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

by

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TABLE OF CONTENTS

CHAPTER 3 MATERIALS AND METHOD

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

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	Poison 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

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 ° C, gentian akan terlekang 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