CHARACTERIZATION OF CONTINUOUS KENAF-GLASS FIBER HYBRID COMPOSITES FOR STRUCTURAL APPLICATION

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Dedicated to:

My beloved parents
My lovely wife and daughter
My dear sisters

Thank you for your prayers and understanding

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ABSTRACT

Kenaf fibers generally has some advantages such as eco-friendly, biodegradability, renewable nature and lighter than synthetic fibers. However, their mechanical properties are lower than synthetic fibers. Hybridization of bio-fiber with a synthetic fiber could improve the mechanical properties of composites. The aims of the study are to characterize and evaluate the properties of kenaf fiber composites and its hybridizations with glass fiber and also to investigate the performance of bio-composite as the strengthening plate for structural applications. The study was conducted in three stages. Firstly, the raw materials and composites were developed by conducting laboratory tests on physical and mechanical properties. The properties and the effects of different conditions of alkaline treatment on the properties of kenaf fibers were studied due to the various alkaline treatment conditions. Besides, the scanning electron microscopy was employed to observe the specimens appearance, fracture area and fiber diameter. The tensile properties of glass fiber composites, kenaf fiber composites and hybrid kenaf/glass fiber composites were determined with various fiber volume contents. The second stage was the application of composite materials as strengthening plate in reinforced concrete beams and subjected to flexural test under the four points loading system until failure. Fifteen beam specimens were prepared and tested for the study. The third stage was analytical investigations and theoretical development of the properties of composites and performance of strengthened reinforced concrete (RC) beams. According to the results of this study, the average diameter, the density and tensile strength of kenaf fiber were 67.6 μm, 1.2 g/cm^3 and 780 MPa, respectively. Meanwhile, the tensile strength of hybrid kenaf/glass bio-composites exhibited almost equivalence to the glass fiber composites and also the highest strain energy density among the composites in the same value of fiber content. It was observed that increasing the glass fiber fraction more than 10% in hybrid composite caused the reduction in the ultimate tensile strain. For the hybrid bio-composites, debonding between the kenaf and glass layers caused the failure of composites. The flexural tests of RC beams showed the equivalent performance of the hybrid kenaf/glass bio-composite and the glass fiber composite strengthening plates. An analytical investigation has validated that the rule of mixture (ROM) could predict reasonably the elastic modulus of composites. The analytical model of this study based on the nonlinear stress–strain curve of concrete predicted well the moment capacity of RC beams as compared to the ACI 440.2R guideline. Therefore, this model was proposed in order to establish the analytical formulations for RC beams strengthened with the composites plates.

ABSTRAK

Kebaikan gentian kenaf adalah kerana sifat-sifat yang mesra alam, kebolehan biodegradasi, boleh diperbaharui secara penanaman semula dan ringan berbanding dengan gentian sintetik. Walaubagaimanapun sifat-sifat mekanikal gentian kenaf adalah lebih rendah berbanding dengan gentian sintetik. Keadaan ini boleh dipertingkatkan dengan melaksanakan penghibridan gentian asli dengan gentian sintetik. Oleh itu, tujuan kajian ini adalah untuk mencirikan dan menilai sifat-sifat komposit gentian Kenaf dan penghibridannya dengan gentian kaca, dan juga untuk mengkaji prestasi bio-komposit sebagai plat pengukuh untuk aplikasi struktur. Kajian ini telah dijalankan dalam tiga peringkat. Di peringkat pertama, bahan-bahan mentah dan komposit telah dikaji dan dibangunkan melalui pengujian makmal ke atas sifat-sifat fizikal dan mekanikal. Ciri-ciri dan kesan rawatan alkali yang berbeza atas sifat-sifat gentian Kenaf juga telah dikaji. Selain itu, mikroskop elektron pengimbas telah digunakan untuk memerhatikan penampilan spesimen, kawasan patah, diameter gentian, dan ciri-ciri lain yang boleh diperhatikan. Sifat tegangan komposit gentian kaca, komposit gentian Kenaf, dan hibrid komposit gentian Kenaf/kaca telah ditentukan mengikut kandungan jumlah gentian yang berbeza. Peringkat kedua adalah untuk mengkaji penggunaan bahan komposit sebagai plat pengukuh dalam rasuk konkrit bertetulang melalui ujian lenturan berasaskan sistem pembebanan empat titik sehingga mencapai tahap gagal. Sebanyak 15 spesimen rasuk telah disediakan dan diuji untuk kajian ini. Peringkat ketiga melibatkan proses analisis dan pembangunan teori sifat-sifat komposit dan prestasi kekukuhan rasuk konkrit tetulang. Keputusan menunjukkan bahawa diameter purata gentian Kenaf adalah 67.6 µm, ketumpatan ialah 1.2 g/cm^3, dan kekuatan tegangan adalah 780 MPa. Kekuatan tegangan hibrid Kenaf/kaca bio-komposit telah didapati setara dengan komposit gentian kaca dan juga didapati bahawa ia mempunyai ketumpatan tenaga terikan tertinggi di kalangan komposit dengan kandungan gentian yang sama. Malahan, penambahan kuantiti gentian kaca melebihi 10% dalam gentian hibrid juga didapati telah mengurangkan terikan tegangan muktamad. Bagi bio-komposit hibrid, rekahan antara lapisan Kenaf dan lapisan kaca dalam komposit adalah ciri kegagalan yang paling ketara di bawah beban muktamad. Hasil ujian lenturan untuk kedua-dua bio-komposit hibrid kenaf/kaca dan plat pengukuh gentian kaca adalah didapati setara. Kajian analisis secara teori telah mengesahkan bahawa model "rule of mixture" berkebolehan meramalkan nilai modulus keanjalan komposit dengan munasabah. Berdasarkan lengkung tegasan-terikan tak linear, model analisis kajian ini juga boleh meramalkan keupayaan momen bagi rasuk konkrit dengan lebih baik berbanding dengan garis panduan ACI 440.2R. Oleh itu model ini adalah sesuai disyorkan sebagai model teori untuk membangunkan rumusan analisis rasuk konkrit yang diperkukuhkan dengan plat komposit.

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LIST OF ABBREVIATION

KFRP	-	Kenaf fiber reinforced composite
GFRP	-	Glass fiber reinforced composite
HKGFRP	-	Hybrid kenaf/glass fiber composite
RC	-	Reinforced concrete
ROM	-	Rule of mixture

LIST OF SYMBOLS

A	-	Sectional area
C	-	Neutral axis placement
E	-	Modulus of elasticity
F	-	Force
h	-	Height of beam
L	-	Length of specimen
$\rho_{c(p)}$	-	Density of composite
ρ_m	-	Density of matrix
ρ_f	-	Density of kenaf fiber
ρ_G	-	Density of glass fiber
V_m	-	Volume content of matrix
V_f	-	Kenaf fiber volume content
E_k	-	Elasticity moduli of kenaf fiber
E_G	-	Elasticity moduli of glass fiber
V_G	-	Glass fiber volume content
V_G'	-	Glass fiber volume fraction
E_m	-	Elasticity moduli of polymer
V_m	-	Volume content of the polymer matrix
C	-	The distance of neutral axis of beam section from the top of beam
ε_c	-	The distribution of compressive strain of concrete
ε_1	-	The maximum compressive strain of concrete at the top of RC beam
x	-	The distance variable due to neutral axis

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CHAPTER 1

INTRODUCTION

1.1 Introduction

According to environmental concerns and financial problems, natural fibers have become interesting and fascinating nowadays to be used as an industrial material such as sport equipment, automotive application and construction material for structural and non-structural elements [1-4]. Bio-fibers offer several advantages including high specific strength and modulus, low density, renewable nature, biodegradability, absence of associated health hazards and so on. All natural fibers are cellulosic in texture and composed of cellulose, hemicellulose, lignin and pectin. The major ingredients of natural fibers are cellulose and lignin. Cellulose is a semi crystalline polysaccharide hydrophilic component consisting of a linear chain of anhydroglucose units, which contain alcoholic hydroxyl groups. So, all natural fibers are hydrophilic in nature [5-7]. Therefore, fiber-matrix interface adhesion is the most significant parameter in the properties of composites. One of the important issues of natural fiber is the hydrophilic property of cellulose which impacts the weak interface bonding with hydrophobic polymer as a matrix. Chemical surface modifications methods of natural fiber are well documented in literature include alkaline treatment, acidity treatment, coupling agents and, etc.

Using natural fibers in polymer composites has become interesting because of the advantages of renewable fiber source, biodegradability and sustainability. However, an important drawback of natural fibers is the low mechanical properties in comparison to man-made fibers that this issue prevents to use bio fiber as a qualified material for using as load carrying materials and structural elements [8]. Therefore, for enhancing the mechanical properties of natural fiber composites, man-made fiber, e. g. glass fiber, is used as hybridize the composites [9]. This study is conducted to investigate the characteristics of kenaf-glass fiber hybrid composites and its potential use as the structural elements.

1.2 Background of the study

All vegetable fibers are cellulosic in nature and composed of cellulose, hemicellulose, lignin and pectin. So, all natural fibers are hydrophilic in nature [5-7]. Lignin is an untidy, cross-linked polymer which gives rigidity to fiber [10].

Generally, the mechanical properties of natural fibers like kenaf, hemp, flax and jute lower than that of E-glass fiber commonly used in composites but the density of E-glass is high, ~2.5 g/cm^3, while that of natural fibers is much lower (~1.2 to1.5 g/cm^3). So, The specific strength and specific moduli of some of these natural fibers are quite comparable to glass fibers [7, 11].

Several different initial retting methods were reported [7] that alkaline treatment (mercerization) is a well-known chemical treatment of surface modification of natural fiber for making natural fiber reinforced polymer. This treatment removes lignin, hemicellulose, wax and oils covering the surface of the fiber [12].

Due to particular character of kenaf fiber and its benefit to environment, using of kenaf fiber reinforced polymer composite is increased. The performance of materials is always presented in terms of their mechanical characteristics, such as tensile properties, flexural properties, compression properties, impact properties and wears behavior [13]. These features are significant to determine material ability, especially under extreme and critical situations. Recently, many studies have been completed on kenaf fiber reinforced polymer composites; with the purpose of totally characterize its mechanical behavior [14-17]. Generally, the tensile and flexural properties of kenaf fiber reinforced polymer composites, differ depending on the variety of fiber, fiber aspect ratio, treatment method, its orientation (random or arrangement), fiber volume content and form (fiber or fabric), type of polymer used, curing method and also the quality of fabricating.

However, an important drawback of natural fibers is the low mechanical properties in comparison to man-made fibers that this issue prevents to use bio fiber as a qualified material for using as load carrying material and structural element [8]. So, for enhancing the mechanical properties of natural fiber composites, man-made fiber, e. g. glass fiber, is used as hybridize the composites [9]. There are a lot of reports done by scientists about making hybrid composite to prove the natural fiber composite properties such as oil palm fiber, jute, sisal, ramie and etc. [8, 9, 18, 19].

1.3 Problem statement

Fiber reinforced polymer composites (FRPs) are being used widely in all industrial aspects that each FRP contains two major parts include polymer matrix and reinforced fiber. Common thermoset polymers such as epoxy, polyester and vinyl ester and common fibers such as carbon, aramid and glass fiber are synthetic materials which are not sustainable to environment due to high energy consumption during process, long time remaining in environment, high smoke emission; on the other side, the green material especially bio-based materials which are made by plant not only does not have any impact to environment but also help to save the nature. Therefore, scientists are attempting to get green composite materials by using of bio-fiber (natural fiber) named bio-composites. Kenaf fiber is one of natural fibers which is cultivated a lot in Malaysia and could be the main nominee for bio-composite as reinforcing fiber. Indeed, characterization of this fiber is the most important subject.

Significantly, bio-fiber like kenaf fiber has two main drawbacks including the hydrophilic surface which is not compatible with epoxy resin (hydrophobic nature) resulting the insufficient interfacial stress between fiber and matrix. The hydroxyl (-OH) group of kenaf fiber causes the hydrophilic nature of kenaf fiber. Also, the other issue is the lower strength of kenaf fiber as compared to synthetic fiber. The first issue can be improved by using of chemical surface modification method named alkaline treatment which will be done in different conditions in this study. The next issue can be improved by hybridization that in this method the kenaf fiber and synthetic fiber like glass fiber are put in the polymer matrix together as reinforcing material. The aspect ratio of fiber, stacking sequence of fiber layer and fabricating method in FRP can vary depend on the desired goal. For making structural element, it needs to have adequate mechanical properties to meet the design requirements.

Furthermore, due to the changing of design codes in terms of loading coefficients, safety factors and also because of some problems as a result of natural hazards or unexpected loading on structures, some of them need to be strengthened or rehabilitated. Using of strengthening plate to strengthen beams especially RC beams is a well-known method that can be done by using of bio-composite plate. The capability of this green composite should be investigated and clarified.

1.4 Aim and Objectives of the study

The aim of the study is to investigate the characteristics of kenaf-glass fiber hybrid composites and its performance as a strengthening element for reinforced concrete beams. The objectives of the study are,

a) To characterize the properties of kenaf fiber polymer bio-composites
b) To evaluate the mechanical properties of kenaf-glass fiber hybrid polymer composites
c) To investigate the performance of kenaf-glass fiber hybrid polymer composite plates as strengthening element for reinforced concrete beams
d) To propose a theoretical formulation for kenaf-glass fiber hybrid polymer composites and its application as strengthening element

1.5 Scope of the study

This study is conducted as experimental works in laboratory in two major parts. The first part is about the material development including bio fiber and bio composites and another part is about the application of hybrid bio-composite as structural element to strengthen the RC beam.

*** Material development:** The physical and mechanical properties of kenaf fiber which is supplied by the National Kenaf and Tobacco Board (Malaysia) as long fiber are determined due to the four different conditions of initial water retting process and also nine different settings of chemical surface modifications by NaOH solution. According to ASTM C1557-03 (approved 2008)[20], at least 15 specimens from 3 different gauge lengths are needed to test to get the proper result of the tensile properties of kenaf fiber.

Also, the tensile properties of unidirectional kenaf fiber epoxy bio-composite, unidirectional glass fiber epoxy composite and unidirectional kenaf/glass fiber epoxy composite are investigated in this part based on the well-known standard code named ASTM D3039M-08 [21]. The variable parameter of composites and bio-composite series is the fiber volume content while the variable parameters of hybrid composite are total fiber volume content and kenaf/glass fiber volume fraction. Accordingly, total number of composite series and specimens are 15 and at least 75, respectively, because 5 reasonable results are needed to determine the tensile properties of each series.

*** Application as strengthening plate:** The last part is conducted experimentally to investigate the performances of bio-composite plate and glass/kenaf hybrid composite as structural element to strengthen RC beam under pure flexural moment. Consequently, 3 control RC beams and also 12 RC beams strengthened by kenaf fiber bio-composite, glass fiber composite and hybrid kenaf/glass fiber composite in 2 different plate widths are considered to 4 point loading flexural test. Load, mid-span deflection, tensile steel strain at the middle and compressive concrete at the mid-span are reported as results of test for further discussion and analysis. Analytical investigation including analysis the results and suggestion of mathematical model is the last section of this part.

1.6 Significance of research

According to the environmental concerns of the man-made materials such as synthetic fibers for fiber reinforced polymer composites, bio materials like bio fibers becomes the best replacing material for using as reinforced fiber in polymer composite field. To introduce the use of green materials for engineering applications is the main goal of this study that it can help to save the nature and to reduce the emission of carbon dioxide. Increasing the knowledge of hybrid composite properties by using of kenaf and glass fiber, can encourage others to follow this kind of research to gain a sustainable material. Furthermore, this study can define new application of natural fiber and also will benefit engineers and industries to use of renewable materials. Besides, this study introduces the continuous unidirectional natural fiber especially kenaf bio-composites structural application for future research. This study establishes design and construction procedure of kenaf bio-composite to assist designer, engineer and architect. Moreover, it may succor to increase the agronomic activities and improve economic sector in Malaysia due to the demanding of kenaf fiber production.

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