10.1177/0892705711401549

Nasouri, K., Shoushtari, A. M., & Mojtahedi, M. R. M. (2016). Theoretical and experimental studies on EMI shielding mechanisms of multi-walled carbon nanotubes reinforced high performance composite nanofibers. Journal of Polymer Research, 23(4), 71.

Nioua, Y., El Bouazzaoui, S., Achour, M. E., & Costa, L. C. (2017). Modeling microwave dielectric properties of polymer composites using the interphase approach. Journal of Electromagnetic Waves and Applications, DOI:10.1080/09205071.2017.1348261, 1-10.

Note, A. A. (2006). Handbook, Agilent Basics of Measuring the Dielectric Properties of Materials. Agilent Literature Number. Agilent Technologies,Inc.2005, 2006 Printed in USA June 26,2006, 5989-2589 EN.

Oi, T., Shinyama, K., & Fujita, S. (2012). Electrical properties of heat-treated polylactic acid. Electrical Engineering in Japan, 180(1), 1-8.

Omar, R., Idris, A., Yunus, R., Khalid, K., & Isma, M. A. (2011). Characterization of empty fruit bunch for microwave-assisted pyrolysis. Fuel, 90(4), 1536-1544.

Oyharçabal, M., Olinga, T., Foulc, M.-P., Lacomme, S., Gontier, E., & Vigneras, V. (2013). Influence of the morphology of polyaniline on the microwave absorption properties of epoxy polyaniline composites. Composites Science and Technology, 74, 107-112.

Pal, J., Kankariya, N., Sanwaria, S., Nandan, B., & Srivastava, R. K. (2013). Control on molecular weight reduction of poly (ε-caprolactone) during melt spinning—A way to produce high strength biodegradable fibers. Materials Science and Engineering: C, 33(7), 4213-4220.

Paligova, M., Vilčákova, J., Sáha, P., Křesálek, V., Stejskal, J., & Quadrat, O. (2004). Electromagnetic shielding of epoxy resin composites containing carbon fibers coated with polyaniline base. Physica A: Statistical Mechanics and its Applications, 335(3), 421-429.

Pathania, D., & Singh, D. (2009). A review on electrical properties of fiber reinforced polymer composites. International journal of theoretical & applied sciences, 1(2), 34-37.

Patra, A., & Bisoyi, D. K. (2010). Dielectric and impedance spectroscopy studies on sisal fibre-reinforced polyester composite. Journal of materials science, 45(21), 5742-5748.

Pawar, R., Pawar, G., & Mahale, P. (2016). A Review on Effect of Variation in Material Composition and Structural Dimensions on Vibrational Behavior of Composite Materials. International Journal of Current Engineering and Technology.

Peng, Z., Hwang, J.-Y., Park, C.-L., Kim, B.-G., Andriese, M., & Wang, X. (2012). Microwave permittivity, permeability, and absorption capability of ferric oxide. ISIJ international, 52(9), 1535-1538.

Popovic, Z., & Kuester, E. F. (2013). Principles of RF and Microwave Measurements. University of Colorado, Electromagnetics Laboratory Department of Electrical and Computer Engineering Campus Box, 425, 80309-80425.

Pozar, D. M. (2009). Microwave engineering: John Wiley & Sons.

Pramila Devi, D., & Kutty, S. K. N. (2012). Synthesis, characterization and properties of Conductive elastomeric composites based on Polypyrrole and short Nylon-6 fiber, PhD Thesis, Cochin University of Science and Technology.

Prema, K., Kurian, P., Anantharaman, M., Suma, M., & Joseph, M. (2008). Permittivity characteristics in the X-and S-band frequencies of microwave absorbers based on rubber ferrite composites. Journal of Elastomers & Plastics, 40(4), 331-346.

Purwanto, Y. A., Herwawan, E., & Hermawan, W. (2015). Selecting Part of Natural Fiber EFB which has Best Mechanical Strength through Tensile Test Analysis for Composite Reinforced Material. ARPN Journal of Engineering and Applied Sciences, Vol. 11, NO. 17, Septemer 2016, 10522- 10528.

Qin, F., & Brosseau, C. (2012). A review and analysis of microwave absorption in polymer composites filled with carbonaceous particles. Journal of Applied Physics, 111(6), 4.

Ramli, R., Junadi, N., Beg, M. D., & Yunus, R. M. (2015). Microcrystalline cellulose (MCC) from oil palm empty fruit bunch (EFB) fiber via simultaneous ultrasonic and alkali treatment. World Academy of Science, Engineering and Technology, International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, 9(1), 8-11.

Rana, A., & Singha, A. (2015). Dielectric, flammability and physico-chemical properties of surface functionalized Cannabis indica fibers reinforced composite materials. Polymer Science--Series A, 57(2).

Ray, S. S., & Bousmina, M. (2005). Biodegradable polymers and their layered silicate nanocomposites: in greening the 21st century materials world. Progress in materials science, 50(8), 962-1079.

Rayung, M., Ibrahim, N. A., Zainuddin, N., Saad, W. Z., Razak, N. I. A., & Chieng, B. W. (2014). The effect of fiber bleaching treatment on the properties of poly (lactic acid)/oil palm empty fruit bunch fiber composites. International journal of molecular sciences, 15(8), 14728-14742.

Reddy, C., Deshpande, M. D., Cockrell, C., & Beck, F. B. (1994). Finite element method for eigenvalue problems in electromagnetics.

Rui-Gang, Y. (2011). Electromagnetic properties and microwave absorption properties of BaTiO 3–carbonyl iron composite in S and C bands. Journal of Magnetism and Magnetic Materials, 323(13), 1805-1810.

Saba, N., Tahir, P. M., & Jawaid, M. (2014). A review on potentiality of nano filler/natural fiber filled polymer hybrid composites. Polymers, 6(8), 2247-2273.

Satish, H., Ouellet, J., Raghavan, V., & Radziszewski, P. (2006). Investigating microwave assisted rock breakage for possible space mining applications. Mining technology, 115(1), 34-40.

Shinoj, S., Visvanathan, R., & Panigrahi, S. (2010). Towards industrial utilization of oil palm fibre: Physical and dielectric characterization of linear low density polyethylene composites and comparison with other fibre sources. Biosystems engineering, 106(4), 378-388.

Shinoj, S., Visvanathan, R., Panigrahi, S., & Kochubabu, M. (2011). Oil palm fiber (OPF) and its composites: A review. Industrial Crops and Products, 33(1), 7-22.

Shukor, F., Hassan, A., Islam, M. S., Mokhtar, M., & Hasan, M. (2014). Effect of ammonium polyphosphate on flame retardancy, thermal stability and mechanical properties of alkali treated kenaf fiber filled PLA biocomposites. Materials & Design (1980-2015), 54, 425-429.

Silverajah, V., Ibrahim, N. A., Zainuddin, N., Yunus, W. M. Z. W., & Hassan, H. A. (2012). Mechanical, thermal and morphological properties of poly (lactic acid)/epoxidized palm olein blend. Molecules, 17(10), 11729-11747.

Siyamak, S., Ibrahim, N. A., Abdolmohammadi, S., Yunus, W. M. Z. B. W., & Rahman, M. Z. A. (2012). Enhancement of mechanical and thermal properties of oil palm empty fruit bunch fiber poly (butylene adipate-co-terephtalate) biocomposites by matrix esterification using succinic anhydride. Molecules, 17(2), 1969-1991.

Snyder, A. W., & Love, J. (2012). Optical waveguide theory: Springer Science & Business Media,document ID: 19950011772 (Acuired Dec 28, 1995) Accession Number 95N18187, 1-27.

Sreekumar, P., Saiter, J. M., Joseph, K., Unnikrishnan, G., & Thomas, S. (2012). Electrical properties of short sisal fiber reinforced polyester composites fabricated by resin transfer molding. Composites Part A: Applied Science and Manufacturing, 43(3), 507-511.

Stergiou, C. A., & Litsardakis, G. (2016). Y-type hexagonal ferrites for microwave absorber and antenna applications. Journal of Magnetism and Magnetic Materials, 405, 54-61.

Venkatesh, M., & Raghavan, G. (2005). An overview of dielectric properties measuring techniques. Canadian biosystems engineering, 47(7), 15-30.

Vimalan, M., Ramanand, A., & Sagayaraj, P. (2007). Synthesis, growth and characterization of l-alaninium oxalate-a novel organic NLO crystal. Crystal Research and Technology, 42(11), 1091-1096.

Vo, H. T., & Shi, F. G. (2002). Towards model-based engineering of optoelectronic packaging materials: dielectric constant modeling. Microelectronics Journal, 33(5), 409-415.

Wahit, M. U., Akos, N. I., & Laftah, W. A. (2012). Influence of natural fibers on the mechanical properties and biodegradation of poly (lactic acid) and poly (ε-caprolactone) composites: A review. Polymer Composites, 33(7), 1045-1053.

Wang, X., Gong, R., Li, P., Liu, L., & Cheng, W. (2007). Effects of aspect ratio and particle size on the microwave properties of Fe–Cr–Si–Al alloy flakes. Materials Science and Engineering: A, 466(1), 178-182.

Wei, L., Che, R., Jiang, Y., & Yu, B. (2013). Study on preparation and microwave absorption property of the core-nanoshell composite materials doped with La. Journal of Environmental Sciences, 25, S27-S31.

Xu, J., Liu, J., Che, R., Liang, C., Cao, M., Li, Y., & Liu, Z. (2014). Polarization enhancement of microwave absorption by increasing aspect ratio of ellipsoidal nanorattles with Fe 3 O 4 cores and hierarchical CuSiO 3 shells. Nanoscale, 6(11), 5782-5790.

Xu, S., Habib, A., Gee, S., Hong, Y., & McHenry, M. (2015). Spin orientation, structure, morphology, and magnetic properties of hematite nanoparticles. Journal of Applied Physics, 117(17), 17A315.

Yaacoba, W., Nadiah, W. S., Jamarib, S. S., & Ghazalic, S. (2015). Effect of particle size of natural based carbon filler to the absorbency of superabsorbent polymer composite synthesis by graft polymerization method. Paper presented at the Advanced Materials Research, ISSN: 1662-8985, Vol. 1119, pp 301-305.

Yahaya, N. Z., Abbas, Z., Yahaya, M. Z., Norimi, A., Ashikin, N. N., Razak, A., & Mustafa, I. S. (2015). Development of Calibration Equation Based on Complex Permittivity of Hevea Rubber Latex. Asian Journal of Applied Sciences (ISSN: 2321–0893), 3(03).

Yakubu, A., Abbas, Z., Esa, F., & Tohidi, P. (2015). The Effect of ZnO Nanoparticle Filler on the Attenuation of ZnO/PCL Nanocomposites Using Microstrip Line at Microwave Frequency. International Polymer Processing, 30(2), 227-232.

Yakubu, A., Abbas, Z., & Hashim, M. (2014). Effect of Material Thickness on Attenuation (dB) of PTFE Using Finite Element Method at X-Band Frequency. Advances in Materials Science and Engineering, 2014.

Yee, Y. Y., Ching, Y. C., Rozali, S., Hashim, N. A., & Singh, R. (2016). Preparation and characterization of poly (lactic acid)-based composite reinforced with oil palm empty fruit bunch fiber and nanosilica. BioResources, 11(1), 2269-2286.

Yunus, R., Salleh, S. F., Abdullah, N., & Biak, D. R. A. (2010). Effect of ultrasonic pre-treatment on low temperature acid hydrolysis of oil palm empty fruit bunch. Bioresource technology, 101(24), 9792-9796.

Zahid, L., Malek, M. F. B. A., Nornikman, H., Mohd Affendi, N. A., Ali, A., Hussin, N., . . . Abdul Aziz, M. Z. A. (2013). Development of pyramidal microwave absorber using sugar cane bagasse (SCB). Progress In Electromagnetics Research, 137, 687-702.

Zaidi, L., Kaci, M., Bruzaud, S., Bourmaud, A., & Grohens, Y. (2010). Effect of natural weather on the structure and properties of polylactide/Cloisite 30B nanocomposites. Polymer Degradation and Stability, 95(9), 1751-1758.

Zoughi, R., & Ganchev, S. (1995). Microwave Nondestructive Evaluation: State-of-the-Art Review: DTIC Document.