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**MECHANICAL PROPERTY CHARACTERISATION
OF NAPIER GRASS FIBRE REINFORCED
POLYESTER COMPOSITES**

by

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LIST OF ABBREVIATIONS

AMREC	Advanced Materials Research Centre
ASTM	American Standard Testing Material
DSC	Digital Scanning Calorimetry
DTA	Differential Thermal Analysis
NAOH	Sodium Hydroxide
RT	Room Temperature
SEM	Scanning Electron Microscope
SIRIM	Standard Industrial Research Institute Malaysia
TGA	Thermogravimetric Analysis
VFF	Volume Fraction Fibre
XRD	X-Ray Diffraction

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LIST OF SYMBOLS

°C	Temperature
µm	Nanometer
Deg C/min	Degree c per minute
g/cm ³	Gram per centimeter cube
GPa	Gigapascal
I ₀₀₂	Peak intensity
I _{am}	Counter reading at 2θ
kg/m ³	Kilogram per meter cube
kV	Kilovolt
mA	Miliampere
mL/min	Millimeter per minute flow rate
m _o	Mass after immersed in distilled water
MPa	Megapascal
m _t	Mass before immersed in distilled water
T _c	Crystallinity temperature
T _g	Glass transition temperature
T _m	Melting temperature
θ	Alpha

Pencirian Sifat Mekanikal daripada Serat Rumput Napier diperkukuhkan dengan Komposit Poliester

ABSTRAK

Sifat-sifat mekanik rumput Napier diperkukuhkan dengan gentian komposit telah disifatkan. Serat rumput Napier ini diperolehi melalui proses pengeretan air. Kesan rawatan alkali kepada sifat-sifat tegangan rumput Napier dan morfologi telah dikaji. Rumput serat tersebut dirawat menggunakan NaOH yang mana terdiri daripada kepekatan 5, 10, 15 dan 20% serta dipertaklukkan kepada ujian tegangan serat tunggal. Morfologi rumput diperhatikan menggunakan mikroskop elektron pengimbas (SEM). Rumput Napier yang dirawat menggunakan 10% alkali menghasilkan kekuatan tegangan yang paling tinggi. Untuk menghasilkan komposit, rumput Napier dipergunakan sebagai pengukuhan serta resin poliester digunakan sebagai bahan polimer. Sifat tegangan dan lenturan komposit telah dikaji. Secara umum, sifat tegangan dan kekuatan lenturan bagi komposit meningkat apabila jumlah isipadu pecahan serat meningkat, namun begitu terdapat pengurangan dalam kekuatan pada jumlah pecahan serat yang tinggi. Tegangan dan lenturan maksimum kekuatan bagi komposit telah diperolehi pada 25% isipade pecahan serat. Ujian penyerapan air yang telah dijalankan dengan merendam sampel dalam air suling pada suhu bilik (25°C) pada jangka masa yang berbeza. Sampel basah dan kering komposit tersebut diperlakukan pada tegangan, lenturan dan ujian mikroskop imbasan elektron (SEM) mengikut standard ASTM masing-masing. Corak penyerapan air Napier komposit serat rumput mematuhi tingkah laku Fickian apabila direndam dalam suhu bilik. Peratusan penyerapan air yang lebih tinggi terdapat bagi gentian sampel yang tidak dirawat dan akibat pembuangan lignin dan hemicelluloses pada permukaan serat. Tegangan dan sifat lenturan rumput Napier komposit menurun apabila peratusan penyerapan air meningkat dlm komposit. Kesan suhu tinggi telah dikaji pada suhu bilik, 45°C , 65°C dan 75°C . Suhu yang lebih tinggi mendorong kepada perubahan fizikal dan kimia dalam komposit malahan sifat mekanikal yang juga dipengaruhi oleh poliester. Walau bagaimanapun, penurunan ketara dalam sifat-sifat tegangan dan lenturan diperhatikan untuk seluruh komposit yang diuji pada suhu tinggi. Secara umumnya, kajian ini amat berguna untuk meramalkan kesesuaian menggunakan serat rumput Napier sebagai pengukuhan dalam resin poliester.

Mechanical Property Characterisation of Napier Grass Fibre Reinforced Polyester Composites

ABSTRACT

The mechanical properties of Napier grass fibre-reinforced composites were characterised. Napier grass fibres were extracted through water retting process. The effect of alkali-treatment on the tensile properties and morphology of the fibres was investigated. The fibres were alkali-treated using NaOH solutions of 5, 10, 15 and 20% concentrations which subjected to single fibre testing. The morphology of the fibres was observed using scanning electron microscopy (SEM). The 10% alkali-treated Napier grass fibres yielded the highest strength. To fabricate the composites, Napier grass fibre and polyester resin were used as the reinforcing material and polymer matrix, respectively. The tensile and flexural properties of the composites were studied. In general, up to a certain threshold value, the tensile and flexural strengths of the composites increased as the fibre volume fractions increased, following which, there was a reduction in strength. The maximum tensile and flexural strengths of the composites were obtained at 25% fibre loading. Water absorption test were conducted by immersing samples in distilled water bath at room temperature (25°C) at different time durations. The wet and dry specimens of composites were subjected to tensile, flexural and scanning electron microscopy (SEM) tests according to ASTM standard respectively. The water absorption pattern of Napier grass fibre composites obeys Fickian behavior at room temperature immersions. The percentage of water absorption is higher for untreated fibres samples rather than treated due to removal of both lignin and hemicelluloses on the fibre surfaces. Tensile and flexural properties of Napier grass composites decreased with increase in percentage of water absorption. Effects of elevated temperature were studied temperature set at room temperature, 45°C, 65°C and 75°C. Higher temperature induces physical and chemical changes in the composites the mechanical properties which are also governed by the unsaturated polyester. However, a significant decrease in tensile and flexural properties was observed for the entire composite tested at elevated temperature. Generally, this study is useful to predict the suitability of using the novel Napier grass fibre as reinforcement in polymer resins.

CHAPTER 1

INTRODUCTION

1.1 Background history

This research concerns with the development of a novel reinforcing material in polymer composites. The productions of synthetic fibres are very polluting and one of the major factors that contributes to global warming (Job, 2013). The increasing interests in the environmental issues have provided an impetus to the promotion of natural fibres as reinforcing material in polymer composites. Utilization of natural fibres as a substitute for traditional synthetic fibre such as glass and carbon has received more attention and interest in recent years to overcome environmental issues. Natural fibres, on the other hand, are completely biodegradable, low cost, low density, and environmentally friendly (Nabi Saheb & Jog, 1999).

As the demands for natural fibres as reinforcing materials in polymer composite increase, particularly in engineering applications, it is thus essential to identify new fibrous plants that can provide an easy and cost effective fibre extraction with high-quality fibre. Nonetheless there are still drawbacks to the use of natural fibre in reinforced composites which includes (i) poor interfacial bonding between the cellulose fibres and the thermoplastic matrix; (ii) constrained moisture and thermal properties of the composites and (iii) poor fibre partition and dispersion inside the composites (John & Anandjiwala, 2008).

1.2 Problem statement

Due to the readily available of Napier grass in the state of Perlis, the potential of Napier grass fibre as reinforcing fibre in polymer composite is to be investigated. The Napier grass fibre is to be investigated to determine their physical and mechanical properties as well as their morphological characteristics prior to their use as reinforcing materials. Although there are some previous research works conducted on Napier grass fibre available in the literature, their thorough study and potential as reinforcing fibres in polymer composites have never been fully explored. Nevertheless, few early studies suggest that this type of natural fibres has the potential to be used as the reinforcing materials for development of composites. Further study into the effects of moisture and high temperatures on the mechanical behavior of the Napier fibre/polyester composites is expected to yield interesting findings. The findings in this investigation are hoped to provide more information about the possibility of using Napier grass fibres as composite reinforcement materials.

1.3 Objective

- To investigate, characterize and compare the mechanical properties of Napier grass fibres with other traditionally available natural fibres.
- To investigate the tensile and flexural strength of Napier reinforced polyester composites at different volume fractions.
- To investigate the effects of moisture and temperature on the mechanical properties of Napier grass fibre reinforced composites.

1.4 Scope

The scope in this investigation is to extract Napier grass fibre using water retting process. Then it is extended to treat the fibres with NaOH at four different concentrations (5, 10, 15 and 20%). Fabrication of the Napier grass fibre reinforced composites by using unsaturated polyester resin at 10%, 15%, 20%, 25% and 30% volume fractions of fibre is needed to carry out. The composite laminates will then be subjected to tensile and flexure tests to determine the mechanical properties in accordance to the standard ASTM D638 and ASTM D790 respectively. Results obtained will be analyzed and characterized to evaluate the tensile and flexural properties of Napier grass fibre reinforced composites. Further investigation on the effects of moisture and thermal will be incorporated into this investigation. Results of the characterization of Napier grass fibre are to be compared with the mechanical properties of more traditionally available natural fibres.

1.5 Thesis organization

The thesis is separated into five chapters. Chapter 1 of this thesis describes the introductory chapter to this project. The aim of this chapter is to give a brief introduction to the reader's to understand what they will go throughout this thesis and what they can expect in this investigation in the end. It consists of the problem statement, objective, and scope of this research conducted.

Chapter 2 provides literature review of previous work similar to this investigation. This chapter intends to give some review to the readers about scope of research that has been conducted. Moreover it contains a comprehensive review of the available literature about the fibres and leads to a direction for the development and characterizing of composites.

Chapter 3 of this thesis elucidates the methodology undertaken in this project. In this chapter, readers are presented with the method used in order to achieve the objectives of this project.

Chapter 4 presents the results obtained and discussion of the findings, mainly focusing on the characterization of the Napier grass fibres. This chapter also presents the thermal, structural, mechanical and morphological analysis of untreated and treated Napier grass fibres.

Chapter 5 provides the conclusion of the present work by highlighting the objectives and suggestions for future work.

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CHAPTER 2

LITERATURE REVIEW

2.1 Composite material

Composites materials that are applied nowadays include strong load carrying material which is known as reinforcement. These reinforcement materials are combined in bonding material that is resin. Reinforcement materials provide extra strength and stiffness, to help sustain load applied. The resin maintains the position and orientation of the reinforcement. Essentially, the combination of resin and reinforcement results in making a stronger material (Hull & Clyne, 1996). There is few type of composites classification such as polymer, metal and ceramic matrix composites. The most widely choice of composites is polymer matrix composites.

Glass fibre is the most common type of synthetic fibres that are most applied in industry. Glass fibres are made from melted sand by using large furnaces at a very high temperature. The melted sand later on extruded through orifices and chemical are added to turn them into filament to produce roving in large scale. Glass fibres have many advantages such as used comprehensively on chemical and marine application because it can withstand corrosive. These glass fibres also have outstanding strength and stiffness making them applied on wide range of applications (Cowking, Attou, Siddiqui, Sweet, & Hill, 1991). On the other hand, glass fibres also many negative impacts. They are abrasive as they increase the wear and tear on the processing machines. Moreover, working with glass fibres increases the health risk making it dangerous to work it even in controlled environments (El-Shekeil, S.M. Sapuan, M. Haron, 2014). The major issue with other synthetic and glass fibre is that their difficulty in disposing them after their end life period. Theses composites cannot be destroyed and thus recycling them is also

impossible. The only proper way of disposing them is filling up landfills which are costly (Bos, Van Den Oever, & Peters, 2002). Thus, natural fibre is introduced as they require less energy to be produced and importantly can be incinerated at their end lifetime (Vijay Kumar Thakur, 2010).

2.2 Polymer matrix materials

Most of the natural fibres exhibit a very good strength property but to put in good use of these properties the fibres should be bonded by a suitable matrix. The matrix is the resin that acts as a connection bridge to hold the fibres in place. A good matrix resin should have the ability to deform at ease when load is applied and transfers the load to the fibres (Davallo, Pasdar, & Mohseni, 2010). Moreover, the matrix resin will protect the fibres from environmental effects and abrasion during composite processing. The matrix resin also determines the overall limited temperature to the composites. The matrix resin should have adequate mechanical strength corresponding with that of the suitable reinforcement fibres. It must be easily fabricated and also stand up to the environmental conditions. Furthermore, the matrix resin must possess a good wetting and penetrating into fibres which provide the reinforcement, thus enhancing the strength of the fibres. Polymer matrices is divided into two main components namely, thermosets and thermoplastics (Allan C Manalo, Wani, Zukarnain, Karunasena, & Lau, 2015). The selection of the matrices depends on their processing temperature, properties and end product requirements.

2.3.1 Thermosets

Thermosets are liquid resin that turned into infusible material which an aid of heat and catalyst. These polymers after cured form a strong polymer chains but when the end shape is formed it cannot be melted by heating. Further heating will only disintegrates these polymers and loss it mechanical strengths (Gutowski, 1999). The thermosets resin that is widely use are unsaturated polyester, vinyl ester and epoxies. The comparisons among the thermosets resin is presented in Table 2.1. It shows that the epoxy exhibits the most advantages but comparing in real time epoxy is four to five times more expensive than polyesters. Thus polyester is seen to easiest to handle and the cheapest.

Table 2.1: Thermosets resin comparison for its advantages and disadvantages.

Resins	Advantages	Disadvantages
Polyesters	Easy handle Cheapest	Moderate mechanical properties High cure shrinkage Less working time
Vinyl ester	High environmental resistance Higher mechanical properties than polyesters	High cure shrinkage Expensive than polyesters High content of styrene
Epoxy	Highest mechanical and thermal properties High water resistance Long working times Can withstands higher temperature Low cure shrinkage	Most expensive Critical mixing procedure High corrosive

(Goodman, 1999; Khoun, Centea, & Hubert, 2010; Pinho, Darvizeh, Robinson, Schuecker, & Camanho, 2012)

2.3.2 Thermoplastics

Thermoplastics on the other hand is opposite from thermosets. Thermoplastics are homogenized liquid. This means that thermoplastics become liquid when heated and hard when cooled but when frozen turns into glass like thus can be fractured.

Thermoplastics have the simplest molecular structure which makes them chemically independent macromolecules. Repeated cycle of heating and cooling to thermoplastics can be done with less damage towards the macromolecules, allowing recyclability. Thermoplastics disadvantages are their availability in solid forms which requires expensive machinery to manufacture them. Another major disadvantage is the wetting of natural fibre to produce composites. Thermoplastic composites do not easily bind in solvent and would not perform to its maximum when there are reinforcements (Goodman, 1999).

2.3 Natural fibre

Natural fibre composites are being used massively on most fields beginning from household until aerospace applications. The main advantages of natural fibre against man-made fibres are their availability, renewability, biodegradability, low cost, light weight and relatively high strength. Natural fibre is actually a lignocelluloses material. They consist of cellulose covered by lignin with hemicelluloses as matrix (Szolnoki et al., 2015). They can be divided based on their source from minerals, plant and animal. Figure 2.1 shows an overview classification of natural fibres.

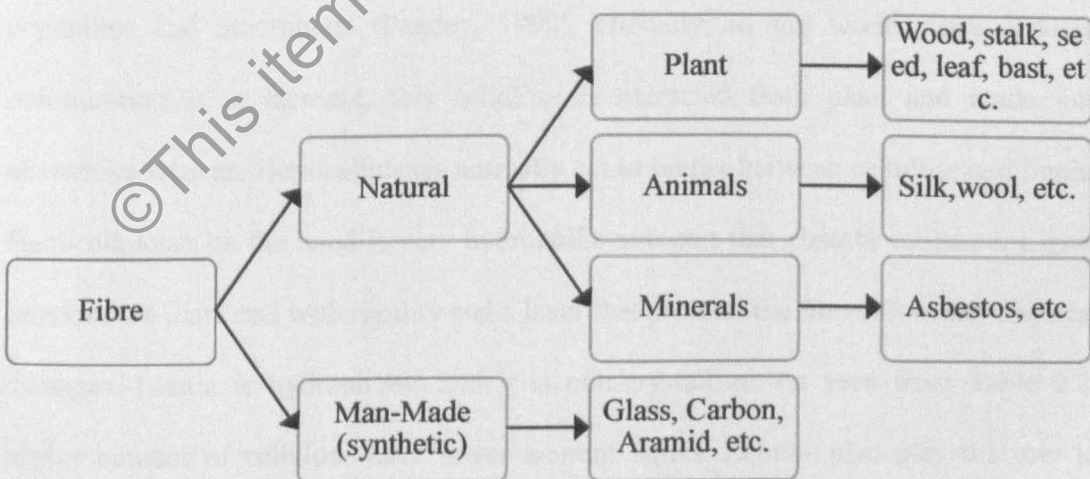


Figure 2.1: Fibre classifications (Ichhaporia, 2008)

2.4 Natural fibre compositions and structure

Lignocellulosic are the main building composition for plant fibres. Lignocellulosic consists of cellulose, hemicelluloses and lignin. The proportions of these components in fibres relies on the source of the fibre, maturity, harvesting the plants and the method applied to extract the fibres from plants. A comparison of chemical compositions is presented in Table 2.2.

Table 2.2: Comparison of Natural fibres chemical compositions.

Fibre	Cellulose (%)	Hemicelullose (%)	Lignin (%)	Extractives (%)
Alfa	47.6	22.1	17.7	12.6
Bamboo	43.0	29.0	28.0	-
Banana	34.5	25.6	12.0	27.9
Coir	44.2	12.1	32.8	10.9
Coconut	37.3	20.3	32.2	10.2
Jute	58.0	17.0	25.0	-
Napier grass	45.6	33.8	20.6	-
Sisal	60.0	13.0	27.0	-

(Abdul Khalil, Siti Alwani, Ridzuan, Kamarudin, & Khairul, 2008; Bouiri & Amrani, 2010; Cordeiro, Belgacem, Torres, & Moura, 2004; John & Anandjiwala, 2008; Reddy, Maheswari, Shukla, & Rajulu, 2012; Sahin & Young, 2008)

Cellulose is the core structural components in fibre providing them with strength and stability to the walls. This cellulose is a semi-crystalline structure which is highly crystalline and amorphous (Pandey, 1999). Globally, as the world paper indexed consumption is at increase, this cellulose is extracted from plant and made into alternative sources. Hemicelluloses normally act as binder between cellulose and lignin. Hemicelluloses on the hand is very hydrophilic and part that absorbs moisture. Lignin provides the plant cell with rigidity and a layer that protects the fibres from any physical damages. Lignin is hydrophobic and it is non-crystalline. As seen from Table 2.2, higher amount of cellulose have lower amount lignin. Lignins also play the role to flexibility of individual fibres (Chen, 2014).

2.5 Natural fibre reinforcement composites

The plant fibres mechanical strength alone is much lower if directly compared with synthetic fibres. Nevertheless, the major benefits of natural fibres is that their lower in density, low cost, renewability, biodegradability and eco-environment (Dai & Fan, 2014). Over the decade, natural fibre reinforced composites had gained attraction to be applied in automotive industry, building structural, acoustic medium and even as insulators for walls. In automotive world natural fibre such as kenaf, sisal and flax is reinforced as body panels. In Figure 2.2 a BMW i3 door panel is shown made using Hemp fibres using compression moulding. A weight cutback of between 5 and 10 % in interiors was attained by using these materials rather than normal moulded plastics, thus significantly improving the environmental performance review of vehicles. Moreover, the weight reduction help to sustain lower the fuel usage making it energy efficient vehicle (Madsen & Lilholt, 2003).

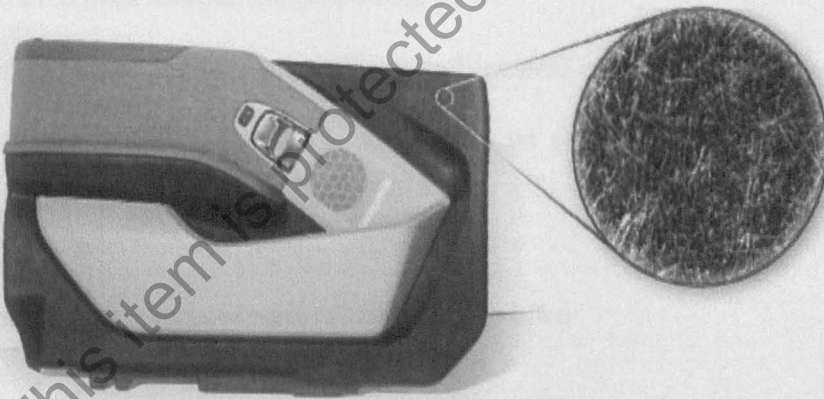


Figure 2.2: BMW i3 door panel (left) with Hemp structure as magnified on the right (“BMW i3 Saves Weight Using Hemp Fibers,” 2013).

2.5.1 Natural fibre composites advantages

- Natural plant fibres are relatively cheap, recyclable as a part or whole, biodegradability and the availability is throughout any part of world with suitable to be planted.