UNIVERSITI PUTRA MALAYSIA

KENAF-FILLED THERMOPLASTIC POLYURETHANE-NATURAL RUBBER COMPOSITE FOR AUTOMOTIVE ENGINE RUBBER MOUNT

NOOR AZAMMI B. ABDUL MURAT

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By

NOOR AZAMMI B. ABDUL MURAT

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Chairman : Prof. Ir. Mohd Sapuan B Salit @ Sinon, PhD
Faculty : Engineering

This study focuses on the compatibility of natural rubber (NR) and thermoplastic polyurethane (TPU) blends with kenaf fiber as filler. The early stage is to prepare the raw material as the NR is in liquid form, while the TPU is in resin form. All three material is then blended into the Brabender machine using the correct temperature. When the three material is bonded nicely, is then prepared into sample board using 40-tonne hot press machine using specific temperature and cut into specific specimen sample according to the ASTM standard required. The first aim is to identify the mechanical properties of the new develop composite such as tensile, flexural, impact, thermal and kinetic behaviour. The physical test is then compared to the untreated and the treated kenaf using NaOH. The comparison is done to identify the bonding effect between the polymer composite. The result for tensile strength achieve for untreated and treated is almost the same which is 5.5 Mpa. The flexural strength for the untreated fiber is 4 Mpa and for the treated fiber is 3.4 MPa. Meanwhile for the impact strength for the treated fiber shows slightly higher 2.5 MPa then the untreated fiber which is 1 MPa. The bonding comparison is carefully observe using a scanning electron microscope (SEM). The TPU-NR kenaf filler polymer composite the then proposed to be applied in the automotive parts such as engine rubber mounting to replicate the standard engine rubber mountings function. A conceptual design study has been initiated to select the new conceptual engine rubber mounting design using TRIZ, morphology chart and analytical network programme (ANP). Finally, the selected engine mounting design will be analysed using ANSYS simulation for stress-strain analysis to check the compatibility of the TPU-NR kenaf filled polymer composite with the engine mounting design. A simple stress and deformation simulation using ANSYS are conducted towards the final product design. The performance of rubber mounting is tested with several loading conditions to studies the capabilities of the engine mounting using ANSYS simulation.

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

PENYANGGA GETAH ENJIN AUTOMOTIVE DARI KOMPOSIT THERMOPLASTIC POLYURETHANE–GETAH ASLI DIPERKUKUHKAN DENGAN GENTIAN KENAF

Oleh

NOOR AZAMMI BIN ABDUL MURAT

November 2019

Pengerusi : Prof. Ir. Mohd Sapuan Bin Salit, PhD
Fakulti : Kejuruteraan

Kajian ini memberi tumpuan terhadap keboleh adunan dua bahan polimer iaitu Thermoplastic Polyurethane (TPU) dengan getah asli (NR) dan diperkukuhan dengan gentian kenaf. Pada peringkat awal penyediaan bahan mentah iaitu gentian kenaf dan cecair getah asli harus dilakukan terlebih dahulu. Gentian kenaf di tapis dan diasingkan mengikut saiz yang diperlukan. Sebahagian gentian kenaf tersebut dirawat menggunakan NaOH untuk membuat perbandingan setiap ujikaji yang dijalankan. Cecair getah asli itu di keringkan dan disediakan dalam bentuk resin. Ketiga – tiga bahan tersebut disukat dan dicampurkan ke dalam mesin Brabender mengikut sukatan dan suhu yang telah ditetapkan. Apabila campuran bahan itu dalam keadaan baik ia kemudiannya dimampatkan dengan mesin pemampat bertekanan 40 tan beserta suhu tekanan tinggi untuk dijadikan sampel board. Setelah kesemua sampel board itu di perolehi baru lah ia dipotong mengikut ASTM ujikaji yang akan dijalankan. Pada peringkat awal pencirian campuran komposit itu dilakukan untuk mendapatkan ciri – ciri mekanikal polimer komposit tersebut. Keputusan kajian tersebut menunjukan kekuatan tengangan kedua – dua gentian itu hampir sama iaitu sebanyak 5.5 Mpa. Bagi kekuatan lenturan pula, gentian yang dirawat memperoleh 4 Mpa. Manakala gentian yang tidak dirawat memperolehi sebanyak 3.4 Mpa. Bagi kekuatan hentaman, bacan terhada gentian terawatt adalah lebih tinggi iaitu 2.5 kJ/m^2 dan gentian tidak dirawat memperolehi bacaan 1 kJ/m^2. Kajian terhadap cantuman gentian kenaf dan matriks dijalankan dengan menggunakan pengimbas mikroskop elektron (SEM) terhadap semua jenis koposisi sampel. Kajian termal juga dijalankan bagi memastikan kandungan akhir dan suhu mula lebur komposit tersebut. Disamping itu juga kajian terhadap parameter kelikatan elastik komposit tersebut juga dilakukan dengan menggunaakn kaedah mekanikal dinamik analisa (DMA). Bahan tersbut dicadangkan untuk digunakan pada bahagian penyangga getah enjin automotif. Peringkat permulaan adalah melaksanakan rekabentuk konseptual sehinggalah rekabentuk akhir di

tentukan mengunakan kaedah TRIZ, carta morfologi dan analisis rangkaian program (ANP). Akhir sekali adalah analisis ringkas berkenaan dengan tegangan dan deformasi terhadap rekabentuk akhir yang telah dipilih dengan mengunakan simulasi perisian ANSYS. Perestasi sangga engine polimer getah di uji dengan beberapa kajian terhadap beberapa beban dari tiga jenis enjin yang berbeza beratnya bagi memperlihatkan ketahanan dan kemampuan sangga enjin polimer getah tersebut.

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This thesis was submitted to the Senate of 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:

Mohd Sapuan bin Salit, PhD
Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohamed Thariq Bin Hameed Sultan, PhD
Associate Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohamad Ridzwan bin Ishak, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 12 March 2020

Declaration by graduate student

I hereby confirm that:

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Signature: ______________________________
Name of Chairman of Supervisory Committee:
Prof. Ir. Dr. Mohd Sapuan bin Salit

Signature: ______________________________
Name of member of Supervisory Committee:
Prof. Madya Ir. Dr. Mohamed Thariq Bin Hameed Sultan

Signature: ______________________________
Name of member of Supervisory Committee:
Dr. Mohamad Ridzwan bin Ishak

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CHAPTER 1

INTRODUCTION

Overview

Automotive waste dumping areas are increasing each year in every country throughout the world, creating a hazardous environment for people. Automotive waste is either a liquid or solid substance which creates a chemical reaction in the soil, causing concern to those living near that environment. Due to such factors, scientists and researchers are urged to utilize bio-composite materials when producing automotive components. Of late, several studies were accomplished, and products have been launched in the market.

An automotive component made from composites or a combination of bio-composites has numerous advantages to the environment and to manufacturers. Increasing the number of composite components in a vehicle will decrease the weight of the vehicle. This, in turn, will reduce fuel consumption and lower emission levels in the atmosphere. From the manufacturer's perspective, bio-composites are lower-cost materials, easy, and sustainable resources which further help the local industry in sustaining the domestic economy. However, this also creates the challenge for manufacturers to become pioneers in research and development of automotive bio-composite components or other products.

In an automotive vehicle, there are a number of materials used to compose parts and components. Metals were the dominant materials found in a conventional vehicle and used in the main structure and for other rigid parts. These metals usually consist of steel, iron, and aluminum. Nowadays, some rigid parts have been replaced by composite materials in order to achieve a lighter vehicle. The composites usually consist of reinforced fibers, either natural or synthetic fibers. Some automotive components that use composites are door panels, speaker boxes, door handles, etc.

Polymer materials are also utilized since they act as a seal, vibration absorber, and water barrier which are mostly physically flexible and easy to bend. These materials are usually made of biopolymers and synthetic polymers. Among the polymer components employed in a vehicle include windscreen wipers, tires, door weather strips, floormats, rubber seals, etc.

Natural rubber is widely used in mountings because of its unique combination of properties: high strength, outstanding fatigue resistance, high resilience, low sensitivity to strain effects in dynamic applications, and good resistance to creep

(Kohli et al., 1994). The rigidity of a mount's supporting structure, along with its system strength and geometry, are crucial considerations (Freakley et al., 1978). When joining rubber and plastic to form a composite, the plastic should generally have a heat deformation temperature near to or greater than 127°C (Plast. Des. Forum, 1980).

In the last seventeen years (1990-2007), the total rubber consumed by the industry increased by 209%, from 187 592 tons to 579 248 tons, of which NR was the main material used (Lembaga Getah Malaysia, 2007). Malaysia is now the fifth largest consumer of NR in the world after China, the USA, Japan, and India. It's also the biggest consumer of NR latex. Malaysia is the world's largest producer of latex gloves, catheters, and latex thread.

Natural fibers are environment-friendly, cheap, and easy resources in most countries. Their biodegradable features provide an advantage when compared to other artificial or synthetic fibers. Some natural fibers show compatible results in their application as fillers compared to synthetic fibers. Several types of natural fibers are widely used in composites such as jut, sago, sugar palm, pineapple, and kenaf. As a filler in composites, kenaf fiber has the potential to develop because of its special characteristics. The hydrophilicity feature of the kenaf bast fiber allows its use as a bonding agent between natural rubber (Gunasunderi et al., 2008), polyester (Atiqah et al., 2014; Mohanty et al., 2005), polyurethane (Shakeil et al., 2010), and epoxy (Azwa et al., 2013).

In this study, the kenaf fiber is combined with natural rubber (NR) and thermoplastic polyurethane (TPU). Two types of polymer composites are present; treated kenaf fiber and untreated kenaf fiber polymer composites.

Both composites are compared for their mechanical properties, thermal properties, physical properties, and morphological features. All results and data are recorded and tabulated. The microstructure of both samples is observed using a scanning electron microscope (SEM) for morphological studies.

Several mechanical tests are applied on both polymer composites such as flexural, tensile, and impact tests. For the thermal test, Thermal Gravimetric Analysis (TGA) is conducted to obtain new thermal properties for each sample. Physical and Dynamic Mechanical Analysis (DMA) are employed to test both polymer composites. With the new properties recorded, new material weakness can be predicted by using software analysis such as Ansys to detect stress and strains. The mounting drawing follows the actual and original engine mountings and examines deformation and stress analyses. In this simulation, the parameter used for the analysis is the compression force applied, which is 250 psi.

Further investigations can be accomplished on several types of rubber engine mountings to identify failure. Many tests can be conducted such as running the vehicle into extreme conditions; for instance, at high temperatures or increased speed with strong vibrations (as what occurs on the racing track). In these stages, temperature sensors and vibration or knock sensors can be placed in the engine compartment. All extreme conditions are recorded once failure occurs at the rubber engine mounting. The original sample material is tested for its mechanical properties such as tensile, flexural, and thermal tests. The next step is to prepare the new material for the rubber engine mounting.

1.1 Problem Statement

Recently, natural fibers have attracted numerous researchers to explore their capability as reinforcement materials in polymeric composite engineering so as to replace synthetic fiber. This is because the world is now shifting towards the green technology approach and environmentally friendly products.

Kenaf is a natural fiber with specific mechanical properties and biodegradability. After adequate treatment, it can be used in combination with synthetic materials, such as polyester or rubber, which helps in greatly reducing the fiber's hydrophilicity for the production of composite materials (Ahmad et al., 2005, 2011; Aber et al., 2009; Abu Bakar et al., 2010).

The engine compartment in a vehicle is an environment involving heat dissipation from the engine combustion itself. The exhaust system and the road condition contribute to heat produced under the hood. In such conditions, all component in the engine compartment will be exposed to heat, thus reducing their lifespan and increasing the wear and tear of components. Simultaneously, the vibration produced by the engine and road conditions will create fatigue in most components within the engine compartment. Under these circumstances, engine components such as bearings, rubber seals, hose connectors, and rubber mountings will come to failure much faster.

According to El-Shekeil et al. (2011), the treated TPU/KF reached 70% strain (mean value). A number of studies have explored the potential reinforcement of kenaf fiber with polymeric materials. A higher tensile strength of kenaf composite material can be achieved by using fibers with higher tensile strength filing, but this could reduce the elasticity of kenaf fibers (Ahmad et al., 2005; Edeerozey et al., 2007; Aji et al., 2009, 2011). Research experiments have been accomplished on kenaf fibers such as chemical treatments, matrix combinations, processing techniques, and environmental effects on the composite material. Most of these studies concluded that the problem of the composite's wettability inhibits further increase in fiber stuffing and consequently, fiber pull-out (Ashori et al., 2005; Aber et al., 2009; Aji et al., 2009, 2011).

Up to now, there is no details information regarding the material characterization of kenaf reinforced with Thermoplastic Polyurethane (TPU) and Natural Rubber (NR). There has been no specific research on the performance of the kenaf reinforced (TPU-NR) polymer composites for engine rubber mounting.

In this study, the properties of the kenaf filled TPU-NR was uniquely mixed and reinforced were investigated. The novelty of analyzing the performance of the new Kenaf filled Thermoplastic Polyurethane (TPU) with Natural Rubber (NR) polymer composites in the application of new material for engine rubber mounting.

1.2 Research Objectives

1. To characterize the mechanical, thermal, and physical properties of kenaf filled TPU/NR with different TPU/NR percentage loadings and compare treated kenaf fibers.
2. To investigate the bonding effect of kenaf filled TPU/NR by using SEM for morphological study.
3. To determine the conceptual design of the engine rubber mounting.
4. To analyze the design of the engine rubber mounting structure using finite element analysis simulation (ANSYS)

1.3 Scope and Limitation of the Study

In this experiment, kenaf fiber (the size of 120-300 μm) is employed. The kenaf fiber is treated by using NaOH to investigate the bonding between TPU/NR. The kenaf fiber is processed in a hot twin-screw mixer and a 40-ton hot press machine process with a controlled temperature ranging between 170°C and 180°C.

For characterizing the physical properties of the composites, flexural, tensile, impact, water absorption, thickness swelling, and density tests are conducted. For investigating the interfacial bonding, the fiber and matrix adhesion is observed using the scanning electron microscope (SEM).

The thermal behaviour of kenaf TPU/NR composites is examined through Thermogravimetric Analysis (TGA) and Dynamic Mechanical Analysis (DMA) at INTROP Lab in UPM. TGA investigates the new composite degradation temperature while DMA identifies the mechanical properties regarding the thermal effect such as damping properties, loss modulus, and storage modulus.

The conceptual design of kenaf TPU/NR composite's engine rubber mounting is initiated from the early stage of the design selection, product requirement, and development, up to the final design selection. The methods employed in this work include TRIZ, morphological chart, and analytic network process technique.

Lastly, the structure design analysis of the kenaf TPU/NR engine rubber mount is conducted using ANSYS simulation software which mainly focuses on the force applied to the kenaf TPU/NR engine rubber mount. The validation of the new polymer composites engine rubber mount performance is only done by using ANSYS simulation. The real performance result is only can be achieved by building the prototype and tested on the engine test bench.

1.4 Organization of Thesis

This thesis is divided into five main chapters. The first chapter is the introduction of the research work, scope, objective, and limitation of the study. In Chapter Two, all related previous works of other researchers are collected, and their findings are discussed. This chapter provides a background on the natural fibers used, types of treatments, types of composites, and the techniques of accomplished experiments.

Chapter Three presents the preparation of materials and the types of research experiments conducted. Experiments include tensile test, flexural test, impact test, scanning electron microscope (SEM), Thermal Gravimetric Analysis (TGA), Dynamic Mechanical Analysis (DMA), density, thickness swelling, and water absorption test. All experiments are in accordance to the standards and regulations of the laboratory.

In Chapter Four, all data and results are collected and tabulated. The data are analyzed, and the results are discussed. The output of the data is regarding material characteristics such as mechanical, thermal, and physical properties as well as the design selection and structure analysis.

Hopefully, this research will encourage the automotive industry (especially the engine rubber mounting company) to evolve and produce green composite components so as to help preserve the environment.

Secondly, from this research, the demand for natural rubber may increase and boost the country’s economy as well as benefit the rubber planters and rubber tappers. Malaysia is well-known for its rubber manufacturing industry. It has achieved remarkable progress with the launching of IMPs in terms of rubber consumption and export earnings.

Lastly, this research will support the government's agenda since kenaf is listed as the seventh commodity in Malaysia. In 2010, the National Kenaf and Tobacco Board (NKTB) has received an allocation of more than 30 million for developing the kenaf industry in the state of Terengganu, Pahang and Kelantan under seven (7) key programs of kenaf. This indicates the commitment of our government in supporting the kenaf industry and we, as researchers, must continue to develop new findings.

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BIODATA OF STUDENT

The student, Noor Azammi B. Abd Murat was born on the 10th of May 1976 in Hospital Besar Seremban, Negeri Sembilan. His first exposure in Automotive Technology since in Sekolah Menengah Vocational school in Kajang and pursue his certificate and diploma in Automotive Technology in Politeknik Unku Omar and Politeknik Kota Bharu. He obtained his first degree in B.Sc. in Material Engineering at Univesiti Tun Hussien Onn and continue his M.Sc. in Automotive Engineering at International Islamic Universiti Malaysia. He joined Universiti Kuala Lumpur-Malaysia France Institute since 2002 as Lecturer of Automotive Engineering. In 2015, he registered for his PhD in the Engineering Department under the supervise of Ir.Prof. Dr Sapuan Salit, and two co-supervisors, Dr Muhd Rizdwan Ishak and Dr Mohammad Thariq Hameed Sultan. His study was focus on the natural fiber polymer composites on automotive engine component. His interest in Automotive Technology, conceptual design, composites and renewable energy. During his candidature, he has published 4 ISI journals and 1 Scopus journal. He also involves and participates in 2 postgraduate seminars and 1 National Enau symposium.

LIST OF PUBLICATIONS

Accepted / Published Journal

Azammi, A. M. N., Sapuan, S. M., Ishak, M. R., & Sultan, M. T. H. (2018a). Conceptual design of automobile engine rubber mounting composite using TRIZ-Morphological chart-analytic network process technique. *Defence Technology*, *14*(4). https://doi.org/10.1016/j.dt.2018.05.009. Indexed in InCites Journal Citation Reports (impact factor; 1.261); Rank:(Q3)

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A.M. Noor Azammi, S.M. Sapuan, Mohamed T.H. Sultan, Mohamad R. Ishak, "Structure Analysis Of Kenaf Polymer Composites For Automobile Engine Mounting Modelling", *Int. J. Rect. Tech. Eng.*,2019,. *Scopus Indexed (Accepted).*

A. M. Noor Azammi, R.A. Ilyas, S.M. Sapuan, M.S.N. Atikah, Mochamad Asrofi, "Chapter 10: Characterization studies of biopolymer composites related to functionalized filler-matrix interface" Elsevier, 2019. *(Accepted).*

Conference / Proceeding

A.M. Noor Azammi, S.M. Sapuan, Mohamed T.H. Sultan, Mohamad R. Isha5, A.M. Radzi, R.A. Ilyas, "Structure Analysis for Natural Fiber

Composite for Automotive Component: A Review" in Seminar Enau Kebangsaan 2019.

A.M. Noor Azammi, S.M. Sapuan, Mohamad R. Ishak, Mohamed T.H. Sultan; "Damping Properties of Polymer Composites with Reinforced Natural Fiber for Automobile Component: A review" in 6th Postgraduate Seminar on Natural Fiber Reinforced Polymer Composites 2018, 48 – 50.

AMN Azammi, SM Sapuan, MR Ishak, MTH Sultan, "Thermoplastic Polyurethane – Natural Rubber Polymer composite reinforcement with Kenaf filled Natural Fiber: A Review" in 5th Postgraduate Seminar on Natural Fiber Composites 2016, 24-26.

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