Faculty of Engineering

MODELLING THE MECHANICAL AND MICROSTRUCTURE PROPERTIES OF CELLULAR RUBBER PRODUCED VIA MICROWAVE HEATING METHOD

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Bachelor of Engineering with Honours

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This declaration is made on the 25th day of June 2022

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MODELLING THE MECHANICAL AND MICROSTRUCTURE PROPERTIES OF CELLULAR RUBBER PRODUCED VIA MICROWAVE HEATING METHOD

MD AIMAN DANIAL BIN MD YUSOFF

Report is submitted to
Faculty of Engineering, University Malaysia Sarawak

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Dedicated to my beloved parents, family and friends who always encouraged me to do the best in everything.

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ABSTRAK

Terdapat pelbagai jenis getah selular dan banyak cara untuk menghasilkannya, seperti pemanasan konvensional. Walau bagaimanapun, kaedah pemanasan konvensional tidak memberikan hasil yang baik dari segi kualiti getah selular. Satu lagi aspek yang perlu diberi perhatian ialah jenis agen tiupan yang digunakan untuk proses berbuih pada getah. Malangnya, penggunaan Ejen Peniup Kimia (CBA) memberi kesan buruk kepada alam sekitar dan kesihatan awam. Oleh itu, aktiviti utama projek tahun akhir ini adalah untuk menghasilkan getah selular menggunakan air sebagai agen tiupan hijau dan mampan dibantu oleh kaedah pemanasan gelombang mikro dan perolakan. Kandungan air dipelbagaikan dari 0.5 hingga 2.0 bahagian setiap seratus getah (phr). Dua parameter tetapan berbeza digunakan dalam kajian ini, di mana kuasa gelombang mikro diubah pada 600 W dan 1000 W pada masa pendedahan yang berbeza, manakala pemanasan perolakan dikekalkan pada 150 °C. Laporan ini juga Sifat-sifat getah selular yang dihasilkan telah dicirikan dari segi Mikroskop Elektron Pengimbasan (SEM), Mikroskop Optik, Spektroskopi Inframerah Fourier (FTIR), Ujian Mampatan, Ujian Ketumpatan, Ujian Analisis Termalgravimetrik dan Simulasi Permodelan busa getah. Kemudian, keputusan yang diperolehi dibincangkan dan disimpulkan tentang tetapan parameter dan kuantiti air sebagai agen tiupan yang memberikan sifat terbaik getah selular. Projek ini juga mempamerkan pemodelan yang membina model getah selular dengan menggunakan Solidworks dan simulasi mampatan telah dilakukan pada model dengan menggunakan Ansys. Ini menunjukkan perkaitan antara data eksperimen daripada ujian mampatan dan data simulasi terhadap kesan jenis sel model getah selular. Parameter pemprosesan terbaik ialah melaksanakan kuasa yang lebih rendah (600 W) dan masa pemprosesan yang lebih lama (18 minit) dan kandungan air optimum busa getah ialah 0.5 phr.

ABSTRACT

There were various types of cellular rubber and many ways to produce it, such as conventional heating. However, the conventional heating method did not give a great result in terms of the quality of the cellular rubber. Another aspect that needs to be acknowledged is the type of blowing agent used for foaming process on the rubber. Unfortunately, the usage of Chemical Blowing Agent (CBA) has a bad impact on the environment and public health. Hence, the main activity of this final year project was to produce cellular rubber using water as a green and sustainable blowing agent assisted by microwave and convection heating methods. The water content was varied from 0.5 to 2.0 part per hundred rubbers (phr). Two different setting parameters were used in this study, where the microwave power was varied at 600 W and 1000 W at different exposure times, while convection heating was maintainedat 150 ℃. This report also The properties of the produced cellular rubber were chracterised in terms of Scanning Electron Microscope (SEM), Optical Microscope, Fourier Infrared Spectroscopy (FTIR), Compression Test, Density Test, Thermalgravimetric Analysis Test and Modelling Simulation of rubber foam. Then, the result obtained was discussed and concluded on which parameter settings and quantity of water as blowing agent give the best properties of the cellular rubber. This project also showcased a modelling that built a cellular rubber model by using Solidworks and a compression simulation was done on the model by using Ansys. This showed the correlation between the experimental data from compression test and simulation data on the effect of cell type of the cellular rubber model. The best processing parameter was implementing lower power (600 W) and longer processing time (18 minutes) and the optimum water content of the rubber foam was 0.5 phr.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ASTM	American Society for Testing and Materials
Au	Aurum
BA	Blowing Agent
CBA	Chemical Blowing Agent
CBS	N-cyclohexyl-2-benzothiazole sulfenamide
CCM	Constant Conductivity Mode
CFA	Chemical Foaming Agent
Cr	Chromium
DMA	Dynamic Mechanical Analysis
EPDM	Ethylene Propylene Diene Monomer
ENR	Epoxidized-NR
EVA	Ethylene Vinyl Acetate
FA	Foaming Agent
FTIR	Fourier Infrared Spectroscopy
HFM	Heat Flow Meter
KEPCO	Korea Electric Power Corporation
NR	Natural Rubber
PBA	Physical Blowing Agent

PEDOT:PSS	poly(3,4-ethylene dioxythiopene) ply(styrene sulfonate)
PFA	Physical Foaming Agent
SBR	Styrene Butadiene Rubber
SEM	Scanning Electron Microscope
Si_3N_4	Silicon Nitride
SiO_2	Silicon Oxide
Si	Silicon
SMR-L	Standard Rubber Malaysia grade L
STM	Scanning Thermal Microscope
TGA	Thermalgravimetric Analysis
TCM	Temperature Constant Mode
TMTD	Tetramethylthiuram disulfide
ZnO	Zinc Oxide

NOMENCLATURE

A	Surface area of the sample
°	Degree
℃	Degree Celsius
ρ	Density
Ω	Ohm
ΔT	Temperature difference across plates
%	Percent
GHz	Gigahertz
k	Thermal Conductivity

kg	Kilogram
kHz	Kilohertz
kPa	Kilopascal
L	Litre
m	meter
m/s	Meter per second
min	Minute
µm	Mikrometer
mm	Milimeter
mm/min	Milimeter per minute
nm	Nanometer
N/m	Newton per meter
Pa	Pascal
phr	Part per Hundred
Q	Heat flow
s	Sample thickness
s	Second
W	Watt
wt%	Weight percent

CHAPTER 1: INTRODUCTION

1.1 Project Overview

This project studies analyzing the properties of a cellular rubber produced through the processing method of microwave and convection-assisted heating by using water as the blowing agent. There were different samples produced throughout this project to analyze their properties and the difference in each sample's characteristics. In this project, the properties of the cellular rubber focused on the mechanical, microstructure, modelling, thermal and physical properties. Each property has its own method of analyzing and finding the result of the properties of the materials. Hence, the results obtained were examined and discussed by comparing each sample based on their properties. In addition, the relationship between the processing parameter and properties of the cellular rubber were discussed to identify the best processing method.

1.2 Problem Statement

Cellular materials refer to a material consisting of many open cell or closed cell cells that dispersed throughout the mass of the material. The most common name of the cellular materials was known as foams. This type of material is one of the materials that have good abilities for the future design of engineering structures and the work produced by the material is very efficient (Novak et al.,2021). Cellular materials can be used either by self-sufficient or composites which combined with other materials. There are many possible applications of cellular materials such as in transportation industries for crashworthiness, thermal and acoustic insulation, noise control applications, buildings, purifiers, heat exchanger and decoration arts (Prabhu et al.,2015). According to Baroutaji et al. (2019), cellular materials have been applied in transportation industries due to their lightweight materials with good energy absorption ability.

The processing method of cellular material refers to the production process and for cellular material that are many ways to produce it. Example of production process is by conventional method where fluid within the material was applied heat energy via heat transfer mechanism (Calles-Ariaga et al.,2016). Other than that, there was also a process known as the microwaved assisted heating method, which essentially used microwave radiation energy to generate heat energy within the material (Sen et al.,2011). Methods used heat energy to start a process known as foaming, which will produce a cellular material. Nowadays, it has been proven that microwaved assisted heating more efficient in creating cellular material due to rapid heating and uniform cell structure (Aghvami-Panah et al.,2021).

In this research, the microwave and conventional method were selected due to its ability to achieve uniform cell distribution and rapid heating process. Water was selected as a blowing agent (BA) - for the foaming process. This is due to water is not harmful, environmentally friendly, and very stable to as BA during foaming process (Ariff et al. (2020)).

However, up until this day, there were not many available studies or reviews on water as blowing agent on cellular rubber and focusing on its properties and characteristics and explaining the detail on different type of properties of rubber in a comparative way. Thus, this thesis will be discussing and evaluating the cellular rubber that produced by using microwave assisted heating method and water as the BA. Then, the results on thermal, physical, and mechanical will be analyzed. Addition there have not been many studies or reviews on water as a blowing agent on cellular rubber, focusing on its properties and characteristics and comparing the processing parameter. In conclusion, this thesis discussed and evaluated the cellular rubber produced via microwaved-assisted heating and water as the blowing agent. Then, thermal, physical, and mechanical results will be analysed.

Lastly, comparing the difference between each sample hence providing the best result of the best cellular rubber. Other than that, model of a cellular rubber also was built by using Solidworks and the compression simulation was done by implementing Ansys. The reason behind this was to see the correlation between experimental data from the compression test and the compression simulation done on the model. The relationship that was observed was the matrix structure of the cellular rubber model, which was the effect of the cell type within the cellular rubber on the strength upon compression. Hence, the result from the simulation will be compared to the experimental data from the compression test.

1.3 Research Questions

The research question focuses more on determining the thermal and mechanical properties of a cellular rubber produced from microwave heating.

1) What are the best processing parameters of microwaved-assisted heating method to produce cellular rubber?
2) How can water as the blowing agent affect the cellular rubber's thermal, mechanical, and physical properties?
3) What is the relationship between the structure of cellular rubber and the NR foam's deformation after a certain load?
4) What is the relationship between the cell structure of cellular rubber and thermal stability of the foam?
5) How can a model of cellular rubber showcase the mechanical properties of the cellular rubber in terms of the strength of the cellular rubber?

1.4 Objectives of Study

To achieve the best result of good stability of the cell structure, uniform cell distribution, best compression deformation and other characteristics cellular NR. there are few objectives of study that has been set for this final year project that was listed below:

i. To develop different parameters of processing methods to achieve the desired parameters of microwaved assisted heating.
ii. To observe the effect of the different water content of rubber foam on the properties of the rubber foam.
iii. To characterize the produced cellular rubber in terms of thermal, mechanical, and physical properties.
iv. To establish a cellular rubber cell structure model using modelling software when subjected to a compression test.

1.5 Scope of Study

The first part of this report is more on finding resources and information on producing cellular rubber through microwave assisted heating and other methods on establishing cellular rubber's physical and thermal properties.

1.6 Significant of Study

This study's significance is to help improve the cellular rubber properties for applications nowadays. In addition, this project can also give knowledge and understanding to other people on how cellular rubber does been applied as a material by recognizing its properties and characteristics. Besides that, this study will help determine the best processing parameter in producing cellular rubber and the benefits of using water as the blowing agents.

1.7 Summary

This chapter has explained and gave a rough idea to the readers on the purposes of this paper. With the introduction, the reader can get the idea and understanding easily throughout reading this project’s report. Based on the objectives listed, the readers can also determine this project's expected result. With the provided introduction, the reader can easily grasp the concept and gain comprehension throughout the rest of the report. On the basis of the listed objectives, readers can also determine the anticipated outcome of the project,

CHAPTER 2: LITERATURE REVIEW

2.1 Cellular Rubber

There are many type of rubbers that existed in our world until these days. Each rubber that has been produced or manufactured has their own solely purposes suitable for certain usage such as polyurethane rubber used in medical industries (Rahimi and Mashak,2013). In addition, Ethylene Propylene Diene Monomer Rubber, also known as EPDM rubber, is a type of rubber that is commonly used in sports, particularly in flooring systems (Craciun et al.,2020). There was a type of rubber known as cellular rubber, also referred to as foam rubber, whose name was derived from the fact that it contained cell structure, distinguishing it from other types of rubber that lacked cell structure (Suethao et al.,2021).

Suethao et al. (2021) explained that foam rubber was formed by adding bubble gas into the polymer matrix. These stages lead to porosity and the polymer in the continuous phase. As mentioned before, the foam rubber was differentiated from others because of its cells and these cells also known as porosity. The porosity of the foam rubber can be categorized into two types of structures: open-cell and closed-cell. An open-cell cellular rubber is a rubber that has the ability towards more on its flexibility and as for closed-cell cellular rubber is more to rigidity ability of the rubber (Suethao et al.,2021). This type of characteristic will be one of the indicator that differentiate between various types of cellular rubber. Cellular rubber is also the same as any other rubbers, which consisted of various variations of cellular rubber that have been discovered and manufactured until today.

2.1.1 Type of Cellular Rubber

As mentioned before, cellular rubber or foam rubber has various kind of cellular rubber which has different characteristics, production method and also application. These various cellular rubber types have been used and manufactured in many industries. Open-cell and closed-cell cellular rubber are the two most prevalent types of cellular rubber. According to Rostami-Tapeh Esmaeil et al. (2021), open-cell cellular rubber is the rubber type in which the rubber material is interconnected with the surrounding environment. In contrast, closed-cell rubber is the type of rubber in which the material within the rubber is dispersed individually throughout the rubber's grid and these bubbles are isolated from the outside.

In the previous years, an experiment was conducted to differentiate between open-cell and closed-cell cellular rubber by Akiba and Kobayashi (2001) where in the experiment, it was found that the open-cell type has a lighter weight, lower cost and the porosity of the rubber was higher and the closed-cell type much denser and more expensive due to its advantage of lower moisture absorption and these characteristics very useful to be applied in any products as thermal and electrical insulators. Akiba and Kobayashi (2001) also stated that open-cell type cellular rubber was suitable for separation due to its interaction between the cells that provides spaces for any fluid to pass through the rubber easily. These two types of cellular rubber can be produced using a method called foaming agent where there are two type of foaming agent, Chemical Foaming Agent (CFA) and Physical Foaming Agent (PFA) (Rostami-Tapeh-Esmaeil et al.,2021).

One of the examples of open-cell type cellular rubber was Ethylene Propylene Diene Monomer Rubber (EPDM) which was produced by using PFA which is carbon dioxide (CO_2) (Kong et al.2016). Hence, the EPDM rubber foam produced as CO_2 acted as the PFA and ascribed to the characteristics also led to the formation of open-cell cellular rubber. **Figure 2.1** shows each stage that occurred throughout the formation of open-cell cellular rubber.

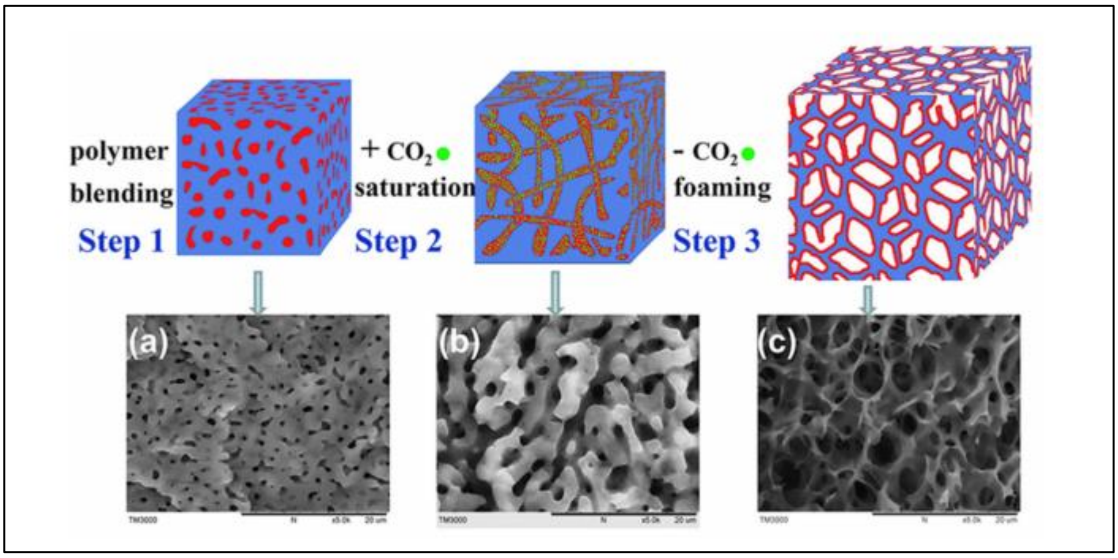
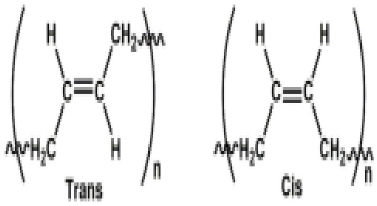
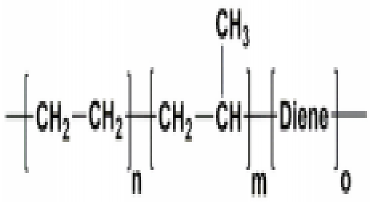


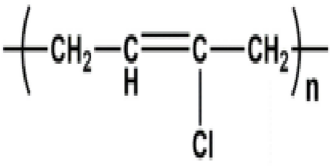
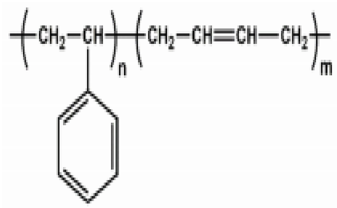
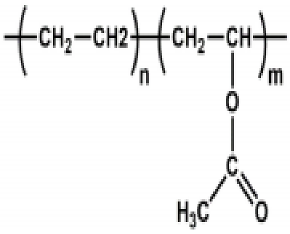
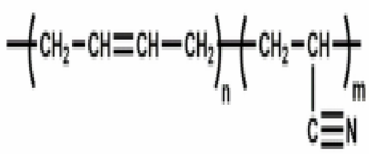
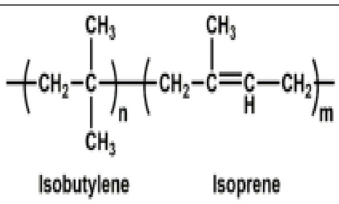
Figure 2.1: Scanning Electron Microscopy (SEM) of each stages taken in forming open-cell cellular rubber. Obtained from Chemistry, processing,

properties, and applications of rubber foams. *Polymers*, 13(10), 1565. by Rostami-Tapeh-Esmaeil et al. (2021).

Aforementioned, EPDM rubber is one of the type of rubber that has the characteristics of open-cell cellular rubber. Therefore, it was proven that different type of rubber can be produced as the cell structure and the mechanical and physical properties of the rubber can be controlled accordingly to the rubber designated. Up to now, various rubber has already been discovered and reported and Table 2.1 summarises the main rubbers with the characteristics and molecular structure of each rubber.

Table 2.1: Type of rubber with the characteristics and molecular structure.

Rubber	**Characteristics**	**Molecular Structure**
Natural Rubber (NR)	i. Bio-compatibility. ii. High elasticity . iii. Resistance of tear and abrasion. iv. Resilience. v. Resistance from oxidation. vi. Resistance from low ozone. vii. Compression set is low. viii. Low performance of chemical resistance and ability of processing.	
Ethylene Propylene Diene Monomer (EPDM)	i. Resistance of abrasion and high tear impact. ii. Chemically stable. iii. High heat aging. iv. Resistance of weather, ozone and oxidation. v. Resistance of break down is high.	
Chloroprene Rubber (CR)	i. Good flexibility in wide range of	

	temperature. ii. Chemically stable. iii. Has self-extinguish behavior.	
Styrene Butadiene Rubber (SBR)	i. High heating age. ii. Resistance from concentrated and diluted alcohols and solvents. iii. High elongation.	
Ethylene Vinyl Acetate (EVA)	i. Toughness at lower temperature. ii. Resistance of stress crack. iii. Adhesive at hot or cold temperature. iv. UV radiation resistance.	
Acrylonitrile Butadiene Rubber (NBR)	i. Thermal stability. ii. Resistance of oxidation. iii. High heat aging. iv. Resistance to non-polar oils, silicon oils, fuels and ordinary diluted acids and alkali.	
Isobutylene Rubber (IIR)	i. Resistance of ozone, heat and oxygen. ii. Low permeability of gas and moisture. iii. Low resilience.	
Polyurethane (PU)	i. Abrasion resistance. ii. Tensile strength high. iii. Tear strength high. iv. Compression strength high. v. High moisture	