UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT AND CHARACTERISATION OF UNSATURATED POLYESTER COMPOSITE INCORPORATING WASTE RUBBER GLOVE CRUMBS AS FILLERS

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By

NUZAIMAH MUSTAFA

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

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DEVELOPMENT AND CHARACTERISATION OF UNSATURATED POLYESTER COMPOSITE INCORPORATING WASTE RUBBER GLOVE CRUMBS AS FILLERS

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October 2020

Chairman : Professor Mohd Sapuan Salit, PhD, PEng
Faculty : Engineering

This thesis, in general, aims to explore the potential of gloves waste rubber to be incorporated into polymer composites and to help minimise waste caused by gloves disposal. This research started with first objective of characterised the rubber crumbs obtained from waste rubber gloves for its shape, size and thermal properties. The waste gloves were downsized into crumbs with size ranging from 300 µm to 2 mm. The crumbs were regular shapes in shape and has smooth surface. The TGA and DSC analyses showed that the degradation pattern of waste gloves crumbs was similar to the degradation pattern of fresh gloves crumbs, suggesting that the properties of waste gloves did not degrade even after they have been disposed of.

Second objective of the research was to evaluates the effects of different contents of rubber crumbs on the properties of composites. The rubber crumbs of 5%, 10%, 15%, 20%, 25%, 30%, 35 % and 40 % (by weight) were incorporated into unsaturated polyester. The addition of rubber crumbs has increased the impact strength of the composites by 6% and continues to increase as the content of the rubber increases. This is because the rubber gives a certain degree of elasticity to the composite and has better capacity to absorb energy from the impact load. The addition of crumbs, however, decreased the tensile and flexural strength by 80% and 75% respectively. The strength decreases as the rubber crumbs increase because the adhesion between the crumbs and the polyester becomes weaker due to the agglomeration of the crumbs prevents the polyester from binding well to the rubber surface. Many voids can be seen in the SEM micrographs of the tensile fracture as the content of the crumbs increases in the composite.

Third objective was analysed the effect of NaOH, H_2S0_4 and $KMnO_4$ treatment on rubber crumbs surface to the composite's properties. Composites with NaOH-treated crumbs had improved tensile strength by 2% because NaOH treatment improves the hydrophilicity of the rubber surface, which facilitates better polyester wetting and improves adhesion between rubber and polyester. The rubber crumbs with NaOH treatment have a rougher surface with numerous micropores and microcracks that allow more polyester to penetrate the rubber surface irregularities, thus improving the adhesion of the rubber-polyester. Furthermore, FTIR peak study indicates more polar functional groups and soluble elements on the NaOH-treated rubber surface. These groups initiate further linkages with the polyester polar groups and improves the interfacial adhesion of rubber-polyester. In addition, NaOH eliminated the passive layer created by rubber additives and further reduced the surface contact angle to 31%, allowing for better polyester wetting on rubber. Contrariwise, treatment with H_2S0_4 and $KMnO_4$ decreased the tensile strength of the composites by 2% and 11% respectively.

Finally, this research assesses the effect on the properties of composites when crumbs have been treated with different concentrations of sodium hydroxide. The 7% of NaOH treatment concentration on rubber crumbs have sufficiently modified the rubber surface and reduced the contact angle of rubber surface by 27%. It increases the hydrophilicity of the rubber and thus improves the rubber-polyester wettability and adhesion. The 7% NaOH intensively etched the rubber and made the surface rougher, more microcracks and irregularities and eliminating the passive layer on the rubber, thereby creating a greater surface area for polyester coverage and better polyester adhesion. It also induced more functional groups as FTIR revealed higher peak intensities, which generate more linkages with polar groups in polyester. These factors strengthened the interfacial rubber-polyester adhesion as the SEM micrograph tensile fracture showed that the rubber crumbs remained intact in the polyester matrix after fractured. In conclusion, waste rubber gloves can be incorporated into unsaturated polyester composites as it improves the composites toughness. Treatment of rubber crumbs with a concentration of 7% of NaOH has effectively modified the rubber surface and strengthens the adhesion between rubber and polyester resulting in improved composite properties.

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

PEMBANGUNAN DAN PERINCIAN BAGI KOMPOSIT POLIESTER TAK TEPU TERISI DENGAN SISA SARUNG TANGAN GETAH

Oleh

NUZAIMAH MUSTAFA

Oktober 2020

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Tesis ini, secara amnya, bertujuan untuk meneroka potensi sisa getah dari sarung tangan untuk dimasukkan ke dalam komposit polimer dan membantu meminimumkan pembuangan sisa getah yang disebabkan oleh sarung tangan terpakai. Penyelidikan ini dimulakan dengan objektif pertama untuk pencirian getah cebis yang diperoleh dari sisa sarung tangan getah bagi bentuk, saiz dan sifat termalnya. Sisa sarung tangan dikecilkan menjadi getah cebis dengan ukuran antara 300 µm hingga 2 mm. Getah cebis mempunyai bentuk yang sekata serta permukaannya licin. Analisis TGA dan DSC menunjukkan bahawa pola degradasi sisa sarung tangan serupa dengan pola degradasi sarung tangan baru, menunjukkan bahawa sifat-sifat sisa sarung tangan tidak merosot walaupun setelah dibuang.

Objektif kedua penyelidikan adalah untuk menilai kesan kandungan getah cebis yang berbeza terhadap sifat komposit. Getah cebis sebanyak 5%, 10%, 15%, 20%, 25%, 30%, 35% dan 40% (dalam ukuran berat) dimasukkan ke dalam poliester tak tepu. Penambahan getah cebis telah meningkatkan kekuatan hentaman komposit sebanyak 6% dan ia terus meningkat apabila kandungan getah meningkat. Ini kerana getah memberikan tahap keanjalan tertentu pada komposit dan mempunyai keupayaan yang lebih baik untuk menyerap tenaga dari beban hentaman. Penambahan getah cebis, bagaimanapun, menurunkan kekuatan tegangan dan lenturan masing-masing sebanyak 80% dan 75%. Kekuatannya semakin berkurang apabila getah cebis meningkat kerana lekatan antara cebisan dan poliester menjadi lemah kerana penggumpalan getah cebis menghalang poliester daripada melekat dengan baik ke permukaan getah. Banyak kekosongan yang dapat dilihat dalam mikrograf SEM bagi fraktur tegangan komposit yang mepunyai kandungan getah cebis yang lebih banyak.

Objektif ketiga adalah menganalisa kesan rawatan NaOH, H_2S0_4 dan $KMnO_4$ terhadap getah cebis kepada sifat komposit. Komposit dengan getah cebis dirawat NaOH mempunyai kekuatan tegangan yang lebih baik sebanyak 2% kerana rawatan NaOH meningkatkan sifat hidrofilik permukaan getah, ia memudahkan kadar pelekatan poliester dan memperbaiki lekatan antara getah dan poliester. Getah cebis dengan rawatan NaOH mempunyai permukaan yang lebih kasar dan mempunyai lebih banyak pori dan retak mikro yang membantu lebih banyak poliester menembusi liang-liang permukaan getah, sehingga meningkatkan lekatan antara getah dan poliester. Selanjutnya, analisa FTIR menunjukkan terdapat lebih banyak kumpulan berfungsi berpolar dan unsur-unsur boleh larut pada permukaan getah yang dirawat dengan NaOH. Kumpulan-kumpulan ini menghasilkan ikatan polar lebih banyak dengan kumpulan polar di dalam poliester dan memperkuatkan lagi lekatan antara getah dan poliester. Di samping itu, rawatan NaOH menghilangkan lapisan pasif yang terhasil daripada serapan bahan didalam getah dan seterusnya mengurangkan sudut sentuhan permukaan menjadi 31%, yang mana menghasilkan lekatan poliester lebih baik terhadap getah. Sebaliknya, rawatan dengan H_2S0_4 dan KMnO4 menurunkan kekuatan tegangan komposit masing-masing sebanyak 2% dan 11%.

Akhirnya sekali, kajian ini menilai kesan terhadap sifat komposit apabila getah cebis dirawat dengan kepekatan natrium hidroksida yang berbeza. Rawatan berkepekatan 7% NaOH terhadap getah cebis berjaya mengubah permukaan getah dengan baik dan mengurangkan sudut sentuhan permukaan getah sebanyak 27%. Ini meningkatkan sifat hidrofilik getah dan dengan itu meningkatkan kemampuan lekatan poliester terhadap getah. 7% NaOH mengubah permukaan getah secara intensif dan menjadikan permukaannya lebih kasar dengan lebih banyak retak-retak mikro, ia turut menghilangkan lapisan pasif pada getah, lalu menyediakan permukaan yang lebih luas untuk liputan poliester dan meningkatkan kadar lekatan poliester. Ia juga menghasilkan lebih banyak kumpulan berfungsi berpolar pada permukaan getah sepertimana ditunjukkan oleh kadar puncak-puncak FTIR yang lebih tinggi, kumpulan fungsi ini menghasilkan lebih banyak hubungan dengan kumpulan fungsi berpolar pada poliester. Faktor-faktor ini menguatkan lekatan poliester terhadap getah seperti yang ditunjukkan dalam mikrograf SEM pada permukaan patah tegangan yang mana getah cebis tetap utuh terikat di dalam matriks poliester. Kesimpulannya, sisa sarung tangan boleh dimasukkan kedalam poliester tidak tepu kerana ia membantu meningkat kekuatan impak bagi komposit. Rawatan getah cebis dengan menggunakan kekuatan larutan NaOH sebanyak 7% dapat membantu memperbaiki sifat-sifat bagi komposit.

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

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Declaration by graduate student

I hereby confirm that:

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3D	Three-Dimensional
ATR	Attenuated Total Reflectance
BR	Butadiene Rubber/ Polybutadiene
C=C	Carbon–carbon bond
C–H	Carbon-hydrogen bond
CH_2	Methylene group
CH_3	Methyl group
CO	Carbon–oxygen bond
CR	Polychloroprene/ Neoprene
CR	Polychloroprene
C-S	Carbon-sulphur bond
CSM	Chlorosulphonated Polyethylene rubber
EOC	Ethylene- 1-octene copolymers
EPDM	Ethylene-propylene-diene monomer
FDA	US Food and Drug Administration
FTIR	Fourier Transform Infrared Spectrometry
H_2O_2	Hydrogen peroxide
H_2SO_4	Sulphuric acid
HAF	High Abrasion Furnace
HDPE	High Density Polyethylene
HNO_3	Nitric acid
$K_2Cr_2O_7$	Potassium dichromate
$KMnO_4$	Potassium permanganate
LDPE	Low Density Polyethylene
MA	Maleic Anhydride
MAPE	Maleic Anhydride Grafted Polyethylene

MARGMA	Malaysian Rubber Glove Manufacturers Association
MEKP	Methyl Ethyl Ketone Peroxide
$NaHSO_3$	Sodium bisulfite
NaOH	Sodium hydroxide
NBR	Acrylonitrile butadiene rubber /Nitrile rubber
NR	Natural rubber
NRG	Natural rubber glove
NRP	Natural rubber prophylactic
OH	Hydroxyl group
PE	Polyethylene
PP	Polypropylene
PSF	Polystyrene foam
PU	Polyurethane
PVA	Polyvinyl acetate
PVC	Polyvinyl chloride
PPE	Personal Protective Equipment
RRII	The Rubber Research Institute of India
S=O	Sulphonic group
SBR	Styrene Butadiene Rubber
SEM	Scanning Electron Microscope
SMG	Standard Malaysian Glove
T_g	Glass transition temperature
TGA	Thermogravimetric Analysis
UPM	Universiti Putra Malaysia
UP	Unsaturated Polyester
WHO	World Health Organization
kg	kilogram
g	gram

mg	milligram
m	metre
cm	centimetre
mm	millimetre
µm	micrometre/micron
mL	millilitre
µl	microliter
cm^{-1}	reciprocal wavelength
cm^3	cubic centimetre
cps	centipoise
h	hour
min	minute
MPa	Megapascal
GPa	Gigapascal
J	Joule
kN	kilo Newton
kV	kilovolts
phr	Parts per hundred rubber
RM	Ringgit Malaysia
°	Contact angle
° C	Temperature
wt.%	Weight percent
%	Percent
vol.%	Volume percent

CHAPTER 1

INTRODUCTION

1.1 Background

Recycling and recovery of waste rubber product such as glove, tyres, mattresses, shoe soles, automotive parts have received much attention in recent years. It provides an important implication such as protection to the environment, conservation of energy, as an alternative raw materials, helps in reducing cost, turning the waste to eco-friendly materials and improves the existing rubber related processing and properties (Rajan et al., 2006; Sienkiewicz et al., 2017). Rubber is difficult to degrade due to the highly durable properties which poorly managing the waste rubber products can lead to many environmental issues. As a result, many innovations and initiatives have been taken to recycle rubber goods and continue to evolve. Waste rubber has many valuable features that are worth reusing instead of being discarded and are relatively inexpensive and easy to obtain. The development of composites filled with waste rubber therefore provides a new future in the field of polymer research.

Several studies have shown that researchers are utilising waste rubber by generating new material or new products and incorporating waste rubber into existing product compounds or formulations. The history of using waste rubber as fillers begins with Charles Goodyear, the rubber historian who invented the vulcanisation process. He patented his work in 1853 of which describes the process of making a polymer materials from rubber granulate and natural rubber (Sienkiewicz et al., 2017). The works soon grew with many researchers exploring the mixing of waste rubber products into many mediums such as cements and resins.

Waste rubber has many excellent qualities that can be fully exploited for use in many useful applications. Rubber plays a major role in polymer-based composites, as the soft rubber phase gives flexibility to the composite, while the hard phase in polymers, such as polyester, provides strength. (Esmizadeh et al., 2017). The combination of these two distinct properties of the two components gives the composite some remarkable properties. In this research, waste rubber glove has been chosen as a raw material because of its high elasticity (Eng, 2016; Ikram, 1999; MREPC, 2017). Elastic behaviour of this elastomer can be benefited into functional material such as asphalt modifier, damping components, thermal and noise insulator and others. In addition, waste rubber glove is relatively inexpensive and easy to acquire, as this can lead to low production costs (Ahmad et al., 2016). This unique behaviour of glove has attracts researchers to further explore it potential in developing new sustainable material (Ismail et al., 2009; G. Mathew et al., 2001, 2006; Riyajan et al., 2012).

1.2 Problem Statements

As the standard of life improved and healthcare awareness risen globally, the rubber glove industry has grown rapidly over the years. Moreover, the rubber glove demand at surge due to the latest Covid-19 pandemic that hit the world badly. The pandemic had caused hundreds of thousands of people dead and millions of people more infected. As of 19 July 2020, there were 597,583 deaths and 5,934,936 confirmed cases worldwide, according to the World Health Organization (WHO). Hence, the gloves industry, faced with high global demand as gloves are used by frontliners, industries and individuals in the fight against the global pandemic. Before the pandemic, an average growth of rubber glove was 8%, generally due to the growing population, increasing usage in industrial such as food and electronic industries and development in healthcare systems.

Malaysian Rubber Glove Manufacturers Association (MARGMA) previous estimation of global demand for rubber gloves are 345,000 million pieces in 2020. However, when the COVID-19 pandemic hit and spreads aggressively across the globe, the Economic Intelligence Center estimated that global demand for total rubber gloves in 2020 will be 360,000 million pieces, which is 20% higher than the usual projection. It is the result of a 57% rise in the average demand for medical rubber gloves, which increased to 60,000 million pieces from normal (Kanjanavisut, 2020).

As a consequence, the high use of rubber gloves led to significant gloves being disposed of, which would ultimately contribute to a rise in dumping gloves, either in the landfill, incineration plant or random dumping, such as in the housing area and parks. Rubber gloves are not easy to biodegrade as they have undergone a vulcanisation process that creates highly cross-linked thermoset materials that makes gloves very elastic, robust and incredibly effective for protecting against many harmful substances such as blood, pathogens, microbes, chemicals and gases. Also, the rubber gloves resistance to abrasion, cut, tear and puncture. These features makes rubber gloves resilient to most environmental agents and may take more than 100 years to degrade (McKeen, 2014; Riyajan et al., 2012; Samsuri, 2010; Saxena et al., 1999; Torretta et al., 2015). Because of that, the excessive dumping rubber gloves consequently will create a serious environmental problem such as breeding ground for mosquitoes and rodents as well as dangerous animals like snakes and scorpions. In addition, chemicals additives in the gloves such as zinc and sulphur can leach out and pollute soil and water. Furthermore, illegal gloves burning can release toxic gases, hazardous smoke, particulate matter into the atmosphere and pollute the air (Adhikari et al., 2000; Bailey et al., 2002; Nuzaimah et al., 2018; Ramarad et al., 2015; Thomas & Gupta, 2016). The initiative of this research to explore the feasibility of incorporating waste rubber gloves into polymer composites would help to minimise the amount of discarded waste gloves. With the aim of helping to mitigate the environmental issues caused by rubber products. Furthermore, polymer composites have a large market share which, with only 5% of the waste gloves in the polymer composites it will have a significant impact on the consumption of waste gloves.

1.3 Research Objectives

The objectives of this research are:

1. To characterise the rubber crumbs obtained from waste rubber gloves for the physical, thermal and morphological properties.
2. To evaluate the effect of different contents of rubber crumbs on the mechanical and morphological properties of the waste rubber glove-unsaturated polyester composites.
3. To analyse the effect of sodium hydroxide sulphuric acid and potassium permanganate treatment on the rubber crumbs surface and its effect on the mechanical and morphological properties of waste rubber glove-unsaturated polyester composites.
4. To assess the effect of different concentrations of sodium hydroxide on the rubber crumbs surface and its effect on the mechanical and morphological properties of waste rubber glove-unsaturated polyester composites.

1.4 Significance of the Study

This study adds the following:

1. Successful development of unsaturated polyester composites with waste rubber gloves could benefit by adding more value to the waste rubber and by widening the use of waste rubber gloves in the field of material engineering in general and in the field of polymer composite in particular. To date, most of the recycled waste rubber has been from waste tyres, and is commonly used as fillers in concrete and asphalt.
2. The development of unsaturated polyester composites with waste rubber gloves is expected to widen the source of alternative filler materials as a substitute for conventional materials such as mineral fillers.
3. The study is expected to further explore the potential of waste rubber gloves in the development of recyclable products.
4. The outputs and findings of this research are expected to enhance the knowledge about incorporation of waste rubber in polymer composites.
5. The development of waste rubber gloves as fillers in unsaturated polyester composite is one of the effort to divert the previously known as hard-to-recycle rubber materials into a more beneficial usage.
6. The development of waste rubber gloves unsaturated polyester composite is expected to reduce the rubber gloves disposal issues which eventually reduce the environmental pollutions.
7. The recycling of waste rubber gloves helps to reduce the consumption of fresh raw materials and thus reduces the need for raw materials to be extracted and processed. The recycling of waste rubber gloves will therefore save energy and save natural resources.

1.5 Scope and Limitation of the Study

This research focuses on the method of producing rubber crumbs from waste gloves and on assessing the potential for the crumbs to be incorporated into an unsaturated polyester matrix. The waste rubber gloves were disposable glove collected from laboratories within Universiti Putra Malaysia (UPM). The waste gloves were grounded into crumbs using cryogenic grinding and were characterised for sizes, shapes, surface morphology using SEM and thermal analysis using TGA. The results of the analyses were then compared to the crumbs obtained from fresh rubber gloves. Toxicity level was not being analyse in this research as this research focus on assessing the potential incorporation of waste gloves into composite. Subsequently, this research was to determine the optimum rubber content in the unsaturated polyester composites by evaluating the effect of addition of 5, 10, 15, 20, 25, 30, 35 and 40 wt. % of rubber content in the composites. The composites were characterised for tensile, flexural and impact strength, elastic modulus, and fracture surface morphology. Composites with rubber content that gives optimum properties was used to analyse the effect of rubber crumbs treatment with sodium hydroxide, sulphuric acid and potassium permanganate. The rubber crumbs that treated with these chemicals underwent FTIR analysis, SEM surface morphology analysis and contact angle measurement and the composites prepared with addition of the treated rubber crumbs underwent tensile testing and fracture morphology analysis. The sodium hydroxide treatment had sufficiently modified the rubber surface which enhances the interfacial rubber-polyester adhesion thus improved the mechanical properties of the composite. Thus, in the final phase of this research was evaluates the effects of different sodium hydroxide concentration on the rubber surface. The rubber crumbs were treated with 1%, 4%, 7%, and 10% by volume of sodium hydroxide and being analysed for surface morphology using SEM, FTIR analysis and contact angle measurement. Composites were prepared with addition of rubber crumbs from each treatment respectively. The tensile test was performed to determine the treatment that gives composites with good tensile strength and the SEM analysis was performed to study the fracture behaviour of the composites. Besides that, the level of toxicity of recycled waste gloves has not been determined in this research as it is not the focus of the study.

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 represents a separate study that has its own ‘Introduction’, Materials and Methodology’, ‘Results and Discussion’, and ‘Conclusions’. The details of the structure are presented as follows:

Chapter 1

Background of the research with problem statement that initiates this research is explained in this chapter. Research objectives, significant of the research, scope and limitation of the research also highlighted in this chapter.

Chapter 2

A comprehensive literature review on the generation of waste rubber worldwide, the environmental impact of waste rubber, waste rubber management and waste rubber recycling efforts. This chapter also includes general information on rubber, applications and global rubber production and consumption. In addition, the chapter briefly explains about rubber gloves, the manufacturing process and their properties. Finally, this chapter presents the development of various composites incorporating different types of waste rubber.

Chapter 3

A detail methodology of preparation of materials, testing procedures, and data collection are presented in this chapter.

Chapter 4

This chapter presents the first article entitled **"Physical and Thermal Properties of Rubber Glove Waste as Potential Filler for Polymer Composites"**. In this article, the properties of waste rubber gloves were evaluated to discover the potential of the waste glove to potential to be used as a filler for the polymer composites.

Chapter 5

This chapter presents the second article entitled **"Microstructure and Mechanical Properties of Unsaturated Polyester Composites Filled with Waste Rubber Glove Crumbs"**. In this article, the focus is on studying the effect of different rubber crumbs loading on microstructure and mechanical properties of unsaturated polyester composite filled with waste rubber gloves crumbs.

Chapter 6

This chapter presents the third article entitled **"Effect of Surface Treatment On the Performance of Polyester Composite Filled with Waste Glove Rubber Crumbs"**. In this article, the study conducted is to investigates the effect of different rubber crumbs treatments on the composite properties.

Chapter 7

This chapter presents the fourth article entitled **"Sodium Hydroxide Treatment of Waste Rubber Crumb and Its Effects On Properties of Unsaturated Polyester Composites"**. In this article, presented the investigation of finding the optimum NaOH concentration treatment for rubber crumbs that improves adhesion between the polymer matrix and rubber filler in rubber polyester composites.

Chapter 8

This chapter presents a further discussion of the findings of this research.

Chapter 9

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

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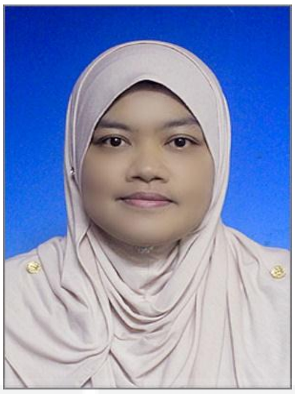

The student Nuzaimah Mustafa was born on the 12th July 1978 in Jasin, Melaka, Malaysia. She received her early primary education in 1985 at Sekolah Rendah Kebangsaan Felda Bukit Senggeh, Melaka. She later furthered her secondary education at Sekolah Menengah Kebangsaan (Agama) Sharifah Rodziah, Telok Mas, Melaka from 1991 to 1993 and end extended her study at Kolej Islam Sultan Alam Shah, Klang, Selangor from 1994 to 1995. The author later further her study in Bachelor of Engineering (BEng) in Materials Engineering at Universiti Sains Malaysia, Tronoh, Perak and graduated in 2001. Later in 2002, she completed her Master of Science (Msc) in Materials Engineering from Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang. In 2016, she started his PhD programme in the field of Mechanical Engineering at the Faculty of Engineering, Universiti Putra Malaysia, Malaysia.

LIST OF PUBLICATIONS

Papers in Journal

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Proceedings/ Conferences Presentation

M. Nuzaimah, S.M. Sapuan, R. Nadlene, and M. Jawaid, Incorporation of Waste Rubber into Different Matrices: A review, Proceeding of 5th Post-Graduate Seminar on Natural Fiber Composites 2016, 28th December 2016, INTROP UPM, Serdang, Selangor, Malaysia.

M. Nuzaimah, S.M. Sapuan, R. Nadlene, and M. Jawaid, Recycling of Waste Rubber as Fillers: A review, Wood and Biofiber International Conference (WOBIC), 21st-23rd November 2017, Putrajaya, Malaysia.

M. Nuzaimah, S.M. Sapuan, R. Nadlene, and M. Jawaid, Rubber Waste as Potential Filler for Polymer Composites: Material Characterisation, 2nd Colloqium Paper: Advanced Materials and Mechanical Engineering Research (CAMMER), FKM UTeM, Melaka, Malaysia.

M. Nuzaimah, S.M. Sapuan, R. Nadlene, and M. Jawaid, An Overview of Rubber Glove Manufacturing Process, Proceeding of the 6th Post-Graduate Seminar on Natural Fiber Reinforced Polymer Composites 2018, 5th December 2018, INTROP UPM, Serdang, Selangor, Malaysia.

M. Nuzaimah, S.M. Sapuan, R. Nadlene, and M. Jawaid, Development of Waste Rubber-Unsaturated Polyester Composite, Seminar Enau Kebangsaan 2019, 1st-2nd April 2019, Bahau, Negeri Sembilan, Malaysia.

Chapters in Book

M. Nuzaimah, S. M. Sapuan, R. Nadlene, M. Jawaid, and R. A. Ilyas. (2020). 9 Medical Rubber Glove Waste as Potential Filler Materials in Polymer Composites. In *Composites in Biomedical Applications* (pp. 191-206). ISBN: 978-0-367-27168-8 (hbk). CRC Press.

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Awards and Achievements

Best presenter in Seminar Enau Kebangsaan 2019, 1st-2nd April 2019, Bahau, Negeri Sembilan, Malaysia.

Best presenter in 5th Post-Graduate Seminar on Natural Fiber Composites 2016, 28th December 2016, INTROP UPM, Serdang, Selangor, Malaysia

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