



**Development and Characterisation of Hybrid
Napier/Glass Fibre Reinforced Epoxy Composites**

by

**MOHD RIDZUAN BIN MOHD JAMIR
(1441411504)**

A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy in Mechanical Engineering

**School of Mechatronic Engineering
UNIVERSITI MALAYSIA PERLIS**

2016

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name : MOHD RIDZUAN BIN MOHD JAMIR
Date of birth : 26TH MARCH 1985
Title : DEVELOPMENT AND CHARACTERISATION OF
HYBRID NAPIER/GLASS FIBRE REINFORCED
EPOXY COMPOSITES
Academic Session : 2016

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

- CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*
- RESTRICTED** (Contains restricted information as specified by the organization where research was done)*
- OPEN ACCESS** I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of ____ years, if so requested above).

Certified by:

SIGNATURE

850326-14-5439

(NEW IC NO. / PASSPORT NO.)

Date : _____

SIGNATURE OF SUPERVISOR

ASSOCIATE PROFESSOR IR. DR.
MOHD SHUKRY BIN ABDUL MAJID

NAME OF SUPERVISOR

Date : _____

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

ACKNOWLEDGEMENT

Praise to Allah, the Most Gracious and Most Merciful, for giving me the strength and guidance to complete this thesis. The research work which led to this thesis was conducted since 8th October 2014 at the Solid Mechanics Laboratory, School of Mechatronics, Universiti Malaysia Perlis. Firstly, I wish to acknowledge my sponsors, Ministry of Higher Education Malaysia (MOHE) and Universiti Malaysia Perlis (UniMAP) for providing the financial support that enabled me to conduct these studies.

My special thanks go to Ir. Dr. Mohd Shukry Bin Abdul Majid for his guidance and continual support throughout the course of this work. I equally appreciate his wisdom, tolerance, patience and challenging criticisms. I would also like to thank Dr. Mohd Afendi Bin Rojan for his expert views, advice and fruitful discussions throughout the completion of this project.

I am very grateful to all staff at School of Mechatronics, especially En. Muhamad Aliff bin Mad Yussof who helped with the experimental work. Many thanks also extended to Politeknik Sultan Abdul Halim Muadzam Shah (POLIMAS) especially to En. Mohd Zahri Bin Jaafar for his collaboration on this project.

And most importantly, I wish to express my special thanks to my wife, Azduwin Binti Khasri and my daughter, Dhia Adelia Binti Mohd Ridzuan for their support and encouragement throughout my project and thesis, as well as my parents, siblings and friends.

TABLE OF CONTENTS

	PAGE
THESIS DECLARATION	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS	xv
ABSTRAK	xvii
ABSTRACT	xviii
CHAPTER 1 INTRODUCTION	
1.1 Overview	1
1.2 Problem Statement	8
1.3 Objectives	9
1.4 Scopes	9
1.5 Thesis Outline	11
CHAPTER 2 LITERATURE REVIEW	
2.1 Introduction	12
2.2 Natural Fibres	13

2.2.1	Napier grass	18
2.3	Natural Fibre Treatment	19
2.4	Synthetic fibres	22
2.4.1	Glass fibre	23
2.5	Matrix Materials	24
2.5.1	Epoxy	26
2.6	Hybrid Composites	27
2.7	Vacuum Infusion Method	29
2.8	Mechanical Properties	30
2.8.1	Tensile Properties	30
2.8.2	Flexural Properties	32
2.8.3	Impact Properties	32
2.8.4	Energy absorption	33
2.9	Theoretical Models for Hybrid Composite	35
2.10	Effect of Moisture Absorption	40
2.11	Effect of Thermal Properties	42

CHAPTER 3 MATERIALS AND METHOD

3.1	Introduction	45
3.2	Characterisation of Single Napier Grass Fibre	47
3.2.1	Extraction of Napier Grass Fibre	47
3.2.2	Alkali Treatment	47
3.2.3	Physical Test of Fibres	49
3.2.4	Moisture Content (MC)	50
3.2.5	Single Fibre Tensile Testing	51
3.2.6	Thermogravimetric Analysis (TGA) and Derivative Thermogravimetric(DTG)	52

3.2.7	Fourier Transform Infrared Spectroscopy (FTIR)	53
3.2.8	Scanning Electron Microscopy (SEM)	53
3.3	Development of Hybrid Napier/Glass Fibre Reinforced Epoxy Composites	54
3.3.1	Materials	54
3.3.2	Alkali Treatment	55
3.3.3	Fibre Preparation	55
3.3.4	Composite Fabrication	56
3.4	Composites Test Set Up	58
3.4.1	Tensile Test	58
3.4.2	Flexural Test	59
3.4.3	Drop Impact Test	60
3.5	Moisture Absorption Test of Hybrid Composites	62
3.6	Thermal Investigation of Hybrid Composites	63
3.6.1	Thermogravimetric Analysis (TGA)	63
3.6.2	Dynamic Mechanical Analysis (DMA)	63
3.6.3	Tensile, Flexural and Drop Impact Testing at Elevated Temperature	64
3.7	Observation of Surface Morphology by Field Emission Scanning Electron Microscopy (FESEM)	65

CHAPTER 4 RESULTS AND DISCUSSION

4.1	Introduction	66
4.2	Characterisation of Napier Grass Fibre as Reinforcing Materials	66
4.2.1	Alkali Treatment on the Fibre Surfaces	67
4.2.2	Alkali Treatment on the Fibre Diameter	67
4.2.3	Moisture Content (MC) of Fibre	69
4.2.4	Single Fibre Tensile Testing (ASTM D3822)	71

4.2.5	Thermo-gravimetric Analysis (TGA) and Derivative of Thermo-gravimetric (DTG)	73
4.2.6	Fourier transform infrared spectroscopy (FTIR)	77
4.2.7	Morphological Observation	81
4.3	Mechanical Properties of Hybrid Napier/Glass Fibre Reinforced Epoxy Composites	85
4.3.1	Densities and Void Content	85
4.3.2	Tensile Properties	87
4.3.3	Theoretical Models of Tensile Properties	90
4.3.4	Flexural Properties	96
4.3.5	Fractured Surface Morphology	98
4.3.6	Drop Impact Response	103
4.4	Effects of Moisture Absorption on Mechanical Properties of Hybrid Napier/Glass Fibre Reinforced Epoxy Composites	109
4.4.1	Effect of Glass Fibre Loading and Moisture Absorption on the Mechanical Properties of the Hybrid Napier/glass Fibre Reinforced Epoxy Composites	109
4.4.2	Effect of the alkali treatment of Napier fibre and moisture absorption on the mechanical properties of hybrid.Napier/glass fibre reinforced epoxy composites	121
4.5	Effects of Elevated Temperature on the Mechanical Properties of Hybrid Napier/Glass Fibre Reinforced Epoxy Composites	141
4.5.1	Thermogravimetric analysis (TGA) and derivative thermogravimetric (DTG) analysis	141
4.5.2	Dynamic Mechanical Analysis (DMA)	145
4.5.3	Tensile Properties	150
4.5.4	Flexural Properties	154
4.5.5	Fracture Surface Morphology	158
4.5.6	Drop Impact Response	167

CHAPTER 5 CONCLUSION AND RECOMMENDATION		
5.1	Conclusion	171
5.1.1	Mechanical Properties and Impact Behaviour of the Hybrid Napier/glass Fibres Reinforced Epoxy Composites	171
5.1.2	Hybrid Napier/glass Fibres Reinforced Epoxy Composites Under Elevated Temperatures and Moisture Exposure.	173
5.2	Recommendations for Future Studies	176
REFERENCES		177
LIST OF PUBLICATIONS		193
LIST OF CONFERENCES ATTENDED		194
LIST OF AWARDS		195

©This item is protected by original copyright

LIST OF TABLES

NO.		PAGE
2.1	Physical and mechanical properties of commercially important lignocellulosic fibre	16
2.2	Chemical composition and structural parameters of common lignocellulosic	17
3.1	Physical properties of treated and untreated Napier fibres.	49
3.2	Properties of fibres and epoxy resin	54
3.3	Composition and designation of the hybrid formulations	57
4.1	Mechanical properties of alkali-treated and untreated Napier grass	72
4.2	Thermo-gravimetric analysis (TGA) of Napier grass fibre	76
4.3	Densities and void content of hybrid Napier/glass fibre reinforced epoxy composites	86
4.4	Properties of Napier fibre, glass fibre and epoxy resin	90
4.5	Data comparison of tensile properties between ROHM and experimental of hybrid Napier/glass fibre reinforced epoxy composites	94
4.6	Percentage (by volume) of the constituents of the hybrid composite samples	110
4.7	Moisture absorption properties of hybrid Napier/glass fibre-reinforced epoxy composites	111
4.8	Thermogravimetric analysis (TGA) results obtained for hybrid Napier/glass fibre reinforced epoxy composites	145
4.9	T_g values obtained from loss modulus curve	150

LIST OF FIGURES

NO.		PAGE
2.1	Classification of natural and synthetic fibres	14
2.2	Vacuum infusion method	30
3.1	Flow chart for overall procedure	46
3.2	a) Napier grass and b) Napier grass crushes process, c) soaked Napier grass, and d) the extracted Napier fibres	48
3.3	Sodium Hydroxide (NaOH) for fibre treatment	48
3.4	Metallurgical microscope (MT8100)	50
3.5	Diameter measurement of a single Napier fibre using a standard metallurgical microscope	50
3.6	Humidity chamber	51
3.7	Tab-shaped of paper on fibre	52
3.8	Thermogravimetric Analysis (TGA) and Derivative Thermogravimetric	53
3.9	a) Napier grass fibre, b) E-glass fibre and c) EpoxyAmite 100	54
3.10	Differences between a) untreated and b) treated Napier grass fibre	55
3.11	Vacuum infusion process used to fabricate hybrid Napier/glass fibre reinforced epoxy composite	56
3.12	Schematic of the vacuum infusion system	57
3.13	Tensile test operation using the universal testing machine (SHIMADZU)	58

3.14	Plate composite that was fully developed after the infusion and had been cut into specimen in rectangular shape	60
3.15	Flexural test operation using the universal micro tester (INSTRON 5848)	60
3.16	Drop impact tester device IMATEK IM10	61
3.17	a) Clamped specimen, b) Impactor is adjusted to desired height, and c) Impact test on the specimen	61
3.18	Pyris diamond DMA (Perkin Elmer) and specimens held in a dual cantilever arrangement	64
3.19	a) Instron environmental chamber; b) tensile testing and c) flexural testing of hybrid Napier/glass fibre reinforced epoxy composites	65
4.1	Physical appearance of Napier grass fibre	68
4.2	Variations in average diameter of fibres	69
4.3	Moisture content of Napier grass fibres	70
4.4	Stress-strain responses for selected untreated and alkali-treated Napier grass fibres.	73
4.5	TGA-DTG curves (a) Untreated fibre, (b) 5 and 7% alkali-treated fibre, (c) 10, 12, 15% alkali-treated fibre	76
4.6	FTIR (a) Untreated fibre, (b) 5 and 7% treated fibre, (c) 10, 12, and 15% treated fibre	80
4.7	(a–f) Surface morphologies of untreated and alkali treated Napier grass fibres	83
4.8	(a–f) Cross-sectional morphologies of untreated and alkali treated Napier grass fibres	84
4.9	Tensile properties of hybrid Napier/glass fibre reinforced epoxy composites	89
4.10	Comparison of tensile properties between ROHM and experimental	93

4.11	Flowchart of the ROM and ROHM modelling for predicting the elastic modulus and strength of the hybrid Napier/glass fibre reinforced epoxy composites	95
4.12	Flexural properties of the hybrid Napier/glass fibre reinforced epoxy composite	97
4.13	Field emission scanning electron microscope (FESEM) images of hybrid Napier/glass fibre reinforced epoxy composite with untreated fibres	100
4.14	Field emission scanning electron microscope (FESEM) images of hybrid Napier/glass fibre reinforced epoxy composite with 5% alkali-treated fibres	101
4.15	Field emission scanning electron microscope (FESEM) images of hybrid Napier/glass fibre reinforced epoxy composite with 10% alkali-treated fibres	102
4.16	Load vs. displacement of hybrid Napier/glass fibre reinforced epoxy composites at different energy levels (a) 7.5 J, b) 15 J and c) 22.5 J	105
4.17	Energy absorption of hybrid Napier/glass fibre reinforced epoxy composites at different energy levels.	106
4.18	Pictures of the front and back surface of hybrid Napier/glass fibre reinforced epoxy composites	108
4.19	Tensile strength of dry and wet samples	114
4.20	Tensile modulus of dry and wet samples	114
4.21	Flexural strength of dry and wet samples	116
4.22	Flexural modulus of dry and wet samples	116
4.23	Field emission scanning electron microscope images of the tensile and flexural fracture specimens under dry conditions	119
4.24	Field emission scanning electron microscope images of the tensile, flexural fracture specimens and the effect of water molecules under wet conditions	121

4.25	Moisture absorption curves of hybrid Napier/glass fibre reinforced epoxy composites	122
4.26	Variation of the tensile properties of hybrid Napier/glass fibre reinforced epoxy composites	124
4.27	Variation of the flexural properties of hybrid Napier/glass fibre reinforced epoxy composites	127
4.28	FESEM images of the fracture specimens under wet conditions for hybrid composites with untreated Napier fibre	131
4.29	FESEM images of fracture specimens and the effect of water molecules under wet conditions for hybrid composites with 5% treated Napier fibre	133
4.30	FESEM images of the fracture specimens and the effect of water molecules under wet conditions for 10% treated Napier fibres	135
4.31	Impact properties of hybrid Napier/glass fibre reinforced epoxy composites at different of immersion times	139
4.32	Pictures of front and back surface of hybrid Napier/glass fibre reinforced epoxy composites at 22.5J with different of immersion times	140
4.33	Thermogravimetric analysis (TGA) curves obtained for hybrid Napier/glass fibre reinforced epoxy composites	144
4.34	Derivative thermogravimetric (DTG) analysis curves obtained for hybrid Napier/glass fibre reinforced epoxy composites	144
4.35	Storage modulus curves of the neat epoxy and the hybrid Napier/glass fibre reinforced epoxy composites	146
4.36	Loss modulus curves of the neat epoxy and the hybrid Napier/glass fibre reinforced epoxy composites	148
4.37	Damping curves of the neat epoxy and the hybrid Napier/glass fibre reinforced epoxy composites	149
4.38	Tensile stress–strain behaviour of hybrid Napier/glass fibre reinforced epoxy composites at elevated temperatures	153

4.39	Flexural stress–strain behaviour of hybrid Napier/glass fibre reinforced epoxy composites at elevated temperature	158
4.40	Field emission scanning electron microscope images of hybrid Napier/glass fibre reinforced epoxy composites with untreated Napier fibres	162
4.41	Field emission scanning electron microscope images of the hybrid Napier/glass fibre reinforced epoxy composites with 5% alkali-treated Napier fibres	164
4.42	Field emission scanning electron microscope images of hybrid Napier/glass fibre reinforced epoxy composites with 10% alkali-treated napier fibres	166
4.43	Impact properties of hybrid Napier/glass fibre reinforced epoxy composites at elevated temperature	169
4.44	Pictures of front and back surface of hybrid Napier/glass fibre reinforced epoxy composites at elevated of temperature	170

©This item is protected by original copyright

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
DMA	Dynamic Mechanical Analysis
DTG	Derivative Thermogravimetric
EFB	Empty Fruit Bunch
FESEM	Field Emission of Electron Microscope
FDT	Final Degradation Temperature
FTIR	Fourier transform infrared spectroscopy
IDT	Initial Degradation Temperature
MC	Moisture Content
MAPP	Maleic Anhydride Grafted Polypropylene
RT	Room Temperature
RH	Relative Humidity
RTM	Resin Transfer Moulding
ROM	Rule of Mixture
ROHM	Rule of Hybrid Mixture
SEM	Scanning Electron Microscope
TGA	Thermogravimetric Analysis
NaOH	Sodium Hydroxide

LIST OF SYMBOLS

v_f	Fibre loading (volume fraction),
w_f	Fibre loading (weight fraction),
w_m	Matrix loading (weight fraction),
ρ_c	Composite density, and
ρ_m	Matrix density.
v_{f1}	Volume fraction of fibre type 1
v_{f2}	Volume fraction of fibre type 2
E_{11}	Longitudinal modulus
σ_{11}	Longitudinal tensile strength
σ_f	Ultimate fibre strength
σ_m	Ultimate matrix strength
E_f	Fibre modulus
E_m	Matrix modulus
v_m	Matrix volume fraction
ρ_f	Fibre density
ρ_m	Matrix density.
ε_c	Strain of the hybrid composites
ε_{c1}	Strain of the first system
ε_{c2}	Strain of the second system
L	Span length
B	Width

D	Thickness
Y	Poisson ratio
V	Volume
M_h	Mass of the sample after exposing it in humidity
M_d	Mass of the dried sample.
T_g	Glass transition temperature
σ_c	Composite strength
E_c	Composite modulus
$\Delta M(t)$	Percentage weight gain

©This item is protected by original copyright

Pembangunan dan Pencirian Hibrid Gentian Rumput Gajah/Kaca Epoksi Komposit

ABSTRAK

Permasalahan alam sekitar yang serius sejak kebelakangan ini menyebabkan penyelidik terdorong untuk menyiasat penggunaan bahan yang mampan sebagai pengganti untuk komposit polimer yang diperbuat daripada gentian sintetik seperti kaca, karbon, dan aramid. Oleh itu ia telah meningkatkan minat penyelidik dalam pembangunan komposit daripada gentian semula jadi. Walau bagaimanapun, komposit daripada gentian semula jadi mempunyai beberapa kekurangan seperti ketahanan yang lemah dalam penyerapan kelembapan dan mempunyai kekuatan hentaman yang rendah. Bagi meningkatkan lagi sifat komposit daripada gentian semula jadi, gentian sintetik seperti kaca, karbon, dan aramid dikombinasikan dengan gentian semulajadi. Sifat mekanik hibrid gentian rumput gajah/kaca epoksi komposit dan, ketahanannya terhadap suhu tinggi dan pendedahan kelembapan telah dikaji dan disiasat. Gentian 5% alkali-terawat gentian rumput gajah telah menunjukkan tegasan tengangan yang maksimum. Hibrid komposit dengan 5% alkali-terawat gentian rumput gajah mempunyai tegangan dan kekuatan lenturan yang paling tinggi. Pemerhatian terhadap kesan permukaan hibrid komposit dengan gentian rumput gajah yang tidak terawat menunjukkan kurang permukaan yang rosak. Penyerapan kelembapan hibrid rumput gajah/kaca epoksi komposit meningkat dengan peningkatam masa rendaman.. Apabila suhu menghampiri T_g , pada $> 60^\circ \text{C}$, gentian akan terlejang dari ikatan matriks dan seterusnya mengurangkan tegangan dan kekuatan lenturan bahan. Kajian ini dijangka menyediakan bukti untuk menyokong pembangunan dan penggunaan bahan tersebut.

Development and Characterisation of Hybrid Napier/Glass Fibre Reinforced Epoxy Composites

ABSTRACT

Owing to serious environmental concerns in recent years, researchers have been driven to investigate the use of sustainable materials as a substitute for common polymer composites manufactured with synthetic fibres, such as glass, carbon, and aramid. This has generated increased interests in the development of natural fibre-reinforced composites. However, natural fibre composites have some limitations such as poor resistance to moisture absorption and possess lower impact strength. To further enhance the properties of natural fibre composites, reinforcements such as glass, carbon, and aramid fibres are hybridized into natural-fibre composites. The mechanical properties of hybrid Napier/glass fibre reinforced epoxy composites and, their durability under elevated temperatures and moisture exposure were characterised and investigated. The 5% alkali-treated fibre had achieved the maximum ultimate tensile stress of single fibre test. The hybrid composites with 5% alkali-treated Napier fibres exhibited the greatest tensile and flexural strengths. Observing the impacted surfaces, it can be noticed that the hybrid composites with untreated Napier fibres present less damage area. The moisture absorption of the hybrid Napier/glass fibres reinforced epoxy composites increased with the water-immersion period of the samples. As the temperature approached T_g , at >60 °C, the fibre would deboned from the matrix and consequently reduced the tensile and flexural strength of the material. This study is expected to provide evidence to support the development and application of this material.

CHAPTER 1

INTRODUCTION

1.1 Overview

The current growth in environmental awareness has generated increasing interest in the use of natural fibres as alternative reinforcement materials for polymer composites. This is largely owing to their low environmental impact, low cost, and relatively good specific properties. Scientists have been striving to develop biodegradable composites using renewable agro-based materials (Kommula, Kanchireddy, Shukla, & Marwala, 2014). Natural fibres derived from plants demonstrate great potentials for use in plastic, automotive, and packaging industries because of their excellent characteristics such as low density, high specific stiffness, good mechanical properties, biodegradability, eco-friendliness, toxicologically harmless effect, good thermal and their acoustic insulation (Mohanty, Wibowo, Misra, & Drzal, 2004; V. K. Thakur, Thakur, & Gupta, 2013b). In addition, these cellulosic fibres can reduce the overall material costs compared to the starting polymer (V. K. Thakur, Thakur, & Gupta, 2013a).

Comprehensive reviews conducted by a number of publications (Bongarde & Shinde, 2014; He et al., 2015; V. K. Thakur, Thakur, & Gupta, 2014; V. K. Thakur & Thakur, 2014, 2015; F. Wang, Shao, Keer, Li, & Zhang, 2015) had outlined the differences found in natural fibres with regards to their mechanical properties and their applications. Several authors documented the use of natural fibres such as bamboo (F. Wang et al., 2015), flax (Moothoo, Allaoui, Ouagne, & Soulat, 2014), coir (Varma, D.

S. Varma, M. Varma, 1986), arundo donax (giant reed) (Fiore, Scalici, & Valenza, 2014), okra (De Rosa, Kenny, Puglia, Santulli, & Sarasini, 2010), jute (Pal, 1984; Prashant, 1986), wheat straw (Lawther, Sun, & Banks, 1996; Sun, Lawther, & Banks, 1996) and alfa (Paiva, Ammar, Campos, Cheikh, & Cunha, 2007) as reinforcements in composite materials.

Nevertheless, there are concerns regarding the attributes of natural fibres such as their hydrophilic nature, high moisture absorption, poor reactivity, and poor compatibility with polymeric matrices, all of which influence their mechanical properties (Indran, Raj, & Sreenivasan, 2014; Obi Reddy, Uma Maheswari, Shukla, Song, & Varada Rajulu, 2013; M. K. Thakur, Gupta, & Thakur, 2014). The hydrophilic nature of natural fibre is known to produce weak interfacial adhesion in polymer-matrix composites (Girisha & Srinivas, 2012). The type of natural fibre can also affect the biological performance of the composites, for example, a composite manufactured from abaca fibre has a much greater moisture content compared to flax reinforced composites (Faruk, Bledzki, Fink, & Sain, 2012). These problems can be rectified through modifications such as alkali treatment to enhance the interfacial adhesion between the natural fibres and composite matrices, in addition to enhancing the mechanical, physical, and thermal properties of the fibres (Li, Tabil, & Panigrahi, 2007). Other modifications during acetylation can modify the surface of the fibres and enhance their hydrophobicity (Faruk et al., 2012).

Napier grass fibre, also scientific name known as *Pennisetum purpureum* is composed of 46% cellulose, 34% hemicellulose, and 20% lignin (Reddy, Maheswari, Shukla, & Rajulu, 2012). The purpose of the alkali treatment is to remove the hemicelluloses, split the fibres in the fibrils, and produce a closely packed cellulose chain owing to the release of the internal strain, which consequently improves the

mechanical properties of the fibre (Bledzki & Gassan, 1999). Following the alkali treatment, the fibrillation of the fibres also increases the effective surface area available for wetting by the resin and enhances the bonding between the fibre-matrix interfaces within the polymer composites. The alkali treatment also breaks the hydrogen bonds and increases the number of free hydroxyl groups of the fibre, thus increasing the fibre reactivity (Dipa Ray, Sarkar, Basak, & Rana, 2002).

The alkali treatments of various lignocellulosic fibres such as jute, hemp, kapok, sisal (Mwaikambo & Ansell, 2002), banana (Zuluaga et al., 2009), coir (Gu, 2009b), and Napier grass (Reddy, Maheswari, Reddy, & Rajulu, 2009b) have been previously investigated. Haameem et al. (2014) recently determined that the maximum ultimate tensile stress of Napier single fibres was achieved with 10% alkali treatment. However, this was contradictory to the results of Reddy et al. (2012) which determined that the maximum ultimate tensile stress of Napier fibre was achieved with 5% alkali treatment. The modulus of jute fibres improved by 12%, 68 %, and 79% following 4, 6, and 8 h of alkali treatments, respectively. The tenacity of the fibre improved by 46% following alkali treatments for 6 and 8 h and the breaking strain was reduced by 23% following an 8 h treatment (D. Ray, Sarkar, Rana, & Bose, 2001). Liu et al. (2006), Rao et al. (2010) and Thakur et al. (2013b) all demonstrated that the natural fibres exhibited great potential for use as an alternative to artificial glass and carbon fibres during the production of thermosetting or thermoplastic composites. The incorporation of two or more types of fibre into a single matrix has led to the development of hybrid composites. The performance of these hybrid composites are determined by many factors, such as the matrix, length and shape of individual fibres, fibre-matrix interface bonding, and volume fraction of the natural/synthetic fibres (Cicala et al., 2009; Júnior, Júnior, Amico, & Amado, 2012; Mishra et al., 2003). Previous studies had studied the

effect of varying the amount of fibre loading on the mechanical properties of hybrid composites consisting of natural fibres and glass fibre. These included bamboo/glass (Rao, Kumar, & Reddy, 2011), sisal/glass (Mishra et al., 2003), kenaf/glass (Atiqah, Maleque, Jawaid, & Iqbal, 2014), okra/glass (Sule, 2014) and jute/glass (Braga & Magalhaes Jr., 2015) hybrid composites. Mishra et al. (2003) reported that the water uptake of hybrid composites is lower than that of un-hybridized composites (Mishra et al., 2003). Moreover, Ahmed and Vijayaragan (2008) revealed that the properties of jute composites can be considerably improved by the incorporation of glass fibres in the form of extreme glass plies. These studies concluded that superior properties were exhibited by the hybrid-reinforced composites, which consisted of natural fibres and synthetic fibres.

Behaviours such as moisture absorption and mechanical degradation of polymers and polymeric composites have been comprehensively investigated (Demirkoparan, Pence, & Wineman, 2010; Demirkoparan & Pence, 2007a, 2007b; Tsai, Pence, & Kirkinis, 2004; Venkateshwaran, ElayaPerumal, Alavudeen, & Thiruchitrambalam, 2011). The mechanical properties and moisture absorption of these materials were greatly influenced by the length of the fibres and the hybridisation ratios used for the reinforcement (Sule, 2014). Phan Braga and Magalhaes (2015) reported that jute/glass composites that contained a greater proportion of jute fibre absorbed more water than those that contained a greater proportion of glass. Khalid et al. (2007) analysed the effect of hybridisation on the mechanical and physical properties of oil palm empty fruit bunch (EFB)/glass-polyester hybrid composites (Khalil, Hanida, Kang, & Fuaad, 2007). The study showed that the hybrid composites exhibited superior properties to the EFB-polyester composites. Recently, it had been established that Napier grass fibres can potentially be used as a reinforcement material within polymer composites (Reddy,

Maheswari, Reddy, & Rajulu, 2009a; Reddy et al., 2012; Ridzuan, Abdul Majid, Afendi, Kanafiah, & Nuriman, 2015; Ridzuan, Abdul Majid, Afendi, Azduwin, et al., 2015).

Despite their great potential, compared with synthetic fibres, such as glass and carbon, natural fibres have some limitations when used as reinforcement materials, such as they have lower modulus and strength, as well as higher moisture absorption. To overcome these drawbacks, potential solutions have been suggested, such as hybridisation with synthetic fibres and chemical modification of the natural fibres. Hybrid composites are materials that are fabricated by combining two or more different types of fibres within a common matrix. Hybrid composites are more advanced than other fibre-reinforced composites and have a wider range of potential applications. The properties of the hybrid composites are dependent on the fibre content, fibre orientation, fibre length, bonding between the matrix and fibre, and the arrangement of the fibres within the laminates. Previous studies on natural-synthetic fibre hybrid composites had primarily focused on reducing the use of synthetic fibres (Assarar, Zouari, Sabhi, Ayad, & Berthelot, 2015; Joshi, Drzal, Mohanty, & Arora, 2004; Kumar, Arumugam, Dhakal, & John, 2015). A previous study had described the potential advantages associated with natural-synthetic fibre hybridisation (M. Jawaid & Abdul Khalil, 2011).

The mechanical properties of a kenaf-aramid hybrid composite were examined by (Bakar, Hyie, Ramlan, Hassan, & Aidah, 2013). They studied the potential hybridisation of the long kenaf fibres with Kevlar. The mechanical properties of the woven jute/glass fabric hybrid composites were examined by (K. S. Ahmed, Vijayarangan, & Kumar, 2007). The mechanical properties of sisal fibre reinforced polyester composites were improved by adding carbon (Noorunnisa Khanam et al., 2010). Hani et al. (2011) investigated hybrid (woven coir/ Kevlar) composites and found that coconut coir could