UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# DEVELOPMENT OF INDIUM ZINC OXIDE COATED KENAF REINFORCED PANi/PLA COMPOSITE FOR ELECTROMAGNETIC INTERFERENCE SHIELDING

NURHERNIDA BINTI ABDULLAH SANI



DOCTOR OF PHILOSOPHY

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**Faculty of Industrial and Manufacturing Technology and Engineering**

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**NURHERNIDA BINTI ABDULLAH SANI**

**A thesis submitted**
**in fulfillment of the requirements for the degree of**
**Doctor of Philosophy**



**Faculty of Industrial and Manufacturing Technology and Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2024**

## DECLARATION

I declare that this thesis entitled “Development of Indium Zinc Oxide Coated Kenaf Reinforced PANi/PLA Composite for Electromagnetic Interference Shielding” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : NURHERNIDA BINTI ABDULLAH SANI

Date : 18/10/2023

**APPROVAL**

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of the degree of Doctor of Philosophy.

Signature : 

Supervisor Name : DR. MOHD EDEEROZEY BIN ABD MANAF

Date : 18/10/2023

**DEDICATION**

Specially dedicated to the most important person in my life

“My beloved husband, my son, my parents, my siblings and the whole family”

for their love, trust, support and prayers

## ABSTRACT

Electromagnetic interference (EMI) has emerged as a major concern for disrupting the performance or operation of electrical equipment as well as being harmful to human health. In order to cope with the interference issues, an innovative development of biodegradable polymer blends incorporating intrinsic conductive polymers (ICPs) such as polyaniline (PANi) was pursued for EMI shielding applications. Nevertheless, PANi-filled polymer blends are frequently susceptible to weakening the mechanical properties due to agglomeration and weak adhesion issues. Thus, the research aims to improve the mechanical properties as well as the electrical properties of PLA/PANi polymer blends by reinforcing them with indium doped zinc oxide (IZO) coated kenaf fiber. In Stage 1, the development of conductive IZO coated kenaf fiber was performed via dip coating process and systematic statistical approach to obtain the most suitable level of alkaline treatment, annealing temperature and indium doping, in order to achieve the lowest surface resistivity possible, indicating an increase in charge carrier. It was found that the combination of an annealing temperature of 130 °C, NaOH treatment of 8.0 % and indium doping of 3.0 wt% has yielded a minimal surface resistivity of 1.87 x $10^9$ Ω/sq with the highest desirability value of 0.933. In addition, the characterizations via XRD, FTIR, morphological and elemental analysis have validated the succesful coating of the IZO on kenaf fiber. In the following Stage 2, the fabrication of biodegradable PLA/PANi polymer blends has been performed to study their electrical, thermal and EMI shielding effectiveness (EMISE) performance. Prior to that, PANi were synthesised via chemical oxidative polymerization (COP) with hydrochloric acid doping. Then, PANi was incorporated into the PLA to produce conductive polymer blends via a melt-mixing process, which were then hot-pressed into polymer sheets. The increasing amount of PANi in the polymer blends has increased the electrical conductivity and the dielectric properties; however, it has substantially reduced the mechanical properties and the thermal stability. In the final Stage 3, the development of the IZO-kenaf/PANi/PLA hybrid composite was carried out using hot compression molding. In this process, the combination of PANi amount (per-hundred-resin) and IZO-coated kenaf fiber weight percentage (wt.%) were investigated using a two-level full factorial statistical approach method to achieve the highest mechanical, electrical and EMISE performance resulting from the synergistic integration of the IZO-kenaf/PANi/PLA hybrid composite. The most suitable compositions of IZO-kenaf and PANi were determined to be 30 wt.% and 10 phr, respectively. The most suitable quantity of IZO-kenaf and PANi was successfully combined, resulting in the highest EMI shielding efficacy value of 42.6 dB, conductivity of 2.39 x $10^{-4}$ S/m, and permittivity value of 6.60. The highest incorporation amount of IZO-kenaf has raised the tensile strength and modulus to 16.6 MPa and 4.04 GPa, respectively, which indicates the reinforcing effect of IZO-coated kenaf fiber. As a result, the synergistic effects from the integration of IZO-coated kenaf fiber and PANi/PLA matrix has improved the electrical, mechanical and EMISE properties, making it a potetial alternative for EMI shielding applications.

***PEMBANGUNAN KOMPOSIT PANi/PLA BERTETULANG KENAF BERSALUT INDIUM ZINK OKSIDA UNTUK PERISAI GANGGUAN ELEKTROMAGNET***

## *ABSTRAK*

*Gangguan elektromagnetik (EMI) telah menjadi kebimbangan utama kerana menyebabkan gangguan terhadap prestasi atau operasi peralatan elektrik serta berbahaya kepada kesihatan manusia. Untuk menangani perkara ini, pembangunan inovatif dengan menggabungkan polimer terbiodegradasi dan polimer konduktif intrinsik (ICP) seperti polianilin (PANi) telah dijalankan untuk aplikasi sebagai perisai EMI. Namun begitu, adunan polimer yang diisi PANi selalunya cenderung mempamerkan prestasi mekanikal yang rendah akibat masalah gumpalan dan lekatan yang lemah. Oleh itu, penyelidikan ini bertujuan untuk menambah baik sifat mekanikal serta sifat elektrik campuran polimer PLA/PANi dengan mengukuhkannya dengan gentian kenaf bersalut zink oksida terdop indium (IZO). Pada Peringkat 1, pembangunan gentian kenaf bersalut IZO konduktif telah dilakukan melalui proses salutan celup dan pendekatan statistik sistematik untuk mendapatkan tahap rawatan alkali, suhu penyepuhlindapan dan dop indium yang paling sesuai, bagi mencapai kerintangan elektrik permukaan yang paling rendah yang juga menunjukkan hasil peningkatan pembawa cas. Didapati gabungan suhu penyepuhlindapan 130 °C, rawatan NaOH 8.0 % dan doping indium 3.0 wt% telah menghasilkan kerintangan permukaan minimum iaitu $1.87x10^{9}$ Ω/sq dengan nilai kemahuan tertinggi 0.933. Selain itu, pencirian melalui analisis XRD, FTIR, morfologi dan unsur telah mengesahkan IZO berjaya disalutkan pada gentian kenaf. Dalam Peringkat 2 berikutnya, fabrikasi adunan polimer terbiodegradasi PLA/PANi telah dilakukan untuk mengkaji prestasi keberkesanan elektrik, haba dan pelindungan EMI (EMISE) mereka. Sebelum itu, PANi telah disintesis melalui pempolimeran oksidatif kimia (COP) dengan mendopkan asid hidroklorik. Kemudian, PANi telah dimasukkan ke dalam PLA untuk menghasilkan campuran polimer konduktif melalui proses pencampuran cair, yang kemudiannya ditekan panas menjadi kepingan polimer. Peningkatan jumlah PANi dalam campuran polimer telah meningkatkan kekonduksian elektrik dan sifat dielektrik; walau bagaimanapun, ia telah mengurangkan dengan ketara sifat mekanikal dan kestabilan termal. Pada Peringkat 3 yang terakhir, pembangunan komposit hibrid IZO-kenaf/PANi/PLA telah dijalankan menggunakan kaedah pengacuan mampatan panas. Dalam proses ini, gabungan jumlah PANi (setiap-ratus-resin) dan peratusan berat gentian kenaf bersalut IZO (berat %) telah dikaji menggunakan pendekatan statistik faktorial penuh dua peringkat untuk mencapai prestasi mekanikal, elektrikal dan EMISE yang tertinggi hasil daripada integrasi sinergi bagi komposit hibrid IZO-kenaf/PANi/PLA. Komposisi IZO-kenaf dan PANi yang paling sesuai ditentukan masing-masing sebagai 30 wt.% dan 10 phr. Dengan menggabungkan kuantiti IZO-kenaf dan PANi yang terbaik, ianya berjaya menghasilkan nilai efikasi pelindung EMI tertinggi iaitu 42.6 dB, kekonduksian sebanyak $2.39x10^{-4}$ S/m, dan nilai kebolehtelapan elektrik sebanyak 6.60. Jumlah penggabungan tertinggi IZO-kenaf telah meningkatkan kekuatan tegangan dan modulus masing-masing kepada 16.6 MPa dan 4.04 GPa, yang menunjukkan kesan pengukuhan gentian kenaf bersalut IZO. Hasilnya, kesan sinergistik daripada penyepaduan gentian kenaf bersalut IZO dan matriks PANi/PLA telah meningkatkan sifat elektrik, mekanikal dan EMISE, menjadikannya alternatif yang berpotensi tinggi untuk aplikasi perisai EMI.*

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