DEVELOPMENT OF DIFFERENTLY TREATED WASTE CARBON FIBER REINFORCED ACRYLONITRILE BUTADIENE STYRENE FOR ELECTROMAGNETIC INTERFERENCE SHIELDING

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DOCTOR OF PHILOSOPHY

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Faculty of Industrial and Manufacturing Technology and Engineering

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A thesis submitted
In fulfillment of the requirements for the degree of
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Faculty of Industrial and Manufacturing Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2025

DECLARATION

I declare that this thesis entitled “Development of Differently Treated Waste Carbon Fiber Reinforced Acrylonitrile Butadiene Styrene 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 :

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Date : 13/7/2024

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 Doctor of Philosophy.

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Date	:	13/7/2024

DEDICATION

To my beloved mother, father, wife, daughters and sons, and my brothers and sisters, for their support and prayers.

ABSTRACT

Although polymers are lightweight, inexpensive, and simple to process, their electrically insulated nature limits their use in electromagnetic interference (EMI) shielding and renders them transparent to electromagnetic radiation. Incorporating conductive fillers into the polymer matrix is one of the methods to improve EMI shielding effectiveness without sacrificing processability or mechanical properties. However, achieving a good shielding effect at high frequencies requires a high content of carbon fibers, and producing composites with high fiber volume fractions through extrusion remains challenging. The objective of this study is to develop and evaluate acrylonitrile butadiene styrene (ABS) composites reinforced with differently treated recycled carbon fibers (rCFs), and to investigate the effects of fiber treatment and electron beam (EB) irradiation on their electrical, mechanical, and EMI shielding properties. Various amounts of rCFs with chemical and mechanical treatments were incorporated into ABS using melt-mixing and compression molding methods, followed by EB irradiation to enhance performance. The results showed that chemical treatment successfully removed most of the resin from carbon fibers, with treated CF containing less than 5 wt% residual resin. The addition of rCF improved both strength and modulus of ABS, with increases of up to 53% and 89% respectively at 30 wt% fiber loading. Composites reinforced with treated rCF consistently outperformed those with untreated CF. In terms of electrical conductivity and shielding effectiveness (SE), fiber treatment contributed positively, yielding improvements of 2 orders of magnitude and 32%, respectively. EB irradiation further enhanced conductivity and EMI SE, with the best performance achieved by the composite containing 30 wt% chemically treated rCF, reaching values of 1.34×10^{-8} S/m and 46.13 dB. Importantly, the required fiber volume fraction to achieve comparable conductivity was significantly reduced through the use of irradiated rCFs. In conclusion, this study demonstrates that EB-irradiated, recycled carbon fiber-reinforced ABS composites are a promising, sustainable, and lightweight alternative to conventional shielding materials. With strong performance in the 8–12 GHz range, these composites show great potential for future commercial EMI shielding applications.

PEMBANGUNAN ACRYLONITRILE STYRENE BERTETULANG GENTIAN KARBON TERBUANG YANG TERAWAT SEBAGAI PERISAI GANGGUAN ELEKTROMAGNETIK

ABSTRAK

Walaupun polimer bersifat ringan, murah dan mudah diproses, sifat penebat elektriknya mengehadkan penggunaannya dalam pelindungan gangguan elektromagnet (EMI) dan menjadikannya telus terhadap sinaran elektromagnet. Pengisian pengisi konduktif ke dalam matriks polimer merupakan salah satu kaedah untuk meningkatkan keberkesanan perisai EMI tanpa menjejaskan kebolehprosesan atau sifat mekanikalnya. Namun, bagi mencapai kesan perisai yang baik pada frekuensi tinggi, kandungan gentian karbon yang tinggi diperlukan, dan penghasilan komposit dengan pecahan volum gentian yang tinggi melalui penyemperitan masih menjadi cabaran. Objektif kajian ini adalah untuk membangunkan dan menilai komposit akrilonitril butadiena stirena (ABS) bertetulang gentian karbon kitar semula (rCF) yang dirawat secara berbeza, serta mengkaji kesan rawatan gentian dan penyinaran pancaran elektron (EB) terhadap sifat elektrik, mekanikal dan pelindung EMI. Pelbagai jumlah rCF dengan rawatan kimia dan mekanikal telah digabungkan ke dalam ABS menggunakan kaedah pencampuran leburan dan pengacuan mampatan, diikuti dengan penyinaran EB untuk meningkatkan prestasi. Keputusan menunjukkan bahawa rawatan kimia berjaya menanggalkan kebanyakan resin daripada gentian karbon, dengan gentian yang dirawat hanya mengandungi kurang daripada 5 wt% resin sisa. Penambahan rCF meningkatkan kekuatan dan modulus ABS masing-masing sehingga 53% dan 89% pada kandungan 30 wt%. Komposit yang diperkukuh dengan rCF terawat sentiasa menunjukkan prestasi lebih baik berbanding CF tidak terawat. Dari segi kekonduksian elektrik dan keberkesanan perisai (SE), rawatan gentian menyumbang secara positif dengan peningkatan masing-masing sebanyak 2 magnitud kuasa dan 32%. Penyinaran EB selanjutnya meningkatkan kekonduksian dan SE, dengan prestasi terbaik dicapai oleh komposit yang mengandungi 30 wt% rCF terawat secara kimia, dengan nilai 1.34×10^{-8} S/m dan 46.13 dB. Lebih penting lagi, keperluan pecahan volum gentian untuk mencapai kekonduksian setara dapat dikurangkan dengan ketara melalui penggunaan rCF yang disinari. Kesimpulannya, kajian ini membuktikan bahawa komposit ABS bertetulang gentian karbon kitar semula yang disinari EB adalah alternatif yang mampan, ringan, dan berprestasi tinggi berbanding bahan pelindung konvensional. Dengan prestasi yang kukuh dalam julat frekuensi 8–12 GHz, komposit ini berpotensi besar untuk aplikasi komersial pelindung EMI pada masa hadapan..

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In the name of Allah, the Most Gracious and the Most Merciful

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LIST OF ABBREVIATIONS

ABS	-	Acrylonitrile butadiene styrene
CF	-	Carbon fiber
CB	-	Carbon black
CNFs	-	Carbon nano fibers
CNTs	-	Carbon nanotubes
CPC	-	Conductive polymer composite
DC	-	Direct current
DMA	-	Dynamic mechanical analysis
DSC	-	Differential scanning calorimetry
EB	-	Elongation at Break
EB	-	Electron beam
EMFs	-	Electromagnetic fields
EMI	-	Electromagnetic interference
GNPs	-	Graphene nanoplatelets
GO	-	Graphene/graphite oxide
H_2SO_4	-	Sulfuric acid.
KGy	-	Kilogray
LLDPE	-	Linear low-densitypolyethylene
MFI	-	Melt flow index
PA12	-	Polyamide 12
PALS	-	Conductive polymer composite
PAN	-	Polyacrylonitrile
PANI	-	Polyaniline
PP	-	Poly propylene
PVC	-	Poly vinyl chloride
RCF	-	Recycled carbon fiber
RGO	-	Reduced graphene oxide
SE	-	Shielding effectiveness
SEM	-	Scanning electron microscopy

Tc	-	Crystallization temperature
TEM	-	Transmission electron microscopy
Tg	-	Glass transition temperature
TGA	-	Thermogravimetric analysis
Tm	-	Melting temperature
TS	-	Tensile strength
UTS WCF	-	Ultimate tensile strength
XRD	-	X-ray diffraction

LIST OF PUBLICATIONS

Indexed Journal:

Adel M. Alkaseh, Mohd Edeerozey Abd Manaf, Zurina Shamsudin, Jamari A. Ghafar, Edynoor Osman., 2020. Characterization of Chemically and Mechanically Treated Recycled Carbon Fibers. International Journal of Advanced Science and Technology, 29 (9s), 1341 - 1347. Retrieved from http://sersc.org/journals/index.php/IJAST/article/view/13605

A.M. Alkaseh, M.E.A Manaf, N. Mohamad., 2022. Electrical and Shielding Properties of Acrylonitrile Butadiene Styrene Filled with Differently Treated Recycled Carbon Fibres. Journal of Advanced Manufacturing Technology (JAMT), ISSN: 1985-3157 Vol. 16 No. 2.

Mohammed Iqbal Shueb, Mohd Edeerozey Abd Manaf, Noraiham Mohamad, Nurhernida Abdullah Sani, **Adel Ali Alkaseh**, 2022. Modification of Nylon 66/Graphene Nanoplatelet Composite via Electron Beam Irradiation. Malaysian Journal of Microscopy Vol.18 No. 2 (2022), Page 132-141

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, growing concern regarding electromagnetic (EM) radiation and the electromagnetic compatibility (EMC) of circuits has attracted significant attention from researchers across diverse technical disciplines. The background for this is various issues related to electromagnetic radiation, including potential health risks, such as cancer, when exposed to electromagnetic fields. Therefore, it is substantial to stop unwanted electromagnetic waves, which are generated by both natural and artificial sources. To protect nearby electronic circuits, shielding materials should be placed over any electronics system that emits electromagnetic waves, whether on purpose or accidentally. Electrically conductive materials, particularly metals, reflect electromagnetic (EM) fields, thereby preventing waves from either penetrating the shield or escaping from the enclosed region. Meanwhile, electromagnetic absorbers effectively eliminate electromagnetic interference (EMI) by attenuating the electric and magnetic components and blocking EM waves. To stop the negative effects of EMI, a variety of EMI shielding materials have been developed. The conventional method involves using metallic materials that exhibit reflective shielding. Traditional metallic shields, on the other hand, are heavier and more prone to corrosion since made of bulk sheets or meshes (Akonda et al., 2012). Electromagnetic waves interacting with a material's surface can undergo four main processes: reflection, absorption, multiple reflections, and transmission. The shielding materials must reflect (multiple reflection) or absorb the EM wave in order to attenuate it (Jagatheesan et al., 2014). Figure 1.1 depicts the shielding of electromagnetic waves passing through a homogeneous barrier.

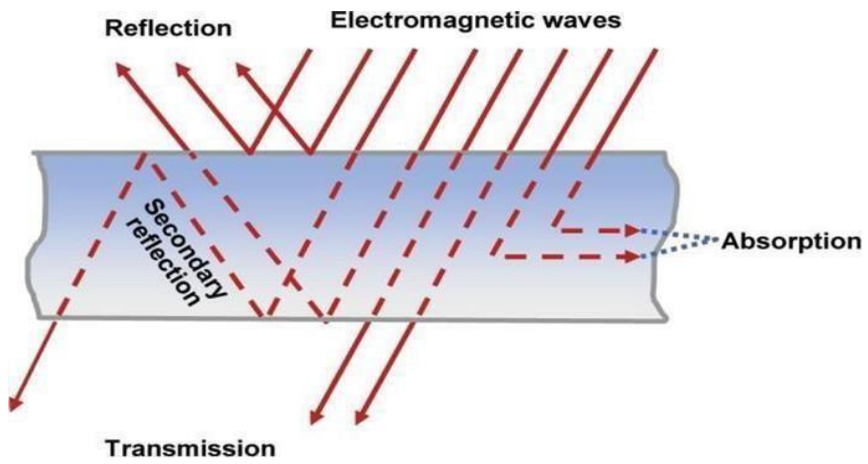

Figure 1.1 Illustration of shielding phenomena for electromagnetic waves passing through a homogeneous barrier (Rajendrakumar and Thilagavathi, 2012)

An appropriate EMI shield is required in order to shield the environment and the surrounding area from electromagnetic radiation, especially those in the X-band (8.2-12.4 GHz) frequency range, which are used by numerous significant applications like weather radar systems, control of air traffic, satellite communication, and broadcasting on television. Consequently, significant efforts have been directed toward developing advanced EMI shielding materials. Metals and metallic composites exhibit excellent shielding effectiveness due to their high electrical conductivity; however, they are often physically rigid, relatively heavy, and susceptible to corrosion

On the other hand, plastics have been used to house electronic devices in recent years because of their lighter weight compared to metals, flexible design, and low cost. Most polymers are naturally electrically insulating. Because they cannot conduct electricity, they are effectively transparent to electromagnetic radiation. Blending polymers with electrically conductive fillers is an effective way to enhance their electrical conductivity while providing EMI shielding. Adding these fillers increases the conductivity of the polymer, producing lightweight, corrosion-resistant conductive composites that can replace metals in some electromagnetic shielding applications, making them suitable for specialized purposes. (Motaghi et al., 2015).