UNIVERSITI TEKNOLOGI MARA

INFLUENCE OF NANO-SIZED PALM KERNEL SHELL BIOCHAR (n-PKSB) AS A POTENTIAL BIO-FILLER ON CHARACTERIZATION AND MECHANICAL PROPERTIES OF NATURAL RUBBER VULCANIZATES

NUR 'AISYAH AR-RAUDHOH BINTI MOHAMMAD TAHAR

Thesis submitted in fulfilment
of the requirements for the degree of
Master of Science
(Polymer Science and Technology)

Faculty of Applied Sciences

July 2025

ABSTRACT

This study aims to evaluate the suitability of nano-sized palm kernel shell biochar (n-PKSB) as a reinforcing bio-filler in natural rubber (NR) vulcanizates. In Part A, the characterization of n-PKSB was carried out using particle size analyser (PSA), ultimate and proximate analyser, Fourier Transform Infrared Spectroscopy (FTIR), Brunauer–Emmett–Teller (BET), Field Emission Scanning Electron Microscope (FESEM), and Energy Dispersive X-ray (EDX) spectrometry. Whereas Part B, the performance of n-PKSB filled NR vulcanizates at loadings from 0 to 10 parts per hundred rubber (phr) was assessed through cure characteristics measurement, bound rubber content (BRC), swelling measurements, tensile test, abrasion test, hardness test and compression set test. The n-PKSB exhibited nano-sized particle (10–11 nm) with high carbon content (60–66%). The size reduction enhanced surface functionality with the presence of C=C, C–O, and C–H groups, increased surface area (47–50 m^2/g), and formation of micropores with irregular and rough surface. The addition of n-PKSB had minimal effect on curing characteristics of NR vulcanizates. Based on results, 5 phr is the optimum n-PKSB loading. Incorporating n-PKSB into NR increased the crosslink density, BRC, tensile strength and abrasion resistance due to mechanical interlocking between n-PKSB and NR matrix. Therefore, this study demonstrates the potential of n-PKSB as a sustainable and alternative bio-filler in rubber compounding which reduces biomass waste and minimizes environmental impacts.

Keywords: Bio-filler, nano-palm kernel shell biochar, natural rubber, oil palm waste, mechanical properties.

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to Allah SWT for granting me the opportunity to pursue my master's degree and for guiding me through the successful completion of this long and challenging journey. My gratitude and thanks go to my supervisor, Prof. Madya Dr. Siti Nur Liyana binti Mamauod and a co-supervisor from Malaysian Palm Oil Board (MPOB), Dr. Nahrul Hayawin binti Zainal. Thank you for your support, patience, and valuable ideas in helping me with this research project.

I also would like to express my gratitude to the MPOB staff and lab assistants in UiTM Shah Alam, who provided the facilities and assistance during my lab work. Also, to my colleagues and friends for their help and support throughout this project.

Finally, I dedicate this thesis to my beloved family especially Mohammad Tahar (father) and , for giving strength, encouragement and determination to support my education until now. This achievement is for both of you. Not to forget, my siblings as well as my supportive partner, Muhammad Nurfikri Adlan.

Lastly, I want to thank myself for not giving up when the journey is getting harder and keep going strong to finish what I have started. Alhamdulillah.

TABLE OF CONTENTS

CHAPTER ONE
INTRODUCTION

1.1 Research Background

Oil palm, scientifically referred to as *Elais guineensis*, is a plant that is widely produced and cultivated globally. As of 2010, Malaysia ranks as the second-largest producers of palm oil and palm tree plantations in the world, having 4.85 million acres of plantations in 2010 (Abdul Khalil et al., 2015). Nowadays, Malaysian oil palm plantations have an outreach of 5.87 million hectares, accounting for 34.3% of worldwide palm oil commerce and 18.3% of global oils and fats industry in 2021 (Naidu & Moorthy, 2021; Parveez et al., 2021). At the end of 2022, the Malaysian Palm Oil Board (MPOB) reported that the oil palm plantation occupied around 5.65 million hectares which produces 18.55 million tonnes of crude palm oil (CPO) and other materials (Parveez et al., 2024). Loh (2017) has stated that the growing palm oil sector has been readily identified as the primary source of abundant biomass for renewable sources like oil palm waste (OPW). OPW is an unavoidable agricultural by-product of large palm oil production, which can generate serious disposal problems and bring negative impacts to the environment like pollution, smog and global warming if not being handled properly. Moreover, the waste material from the palm oil industry is usually collected and disposed of by burning off, causing serious health effects like respiratory diseases (Syazwani Aqilah et al., 2024). The most common elements of OPW are mesocarp fibres (MF), palm kernel shell (PKS), empty fruit bunches (EFB) and palm oil mill effluent (POME) (Abbas et al., 2019; Onoja et al., 2019). According to Haryati et al. (2018), the production of PKS residues increased every year from 3.56 million tonnes in 2014 to 4.72 million tonnes in 2016, as one of the most commonly produced palm oil biomass in Malaysia. As of 2021, the palm oil industry has occupied 5.9 million hectares of land, which produces 19.86 million tonnes of palm oil and 2.32 million tonnes of palm kernel (Jafri et al., 2021).

Since the palm oil industries produce millions of tonnes of biomass annually, biomass like PKS can be transformed to value-added additives like bio-fillers for rubber compounds (Abidin et al., 2023; Aisyah Ar-Raudhoh et al., 2024). The interaction