UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT AND CHARACTERIZATION OF POLYPROPYLENE WASTE-DERIVED CHAR FILLED SUGAR PALM [Arenga pinnata (Wurmb) Merr.] STARCH BIOPOLYMER COMPOSITE BRIQUETTES

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FK 2022 3

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By

MUHAMMAD HARUSSANI BIN MOKLIS

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To Allah swt. and beloved Prophet Muhammad ﷺ
Indeed, this is Our provision; for it there is no depletion. (*Al-Saad:Verse 54*)
The Prophet ﷺ said, "*Remember Allah during times of ease and He will remember you during times of difficulty."* (*Tirmidhi*)

&

To my beloved father and mother

&

To siblings and dearest friends

Their love, prayers, concerns, and encouragement have encouraged me to accomplish my quest.

May Allah swt. bless each and every one of you.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DEVELOPMENT AND CHARACTERIZATION OF POLYPROPYLENE WASTE-DERIVED CHAR FILLED SUGAR PALM [*Arenga pinnata* (Wurmb) Merr.] STARCH BIOPOLYMER COMPOSITE BRIQUETTES

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Chairman : Mohd Sapuan bin Salit, PhD
Faculty : Engineering

According to Ministry of Health Malaysia (MOH), total utilization of personal protective equipment (PPE) of healthcare workers (HCW) under the MOH is approximately 59 million units per month. PPEs comprised of facemasks, isolation gowns, hair nets and shoe covers, which mainly made of polypropylene (PP). Due to the coronavirus disease (COVID-19) epidemic, increasing PP wastes had been produced by the hospitals and isolation facilities. To counter the increasing plastic wastes production, a proper green strategy to decompose the PP wastes is needed and pyrolysis, a thermal decomposition process, is the best way to decompose and convert the wastes into useful product with lower pollutions. Thus, this work is aimed to decompose and convert PP waste into char via pyrolysis and utilized as raw materials in fuel briquette application. PP wastes collected from university healthcare centre (PKU) were then went through cleaning and washing process under the surveillance from PKU staffs. Then, the raw materials were pulverized into 0.25 mm powder. Pyrolysis with different low pyrolytic temperatures, 450, 500, 550, 600, and 650 ºC selected as final pyrolysis temperatures, was applied to convert disinfected PP-based isolation gown waste (PP-IG) or PP waste into an optimized amount of char yields. A batch reactor with horizontal furnace was used to mediate the thermal decomposition of PP-IG. The optimum solid pyrolysis product (char) yields at different temperature was determined. Elemental, morphological, surface area and thermal properties of the char were analysed. The results show that the amount of yielded char is inversely proportional to the temperature. Optimized temperature for maximum char yields has been recorded. The enhanced specific surface area, S_{BET} values for the char and its pore volume were collected, ~24 m^2g^{-1} and ~0.08 cm^3g^{-1}, respectively. The char obtained at higher temperatures display higher volatilization and carbonization. The yielded chars were then mixed with different amount of sugar palm starch (SPS) loading, 0, 10, 20, 30 and 40%, which then moulded into briquettes via hydraulic press. The mechanical, physical, morphological, thermal and combustion characteristics of char filled sugar palm starch (C/SPS) biopolymer composites were determined using compressive test, Fourier transform infrared (FTIR), field emission scanning electron microscopy (FESEM), thermogravimetric (TGA) and bomb calorimeter analysis,

respectively. The results show that the compressive strength of the briquettes increased as the SPS loading increased, whereas the higher heating values (HHV) reduced. The findings indicate that C-80/SPS-20 briquettes presented excellent combustion characteristics (1,761.430 J/g) with satisfactory mechanical strength (1.463 MPa) in the compression test. Thus, C-80/SPS-20 briquettes are the most suitable composites for domestic and commercial uses. The development of such briquette char is an effort to address the ongoing environmental problems. These findings are beneficial to utilize this pyrolysis model for plastic waste management and convert PP waste into char for further C/SPS briquette biocomposite applications, with the enhanced mechanical and combustion properties, amidst COVID-19 pandemic.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PENYEDIAAN DAN PENCIRIAN BRIKET KOMPOSIT BIOPOLIMER KANJI ENAU [*Arenga pinnata* (Wurmb) Merr.] YANG DIISI DENGAN ARANG DARIPADA SISA POLIPROPILENA

Oleh

MUHAMMAD HARUSSANI BIN MOKLIS

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Menurut Kementerian Kesihatan Malaysia (KKM), jumlah penggunaan peralatan pelindung diri (PPE) oleh pegawai kesihatan di bawah KKM adalah kira-kira 59 juta unit sebulan. PPE terdiri daripada topeng muka, gaun pengasingan, jaring rambut dan penutup kasut, yang kebanyakannya diperbuat daripada polipropilena (PP). Disebabkan oleh wabak penyakit koronavirus (COVID-19), peningkatan sisa PP oleh hospital dan kemudahan pengasingan telah dihasilkan. Untuk mengatasi pengeluaran sisa plastik yang semakin meningkat, strategi hijau yang sesuai untuk mengurai sisa PP diperlukan dan pirolisis, proses penguraian terma, adalah cara terbaik untuk mengurai dan menukar sisa menjadi produk berguna dengan pencemaran yang lebih rendah. Oleh itu, kerja penyelidikan ini bertujuan untuk menghapus dan menukar sisa PP kepada arang (*char*) melalui pirolisis dan digunakan sebagai bahan mentah dalam aplikasi briket bahan api. Sisa PP yang dikutip dari pusat kesihatan universiti (PKU) kemudiannya dibersihkan dan dicuci di bawah pengawasan kakitangan PKU. Seterusnya, bahan mentah dihancurkan menjadi serbuk bersaiz 0.25 mm. Pirolisis dengan suhu pirolitik rendah yang berbeza, 450, 500, 550, 600, dan 650 ºC dipilih sebagai suhu pirolisis akhir, telah digunakan untuk mengurai dan menukar sisa PP daripada sisa gaun pengasingan yang dinyahjangkit (PP-IG) kepada jumlah hasil arang yang paling optimum. Reaktor kelompok dengan relau mendatar digunakan untuk mengantara penguraian terma PP-IG. Hasil produk pirolisis pepejal optimum (*char*) pada suhu berbeza telah ditentukan. Unsur, morfologi, luas permukaan dan sifat terma arang telah dianalisis. Keputusan menunjukkan bahawa jumlah arang yang terhasil adalah berkadar songsang dengan suhu. Suhu yang dioptimumkan untuk hasil arang maksimum telah direkodkan. Luas permukaan khusus yang dipertingkatkan, nilai S_{BET} untuk arang dan isipadu liangnya telah dikumpulkan, masing-masing ~24 m^2g^{-1} dan ~0.08 cm^3g^{-1}. Arang yang diperoleh pada suhu yang lebih tinggi memaparkan pemeruapan dan pengkarbonan yang lebih tinggi. Arang yang terhasil kemudiannya dicampur dengan jumlah muatan kanji enau (SPS) yang berbeza, 0, 10, 20, 30 dan 40%, yang kemudiannya dibentuk menjadi briket melalui penekan hidraulik. Ciri-ciri mekanikal, fizikal, morfologi, haba dan pembakaran bagi komposit biopolimer kanji enau (C/SPS) diisi arang ditentukan menggunakan ujian mampatan,

spektroskopi inframerah fourier transformasi (FTIR), mikroskop elektron pengimbasan pelepasan medan (FESEM), termogravimetrik (TGA) dan analisis kalorimeter bom, masing-masing. Keputusan menunjukkan bahawa kekuatan mampatan briket meningkat apabila beban SPS meningkat, manakala nilai pemanasan yang lebih tinggi (HHV) berkurangan. Dapatan menunjukkan bahawa briket C-80/SPS-20 menunjukkan ciri-ciri pembakaran yang sangat baik (1,761,430 J/g) dengan kekuatan mekanikal yang memuaskan (1.463 MPa) dalam ujian mampatan. Oleh itu, briket C-80/SPS-20 adalah komposit yang paling sesuai untuk kegunaan domestik dan komersial. Pembangunan arang briket tersebut adalah satu usaha untuk menangani masalah alam sekitar yang berterusan. Penemuan ini bermanfaat untuk menggunakan model pirolisis ini untuk pengurusan sisa plastik semasa pandemik COVID-19 dan menukar sisa PP kepada arang untuk aplikasi biokomposit briket C/SPS selanjutnya, dengan sifat mekanikal dan pembakaran yang dipertingkatkan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

ºC	Degree Celsius
ANOVA	Variance analysis
ASTM	American Society for Testing and Materials
ATR	Attenuated total reflective
BET	Brunauer-Emmett-Teller
BTEX	Benzene, toluene, ethylbenzene and xylene
C	Carbon
C/SPS	Char filled sugar palm starch composite
C_5H_{12}	Pentane
CH_4	Methane
CMW	COVID-19 medical waste
CO	Carbon monoxide
COVID-19	Coronavirus disease 2019
CPCB	Central Pollution Control Board
CR	Congo red
D_p	Pore distribution
DSSC	Dye-sensitive solar cells
DTG	derivative thermogravimetry
EDX	energy dispersive X-ray spectroscopy
FCC	Fluid catalytic cracking
FESEM	Field emission scanning electron microscope
fr	feed rate
FTIR	Fourier transform infrared

g	Gram
GN	Graphene nanosheets
h	Hour
H	Hydrogen
H_2	Hydrogen gas
HDPE	High-density polyethylene
HHV	higher heating values
HMOR	H-Mordenite
hr	heating rate
HZSMS-5	H-Zeolite Socony Mobil-5
LCV	Low calorific value
LDPE	Low-density polyethylene
MCM	Mobile Composition of Matter
MFI	Pentasil zeolites
min	Minute
MJ	Mega Joule
MOH	Minister of Health
MPa	Mega Pascal
MWCNT	Multi-walled carbon nanotube
N	Nitrogen
N_2	Nitrogen
O	Oxygen
OMAH	O-mono-aromatic hydrocarbons
OMMT	Organic-modified montmorillonite

P	pressure
PE	polyethylene
PET	polyethylene terephthalate
PKU	Pusat Kesihatan Universiti
PLA	Polylactic acid
PP	Polypropylene
PPE	Personal protective equipment
PP-IG	Polypropylene-based isolation gown
PS	polystyrene
PU	polyurethane
PVC	polyvinyl chloride
rt	residence time
s	Second
SARS-CoV-2	Severe acute respiratory syndrome coronavirus
S_{BET}	Specific surface area
SPS	sugar palm starch
T	temperature
TGA	thermogravimetric analysis
USY	Ultrastable Y zeolite
V	Volt
V_p	Pore volume
W	Watt
WHO	World Health Organisation
wt.%	Weight percentage
ZSM	Zeolite Socony Mobil

CHAPTER 1

INTRODUCTION

1.1 Background

According to WHO (2020a), an approximate 89 million surgical masks, 76 million pairs of medical gloves, 1.6 million pairs of goggles and 30 million gowns are part of the essential PPE demanded monthly by the global. According to Ranney et al. (2020), an increase in new cases has resulted in a rapid accumulation of infectious used PPE in the municipal solid waste system. Furthermore, it has been reported that since the emergence of COVID-19, the manufacturing of PP-based plastic wastes has risen and associated to negative impacts towards the health of the environment. Therefore, pyrolysis method had attracted the researchers' attention as it comprises of high waste decomposition, facile process and supports green waste management rather than current practices of incineration. Pyrolysis is a thermochemical process that converts plastic waste at high temperatures in a deoxygenated atmosphere into lower molecular weight compounds such as liquid oil, hydrocarbon gases and char (Verma et al., 2019). Char is one of the main product from pyrolysis of plastic and agricultural waste. This carbonaceous solid product is widely utilized in chemical adsorbents (Bernardo, 2011; Miandad et al., 2018), nanocomposites (Miandad et al., 2019; Sogancioglu et al., 2020), and supercapacitors (Pandey et al., 2021; Vivekanandhan, 2018).

Sugar palm starch is extracted from the centre of sugar palm stem. It mostly found in tropical countries including Southeast Asia and South Asia, covers from eastern India to Indonesia, Malaysia and Philippines (Ilyas et al., 2020). It has been discovered by previous studies (Sahari et al., 2012; Sanyang et al., 2016) to have excellent potential for usage as an alternative polymer due to its better chemical composition and mechanical reinforcement properties. Thus, the results from these studies demonstrate that by utilizing the natural starch as binder in char briquettes can leads to improve mechanical as well as high heating value of the composites.

There are very little or no research at all have been reported on the conversion and characterization of char composite briquettes from polypropylene waste derived char filled sugar palm starch (SPS). Therefore, the objective of the current study was to pyrolysed polypropylene waste from PPE into carbonaceous char and incorporate it into the sugar palm starch which acts as binder in order to improve the high heating values and mechanical properties of the sugar palm starch based biopolymer composites.

1.2 Problem Statements

At the fourth quarter of 2019, the globe was fiercely assaulted by a severe coronavirus syndrome (SARS-CoV-2 or COVID-19) pandemic. As a result, a public health emergency was proclaimed by the WHO on 30 January 2020 due to the COVID-19

outbreak (WHO, 2020a). In order to treat the piling up infected COVID-19 patients, increasing demand on personal protective equipments (PPE) supply happened. For instance, healthcare workers which constantly serving patients need to wear the PPE. PPE are used to preserve the wearer from contamination or disease transmission if the wearer has contact with the highly contagious substance and solid material (Carlos et al., 2020; Lu et al., 2020). Non-woven fabric polypropylene was used to fabricate PPE such as mask, isolation gown, hair nest and shoe cover. Thus, accumulates the number of petroleum-based PPE production and leads to global plastic waste production where the world generates 381 million tonnes of plastic waste annually (Ritchie & Roser, 2018), with expectation to double by 2034.

The practice used by MOH is burning the PPE after it had been disinfected with chlorine to kill COVID-19 (MOH, 2020a). Burning huge amount of PPE could lead to environmental pollution as these plastics contain additive materials such as cadmium and lead elements. Corburn et al. (2020) stated that improper landfilling and local burning of plastic and medical waste had increased Indian municipal waste issues the pandemic, and this situation aid the spread of the virus contagion. Therefore, there is a problem in handling unconventional waste in a sustainable manner with lowering carbon emissions, minimizing secondary virus transmission, and minimizing potential health risks. Furthermore, without conventional waste management strategy and waste emergency strategies to combat the epidemic, global might face catastrophic repercussions. Waste plastics can account for about 28% of the total cadmium in municipal solid wastes. Burning of plastic wastes can release important atmospheric pollutants (Verma et al., 2016). Due to these negative effects of plastic wastes and their disposal methods on the environment, more environmentally friendly methods should be developed for the disposal of plastic wastes.

Therefore, in this study, pyrolysis method is utilized to decompose the polypropylene (PP) waste derived from disinfected PPE as it is proven to produce less pollution as its end-products are collected and reused into useful outputs. It will be an excellent technology for the transformation of plastic waste to usable output (Worrel & Vesilind, 2012a). In placing more emphasis, Qin et al. (2018) and Vivero et al. (2005) had stated that the conversion of plastic wastes to hydrocarbon blends via pyrolysis is the best way in order to decompose and recycle the PPE waste. It does contribute to the reduction of plastic waste number, the recovery of chemicals and the replacement of fuels and other virgin materials. Furthermore, there are several pyrolysis parameters which affecting the end-products yields including process temperature, residence time, type of reactor, heating rate and presence of catalysts. According to previous studies (Das & Tiwari, 2018b; Park et al., 2012; Saptoadi et al., 2016; Sharuddin et al., 2016), pyrolysis temperature plays significant role in the thermal decomposition to produce highest yield of solid product chars. Increases in temperature result in higher liquid yields, while decreases in temperature result in higher char yields (Basu, 2013; Te et al., 2021). Therefore, altering the pyrolysis temperature is the most crucial to investigate highest and optimum char yields.

Next, the yielded carbonaceous chars were used as raw materials for fabrication of char briquettes for fuel applications (Lubwama et al., 2020). However, the char like most plastic derived carbon products is totally lack of plasticity. Hence, the addition of starch

binder including sugar palm starch is important, in order to hold them together with increased their adhesion to form compressed char briquette (Hapuarachchi et al., 2020). The characteristics and properties of starch have an impact on binder efficiency (Mohd et al., 2016). The characteristics of natural starch mainly determined by its biological origin including its amylose and amylopectin content. The main challenges in selecting the suitable natural starch as binder for the fabrication of char filled natural starch biopolymer composite briquette are the weaknesses regarding its brittleness, processability, poor mechanical properties and low heating values. To overcome this shortcomings, addition of SPS is needed to act as the binder and to enhance their performances (Mohd et al., 2016). This is due to the fact that SPS is one of the good binder with higher amylose content, ranged from 37.0 to 37.8% (Adawiyah et al., 2013; Sahari et al., 2014), compared to other widely used natural starch like tapioca (17%), potato (25%) and corn (28%). In addition, the utilization of SPS in briquette manufacturing is the novelty for this research because there is no published briquetting works used SPS as the binder.

Hence, the motivations behind this study are (1) to yield the highest amount of char from the pyrolysis of polypropylene plastic waste into commercialized fuel briquette applications, with the help of sugar palm starch, (2) to promote green technology of pyrolysis for proper waste management by proposing a policy framework to the Ministry of Health (MOH), Ministry of Agriculture (MOA), and Ministry of Human Resources (MOHR), and (3) to tackle the increasing amount of plastic waste via upcycling of plastic waste into various end-products including char, fuel-like oil, and chemicals, which not only contribute to controlling the virus spreading via waste disposal, reducing environmental pollution, but also solving the rise in energy demand.

1.3 Aim and Objectives

The aim of this research is to transform plastic waste especially medical waste amidst COVID-19 pandemic into char briquettes using carbonaceous char filled sugar palm starch for domestic and commercial uses. To make a new green product, the research objectives can be specified into:

1. To determine the optimum char yield of PP waste pyrolysis product using laboratory-scale batch pyrolysis reactor at different temperature.

2. To appraise the best ratio of PP char and sugar palm (*Arenga pinnata* [*Wurmb.*] *Merr*) starch as binders at different ratios on compressive strength and high heating value.

1.4 Significance of Study

1. The findings from the current study are expected to contribute to the development of sustainable green technology methods for pyrolysis and char generation from plastic waste.

2. In terms of waste management, this study lays the groundwork for converting waste from hospital PP equipment, especially PPE into high-quality char, effectively turning waste into wealth.

3. Slow pyrolysis is a cleaner method of producing char than open burning, which was formerly used.

4. This research may help to reveal the possibility of employing sugar palm starch as a binder in the development of green char composites; otherwise, such a plentiful bioresource may well go underutilized.

5. By providing a non-food source of economic growth for rural parts of the country, the successful production of such green products from sugar palm starch will give chances to enhance the standard of living of sugar palm tree farmers in Malaysia.

6. Creation of jobs especially in the plastic and agricultural waste recycling industry.

1.5 Scope of Study

In this study, non-woven polypropylene (PP) wastes derived from protective personal equipments (PPE) were washed and pulverized into PP powder, which then, converted into chars (C) via slow pyrolysis for optimum char yielded. The yield was optimized using optimized pyrolysis temperature and low heating rate. The elemental composition and structural morphology of the PP wastes and the obtained C was characterized through energy dispersive X-ray spectroscopy (EDX) and field emission scanning electron microscope (FESEM), respectively. Brunauer-Emmett-Teller (BET) surface area analysis which provides value of specific surface area, pore volume and pore size distribution of solid char. The best C with outstanding functional properties was spotted out for further briquette preparation. Then, characterization of their physical, chemical, thermal and structural properties were performed. Later, sugar palm starch (SPS) were manually extracted from the sugar palm tree which used as the binder for the development of char composites.

Char-based briquette biocomposite was developed by using hydraulic press method with the addition of sugar palm starch (0–40 %) as binder. Their properties were characterized including elemental, morphological, thermal, proximate and structural properties. Bomb calorimeter analysis which used to calculate the higher heating values (HHV) of the biocomposites was carried out.

1.6 Structure of Thesis

The structure of this thesis is in accordance with the alternative thesis format of Universiti Putra Malaysia which is based on the publications of this study. Each research chapter represent a separate study that has the introduction, methodology, results and discussion, and conclusions. The details of the structure are as follows:

Chapter 1

The problems that initiate this research and the research objectives were clearly highlighted in this chapter. The significance of this work and the scope of study were also elaborated within the chapter.

Chapter 2

This chapter presents a comprehensive literature review on the areas related to the topic of this thesis. In addition, the research gaps obtained from the review were also clarified within the chapter.

Chapter 3

This chapter presents the methodology used in this study for the preparation of materials, testing procedure, and data collection.

Chapter 4

This chapter presents the first article entitled "**Low-temperature thermal degradation of disinfected COVID-19 non-woven polypropylene-based isolation gown wastes into carbonaceous char**". In this article, the optimum pyrolysis temperature in highest char yields was determined. The yielded chars were also characterized.

Chapter 5

This chapter presents the second article entitled "**Development and characterization of polypropylene waste from personal protective equipment (PPE)-derived char-filled sugar palm starch biocomposite briquettes**". The effect of sugar palm fibre at different loading (0 – 40 %) on the thermal, morphological, tensile, and physical properties of char-based briquettes were investigated.

Chapter 6

This chapter presents the overall conclusions from the whole study as well as future recommendations for further improvement of this study.

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LIST OF PUBLICATIONS

Journal articles

Harussani, M. M., Sapuan, S. M., Rashid, U., & Khalina, A. (2021). Development and Characterization of Polypropylene Waste from Personal Protective Equipment (PPE)-Derived Char-Filled Sugar Palm Starch Biocomposite Briquettes. *Polymers*, 1*3*(11), 1707.

Harussani, M. M., Sapuan, S. M., Rashid, U., Khalina, A., & Ilyas, R. A. (2021). Pyrolysis of polypropylene plastic waste into carbonaceous char: Priority of plastic waste management amidst COVID-19 pandemic. Science of The Total Environment, 149911.

Harussani, M. M., Rashid, U., Sapuan, S. M., & Khalina, A. (2021). Low-Temperature Thermal Degradation of Disinfected COVID-19 Non-Woven Polypropylene-Based Isolation Gown Wastes into Carbonaceous Char. *Polymers*, 13(22):3980.

Harussani, M. M., & Sapuan, S. M. (2021). Development of Kenaf Biochar in Engineering and Agricultural Applications. *Chemistry Africa.*

Harussani, M. M., & Sapuan, S. M., Gohar Nadeem, Raffin T., & Kirubaanand W. (2022). Recent applications of carbon-based composites in defence industry: A review. *Defence Technology* (Submitted).

Harussani, M. M., Sapuan, S. M., Rashid, U., & Khalina, A. (2022). A review on natural starch as binders in fuel briquette manufacturing. *Carbohydrate Polymers* (Submitted).

Harussani, M. M., & Sapuan, S. M. (2022). Waste derived carbon in energy applications. *Carbohydrate Green Energy and Environment* (Submitted).

Harussani, M. M., Sapuan, S. M., Rashid, U., & Khalina, A. (2022). *In vivo* toxicity evaluation of polypropylene waste-derived char filled sugar palm (*Arenga pinnata (wurmb) merr.*) starch biopolymer composites using zebrafish model. *Journal of Hazardous Materials* (Submitted).

Conference/ Seminar

Harussani, M. M., Sapuan, S. M., Khalina, A., Rashid, U., Syafiq R.M.O., Nazrin A., Sherwani S.F.K., Hazrol M.D., Hazrati K.Z., Azlin M.N.M., Abotbina W. & Tarique, J., Recent Development of Carbonaceous Materials Char as Nanofillers in Fuel Biocomposite Briquettes: A Review, Dec 2021, Conference: International Conference on Sugar Palm and Allied Fibre Polymer Composites 2021. At: UPM Serdang, Malaysia.

Harussani, M. M., Salit, M. S., Rashid, U., & Abdan, K. (2021, July). Plastic Waste Conversion into Electrical, Thermal and Fuel Energy Via Incinerations and

Pyrolysis Amidst COVID-19 Pandemic. In AIUE Proceedings of the 2nd Energy and Human Habitat Conference.

Harussani, M. M., Sapuan, S. M., Khalina, A., Rashid, U. & Tarique, J., Slow pyrolysis of disinfected COVID-19 non-woven polypropylene (PP) waste, 7th Postgraduate Seminar on Natural Fiber Reinforced Polymer Composites 2020, May 2021, Conference: International Symposium on Applied Sciences and Engineering ISASE2021At: Erzurum, Turkey.

Harussani, M. M., Sapuan, S. M., Khalina, A., Ilyas, R. A., & Hazrol, M. D., REVIEW ON GREEN TECHNOLOGY PYROLYSIS FOR PLASTIC WASTES, 7th Postgraduate Seminar on Natural Fiber Reinforced Polymer Composites 2020, 17th November 2020, At: Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Serdang, Selangor, Malaysia.

Tarique, J., Sapuan, S. M., Khalina, A., Harussani, M. M. & Sherwani, S. F. K., Mechanical properties of arrowroot starch-based biopolymers plasticized with glycerol, 7th Postgraduate Seminar on Natural Fiber Reinforced Polymer Composites 2020, May 2021, Conference: International Symposium on Applied Sciences and Engineering ISASE2021At: Erzurum, Turkey.

Ilyas, R. A., S. M. Sapuan, M. S. N. Atikah, R. Ibrahim, M. D. Hazrol, S. F. K. Sherwani, M. M. Harussani, Tarique Jamal, A. Nazrin, and R. Syafiq., NATURAL FIBRE: A PROMISING SOURCE FOR THE PRODUCTION OF NANOCELLULOSE, 7th Postgraduate Seminar on Natural Fiber Reinforced Polymer Composites 2020, 17th November 2020, At: Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Serdang, Selangor, Malaysia.

Hazrol, M. D., S. M. Sapuan, M. Y. M. Zuhri, E. S. Zainudin, N. I. A. Wahab, R. A. Ilyas, M. M. Harussani, Tarique Jamal, A. Nazrin, and R. Syafiq., EFFECT OF SORBITOL AND GLYCEROL PLASTICIZER AND CONCENTRATION ON PHYSICAL PROPERTIES OF CORN STARCH (ZEA MAYS) BIODEGRADABLE FILMS, 7th Postgraduate Seminar on Natural Fiber Reinforced Polymer Composites 2020, 17th November 2020, At: Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Serdang, Selangor, Malaysia.

Book

Sapuan, S. M., Harussani, M. M., & Ilyas, R. A., Advanced Composites: Applications for COVID-19 and Beyond. US Springer (To be published in 2022)

Sapuan, S. M., Harussani, M. M., & Ilyas, R. A., Contribution of Composites During COVID-19 Pandemic. Elsevier (To be published in 2022)

Wan Azlina W. A. K. G., Sapuan, S. M., & Harussani, M. M., Char Filled Biocomposites: Production, Characterization and Applications. Elsevier (To be published in 2022)

Chapter in Book

Ilyas, R. A., Sapuan, S. M., Harussani, M. M., Atikah, M. S. N., Ibrahim, R., Asyraf, M. R. M., & Siengchin, S. (2021). Development and Characterization of Roselle Nanocellulose and Its Potential in Reinforced Nanocomposites. In Roselle (pp. 285-317). Academic Press.

Ilyas, R. A., Sapuan, S. M., Kirubaanand, W., Zahfiq, Z. M., Harussani, M. M., Atikah, M. S. N., Ibrahim, R., ... & Syafiq, R. (2021). Roselle: Production, Product Development, and Composites. In Roselle (pp. 1-23). Academic Press.

R.A. Ilyas, S.M. Sapuan, A. Atiqah, M.R.M. Asyraf, N. Mohd Nurazzi, Mohd Nor Faiz Norrrahim, Mohd Azwan Jenol, M. M. Harussani, R. Ibrahim, M.S.N. Atikah, M. Chandrasekar, Chapter 4 Thermal Properties of Sugar Palm Fiber Based Hybrid Composites

N.M. Nurazzi, S.H. Kamarudin, H.A. Aisyah, M.A. Jenol, L.C. Hao, S.M. Yusuff, M.R. Nur Amira, M. M. Harussani, M.N.F. Norrrahim, R.A. Ilyas, A. Norli, S.M. Sapuan, Chapter Nanocellulose Application in Automotive

Other presentations (Poster/Keynote/Conference)

S. M. Sapuan, M. M. Harussani as the co-author of Keynote Speaker, Minho University, Portugal, the Fibrenamics International Workshop: From Waste to Advanced Materials and Products on 21st April 2021, entitled “Recent development in biocomposite research in Malaysia”.

S. M. Sapuan, M. M. Harussani as the co-author of Keynote Speaker, National Textile University (NTU), Faisalabad, Pakistan, the 6th COVITEC on 2nd and 3rd March 2021, entitled “The Contribution of Bio-composites during COVID-19 Pandemic”.

M. M. Harussani, Oral Presenter in 7th Postgraduate Seminar on Natural Fibre Reinforced Polymer Composites on 17th November 2020 by INTROP, UPM.

S.M. Sapuan, and M.M. Harussani, Development of polypropylene-based COVID-19 isolation gown char reinforced sugar palm starch composites, INTROP Open Day (IOD2021), 9 April 2021, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, Selangor, Malaysia.

M. M. Harussani, and S. M. Sapuan, Slow pyrolysis of non-woven polypropylene COVID-19 PPEs into char, INTROP Open Day (IOD2020), 29 December 2020, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, Selangor, Malaysia.

Harussani, M. M., Sapuan, S. M., Khalina, A., Rashid, U. & Tarique, J., Slow pyrolysis of disinfected COVID-19 non-woven polypropylene (PP) waste, May 2021, Conference: International Symposium on Applied Sciences and Engineering ISASE2021At: Erzurum, Turkey.

Harussani, M. M., Salit, M. S., Rashid, U., & Abdan, K. (2021, July). Plastic Waste Conversion into Electrical, Thermal and Fuel Energy Via Incinerations and Pyrolysis Amidst COVID-19 Pandemic. In AIUE Proceedings of the 2nd Energy and Human Habitat Conference.

Additional publications

Harussani, M. M., Sapuan, S. M., Firdaus, A. H. M., El-Badry, Y. A., Hussein, E. E., & El-Bahy, Z. M. (2021). Determination of the Tensile Properties and Biodegradability of Cornstarch-Based Biopolymers Plasticized with Sorbitol and Glycerol. Polymers, 13(21), 3709.

Ilyas, R. A., Sapuan, S. M., Harussani, M. M., Hakimi, M. Y. A. Y., Haziq, M. Z. M., Atikah, M. S. N., ... & Asrofi, M. (2021). Polylactic Acid (PLA) Biocomposite: Processing, Additive Manufacturing and Advanced Applications. Polymers, 13(8), 1326.

Mohd Nurazzi, N., Muhammad Asyraf, M. R., Khalina, A., Abdullah, N., Harussani, M. M., Sabaruddin, F. A., Kamarudin, S. H., ... & Sapuan, S. M. (2021). Fabrication, Functionalization, and Application of Carbon Nanotube-Reinforced Polymer Composite: An Overview. Polymers, 13(7), 1047.

Wahab, M. A. F. A., Sapuan, S. M., Harussani, M. M., Zuhri, M. Y. M., & Saleh, A. A. (2021). Conceptual Design of Glass/Renewable Natural Fibre-Reinforced Polymer Hybrid Composite Motorcycle Side Cover. Journal of Renewable Materials. doi:10.32604/jrm.2021.016221

Norizan, Mohd Nurazzi, Muhammad Harussani Moklis, Siti Zulaikha Ngah Demon, Norhana Abdul Halim, Alinda Samsuri, Imran Syakir Mohamad, Victor Feizal Knight, and Norli Abdullah. "Carbon nanotubes: functionalisation and their application in chemical sensors." RSC Advances 10, no. 71 (2020): 43704-43732.

Nurazzi, N. M., Harussani, M. M., Zulaikha, N. S., Norhana, A. H., Syakir, M. I., & Norli, A. (2021). Composites based on conductive polymer with carbon nanotubes in DMMP gas sensors–an overview. Polimery, 66(2), 85-97.

Norizan, Mohd Nurazzi, Muhammad Harussani Moklis, Aisyah Humaira Alias, Ahmad Ilyas Rushdan, Mohd Nor Faiz Norrrahim, Khalina Abdan, and Norli Abdullah. "Treatments of Natural Fibre as Reinforcement in Polymer Composites-Short Review." Functional Composites and Structures (2021).

Lee, C.H., Khalina, A., Nurazzi, N.M., Norli, A., Harussani, M.M., Rafiqah, S., Aisyah, H.A. and Ramli, N., 2021. The Challenges and Future Perspective of Woven Kenaf Reinforcement in Thermoset Polymer Composites in Malaysia: A Review. Polymers, 13(9), p.1390.

Nurazzi, N. M., Asyraf, M. R. M., Fatimah Athiyah, S., Shazleen, S. S., Rafiqah, S., Harussani, M. M., ... & Khalina, A. (2021). A Review on Mechanical

Performance of Hybrid Natural Fiber Polymer Composites for Structural Applications. Polymers, 13(13), 2170.

Nurazzi, N. M., Sabaruddin, F. A., Harussani, M. M., Kamarudin, S. H., Rayung, M., Asyraf, M. R. M., ... & Khalina, A. (2021). Mechanical Performance and Applications of CNTs Reinforced Polymer Composites—A Review. Nanomaterials, 11(9), 2186.

Kadier, A., Ilyas, R. A., Huzaifah, M. R. M., Harihastuti, N., Sapuan, S. M., Harussani, M. M., ... & Ishak, M. R. (2021). Use of Industrial Wastes as Sustainable Nutrient Sources for Bacterial Cellulose (BC) Production: Mechanism, Advances, and Future Perspectives. Polymers, 13(19), 3365.

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Alias, A. H., Norizan, M. N., Sabaruddin, F. A., Asyraf, M. R. M., Norrrahim, M. N. F., Ilyas, A. R., Harussani, M. M., ... & Khalina, A. (2021). Hybridization of MMT/Lignocellulosic Fiber Reinforced Polymer Nanocomposites for Structural Applications: A Review. Coatings, 11(11), 1355.

Azlin, M. N. M.; Ilyas, R. A.; Zuhri, M. Y. M.; Sapuan, S. M.; Harussani, M. M.; Sharma, S.; Nordin, A. H.; Nurazzi, N. M.; Afiqah, A. N. 3D Printing and Shaping Polymers, Composites, and Nanocomposites: A Review. Polymers 2022, 14, 180.

Patent/ Copyright

Mohd Sapuan bin Salit, Muhammad Harussani bin Moklis, Ahmad Ilyas bin Rushdan, Umer Rashid, and Khalina binti Abdan. COVID-19 Polypropylene Waste-Derived Char Briquettes Reinforced with Natural Fibre (Accepted)

Mohd Sapuan bin Salit, Ahmad Ilyas bin Rushdan, Muhammad Asyraf bin Muhammad Rizal and Muhammad Harussani bin Moklis. Fabrication of Epoxy Composites Filled with Recycled Face Masks. 2020. (Accepted)

Awards

1) **Best of the Best Award,** review paper presented at the International Conference on Sugar Palm and Allied Fibre Polymer Composites 2021, Dec 2021 at Universiti Putra Malaysia (UPM), Malaysia.
2) **Top 3 Best Presenter Award**, review paper presented at the 7th Postgraduate Seminar on Natural Fiber Reinforced Polymer Composites 2020, Nov 2021, at Universiti Putra Malaysia (UPM), Malaysia.
3) **Journal Reviewer**, Nanotechnology Reviews [Q1, Impact factor: 7.848].
4) **Journal Reviewer**, Sugar Tech [Q3, Impact factor: 1.591].
5) **Journal Reviewer**, Polymer Bulletin [Q2, Impact factor: 2.870].
6) **Journal Reviewer**, Journal of Engineering Research and Reports.