EFFECT OF KENAF FIBER ON THE MECHANICAL PROPERTIES OF REINFORCED CONCRETE STRUCTURES

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To my beloved family and friends

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ABSTRACT

There is currently a great deal of interest in developing technology using natural organic fiber materials in cement composites. Kenaf is one of the organic fiber that has potential to be used in concrete. Kenaf fiber has many advantages such as affordability, renewability, recyclability, and biodegradability. Its tensile properties are comparable to those of other natural fibers, such as jute, flax and bamboo. Fiber reinforced concrete (FRC) was introduced to the industry to improve concrete properties and to prevent the cracking of reinforced concrete members. Nevertheless, the limited use of FRC in load-bearing structures seems to be due to a lack of accepted design mixes and guidelines. This study investigates the physical and mechanical properties of Kenaf fiber reinforced concrete (KFRC) and its structural behaviour as concrete beam under static loads. This study was carried out mainly by experiment. The experiments were conducted according to relevant American Standards (ASTM) and British Standards (BS), as well as recommended methods from past researchers. A number of parameters were observed from the experiment, such as physical properties (colour, fiber distribution in concrete, surface morphology, density, aspect ratio, weight loss and water absorption), properties of fresh KFRC (slump, compacting factor and vebe time), properties of hardened KFRC (ultrasonic pulse velocity, rebound hammer, density, compressive strength, splitting tensile strength, flexural strength, static modulus of elasticity and equivalent compressive strength) and performance of KFRC when used as beams under flexural loadings (ultimate load, deflection, cracking, steel strain, concrete strain, bonding between concrete and steel reinforcement and neutral axis). A total of 1300 concrete specimens (cube, cylinder and prism) and 7 beam specimens were casted and tested in this study. A theoretical model for the analysis and design of Kenaf fiber reinforced concrete materials and structural beam elements was proposed and evaluated. Results show that the presence of Kenaf fiber in concrete improved the properties such as splitting tensile strength, flexural strength and ultimate load of beam. However, it reduced the concrete properties if the fiber used was over the limit, the properties such as density, slump, compacting factor, vebe time, ultrasonic pulse velocity, rebound hammer, compressive strength, static modulus of elasticity and equivalent compressive strength. KFRC only can perform well under the suitable fiber to cement volume fractions of up to 0.75%. Fiber length did not affect concrete performance. The performance of KFRC was greatly influenced by the distribution and orientation of Kenaf fibers in concrete. Control and handling during the mixing process of KFRC was a major factor in producing quality concrete. Finally the use of Kenaf fiber as reinforcement in concrete is highly recommended based on improvements in material strength and structural performance.

ABSTRAK

Buat masa ini terdapat banyak faedah dalam membangunkan teknologi dengan menggunakan bahan-bahan gentian semula jadi dalam komposit simen. Kenaf adalah salah satu gentian organik yang mempunyai potensi untuk digunakan dalam konkrit. Gentian kenaf mempunyai banyak kelebihan seperti kemampuan, pembaharuan, kitar semula, dan biodegradability. Sifat tegangan ia adalah setanding dengan gentian semula jadi yang lain, seperti jute, flax dan buluh. Konkrit bergentian (FRC) diperkenalkan kepada industri untuk meningkatkan sifat-sifat konkrit dan juga untuk mengurangkan keretakan struktur konkrit bertetulang. Walau bagaimanapun, penggunaan FRC terhad dalam struktur menanggung beban adalah disebabkan tiada cara reka bentuk dan garis panduan yang diterbitkan setakat ini. Kajian ini mengkaji sifat-sifat fizikal dan mekanikal Kenaf serat konkrit (KFRC) dan tingkah laku strukturnya sebagai rasuk di bawah beban statik. Kajian ini dijalankan terutamanya oleh eksperimen. Kajian ini telah dijalankan dengan mengikuti Piawaian Amerika (ASTM) dan Piawaian British (BS), dan kaedah yang disarankan oleh pengkaji yang terdahulu. Beberapa parameter ditentukan dan diperhatikan dari eksperimen, seperti sifat-sifat fizikal gentian Kenaf (warna, agihan gentian dalam konkrit, permukaan morfologi, ketumpatan gentian, nisbah aspek, penurunan berat gentian selepas dan penyerapan air), sifat-sifat segar KFRC (kemerosotan, faktor mampatan dan masa vebe), sifat-sifat keras KFRC (ultrasonik nadi halaju, pemulihan tukul, ketumpatan, kekuatan mampatan, kekuatan tegangan, kekuatan lenturan, modulus statik keanjalan dan kekuatan mampatan yang setara) dan prestasi bertetulang KFRC yang digunakan sebagai rasuk di bawah beban lenturan (beban muktamad, pesongan, keretakan, ketegangan keluli, terikan konkrit, ikatan antara konkrit dan tetulang keluli dan paksi neutral). Sebanyak 1300 spesimen konkrit (kubus, silinder dan prisma) dan 7 spesimen rasuk telah diuji dalam kajian ini. Model teori untuk analisis dan reka bentuk Kenaf bahan konkrit bergentian dan unsur-unsur rasuk struktur telah dicadangkan. Hasil kajian menunjukkan bahawa Kenaf gentian dalam konkrit menambah baik sifat seperti kekuatan tegangan, kekuatan lenturan dan beban muktamad rasuk. Walau bagaimanapun, ia melemahkan sifat konkrit sekiranya gentian yang digunakan melebihi had, ciri-ciri seperti ketumpatan, kemerosotan, faktor mampatan, masa vebe, ultrasonik nadi halaju, pemulihan tukul, kekuatan mampatan, modulus statik keanjalan dan kekuatan mampatan yang setara. KFRC hanya dapat berfungsi dengan baik di bawah jumlah pecahan gentian untuk simen yang sesuai sehingga 0.75%. Panjang gentian tidak menjejaskan prestasi konkrit. Prestasi KFRC banyak dipengaruhi oleh pengedaran dan orientasi gentian Kenaf dalam konkrit. Kawalan baik dan pengendalian semasa proses pencampuran KFRC merupakan faktor utama untuk menghasilkan konkrit yang berkualiti. Akhirnya, kegunaan gentian Kenaf sebagai tetulang di dalam konkrit amat disyorkan kerana ia dapat meningkatkan kekuatan bahan dan prestasi struktur.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
DEMEC	-	Demountable Mechanical Strain
FRC	-	Fiber Reinforced Concrete
H_2O	-	Water
KFRC	-	Kenaf Fiber Reinforced Concrete
LVDT	-	Linear Variable Displacement Transducer
NaOH	-	Sodium Hydroxide
O_2	-	Oxygen
OPC	-	Ordinary Portland Cement
RC	-	Reinforced Concrete
SEM	-	Scanning Electron Microscopic

LIST OF SYMBOLS

A	-	Area
A_{s1}	-	Area of Tensile Steel Reinforcement
A_{s2}	-	Area of Compressive Steel Reinforcement
A_s	-	Area of Tension Reinforcement
A_s'	-	Area of Compression Reinforcement
a	-	Position of Fracture from Near Support
a_2	-	Distance from the Extreme Concrete Fiber to Centroid of Compressive Steel Bar
b	-	Width
b_p	-	Width of Prism
c	-	corresponding deformation (strain difference)
d	-	Distance from the Extreme Concrete Fiber to Centroid of Tensile Steel Bar
d_c	-	Diameter of Cylinder
d_f	-	Fiber Mean Diameter
d_p	-	Depth of Prism
d_t	-	Distance Travelled for Pulse
E	-	Effective Modulus
E_c	-	static modulus of elasticity in compression
E_c^{fib}	-	Modulus of Elasticity of FRC
E_s	-	Modulus of Elasticity of Steel
f	-	stress difference for measurements
f_{cf}	-	Characteristic Strength of Kenaf Fiber Concrete
f_{ck}	-	Characteristic Compressive Strength of Cube
f_{ct}	-	Characteristic Splitting Tensile Strength
f_t	-	Characteristic Flexural Strength

f_r	-	Modulus of Rupture for the Concrete
f_{yk}	-	Characteristic Strength of Reinforcement
h	-	Depth
I_{cr}	-	Cracking Moment of Inertia
I_e	-	Effective Moment of Inertia
I_g	-	Gross Moment of Inertia
I_{ucr}	-	Uncracked Moment of Inertia
L	-	Effective Span of the Beam
L_a	-	Distance from Support to One of the Loads
L_p	-	Span of Prism
l	-	Length
M	-	Moment
M_a	-	Ultimate Moment
M_{cr}	-	First Cracking Moment
m	-	Coefficient for Branson's Formula
m_c	-	Mass of Concrete
P	-	Applied Load
t_s	-	Time Travelled for Pulse
V_f	-	Volume Fraction
v	-	Volume of Concrete
v_b	-	Interfacial Bond Strength for Fiber
y_t	-	Distance from Neutral Axis of Uncracked Cross-section to Extreme Tension Reinforcement
W_a	-	Weight of Fiber in the Air
W_b	-	Weight of Fiber in the Auxiliary Liquid
W_f	-	Weight of Fully Compacted Concrete
W_o	-	Weight of Fibers before Chemical Treatment
W_p	-	Weight of Partially Compacted Concrete
W_t	-	Weight of Fibers after Chemical Treatment
W_1	-	Weight of Dried Fibers
W_2	-	Weight of Kenaf Fibers after Water Absorption
$\varkappa$	-	Neutral Axis Depth
Z_1	-	Depth of Neutral Axis

z	-	Level Arm
ρ_o	-	Density of Auxiliary at the Given Temperature
ρ_c	-	Density of Concrete
ρ_f	-	Density of Fiber
δ	-	Deflection at Mid Span at Ultimate Load
σ	-	Stress
ε	-	Strain
$\alpha_{e,eff}$	-	Modular Ratio for Steel Bar
$\alpha_{f,eff}$	-	Modular Ratio for KFRC
α_{cc}	-	Different between the Bending Strength and the Cylinder Crushing Strength of the Concrete
η	-	Defining the Effective Strength
γ_c	-	Usual Partial Safety Factor for the Strength of Concrete

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is one of the most durable and widely used building materials, and it is expected to continue to be so in the future. It has advantages over other materials such as timber and steel. The energy used to produce cement is lower than steel or plastics. The energy requirements to produce a cubic meter of cement is 22 times lower than a corresponding volume of steel and the energy cost of cement per unit volume is less than one-fifth that of common plastics (Timothy *et al*., 2013).

Recently, there have been many studies on the development of construction materials in civil engineering. Most researchers investigate and innovate materials based on three aspects, which are availability, environmental compatibility, and financial constraints. This results in the introduction of new construction materials to meet the ever increasing demand for improved mechanical properties and superior workability, in numerous civil and structural engineering applications.

The incorporation of fibers into brittle things as reinforcement has been used since ancient times. 3500 years ago, straw was used in sun-baked bricks and horsehair was used in mortar. Bricks were used to build the 57m high hill of Aqar

Quf near Banghdad (Liew, 2008). In the early 1950s, asbestos fiber began to be used in concrete. However, it was found that asbestos was harmful to human health. In the 1960s, some new fibers were introduced to replace asbestos such as steel, glass, and synthetic fiber, which are still used today (Joshi *et al.*, 2004). A lot of new fibers have potential as reinforcement in concrete and that makes the research of fiber reinforced concrete an interesting topic for researchers. Over the past 40 years, fiber reinforced concrete was used in road and floor slabs, refractory materials, and concrete products (Joshi *et al.*, 2004).

Fiber reinforced concrete contains cement, aggregate, water and discontinuous discrete fibers (Newman and Choo, 2003). Used fiber can be of various shapes and sizes and are classified into metallic, mineral, and organic. The choice of fibers varies from synthetic organic materials such as polypropylene or carbon, synthetic inorganic such as steel or glass, natural organics such as cellulose or sisal to natural inorganic asbestos (ACI, 1986). Currently commercial products are reinforced with steel, glass, polyester, and polypropylene fibers.

Fiber reinforced concrete is an increasingly popular construction material due to its ability to enhance the properties of conventionally reinforced concrete (Isa, 2015). In general, concrete is weak in tension compared to its compression capacity. Normally, steel reinforcement is used to overcome concretes weakness to tension. However, this weakness can also be solved by the inclusion of a sufficient volume fraction of certain fibers (Dianah, 2014). The idea is to disperse fibres into concrete to improve tensile strength.

According to Romualdi and Baston (1963), the plastic and drying shrinkage cracking of concrete can be controlled by the inclusion of fibers. Randomly distributed fibres in concrete act as a crack arrester, which has superior cracking resistance and crack propagation. Moreover, fibres are able to hold concrete together after excessive cracks. Fibers can lower the permeability of concrete and reduce bleeding in water (Dianah, 2014). Some fibers offer greater abrasion, shatter resistance, and concrete impact. Generally fibers cannot be used to totally replace structural steel reinforcements because some fibers reduce the strength of concrete

(Faezah, 2012). However, compared to plain concrete, fiber reinforced concrete is much tougher and has good impact resistance.

There are several fiber-reinforcing materials available in the market, but for structural applications, steel fiber is used. Most recently, there have been research efforts to utilize natural fibers for the production of low-cost building elements, partly due to the energy crisis (Dianah, 2014). This is due to the properties of natural fibers which are readily available, renewable, and cheap to produce compared to man-made fibers.

However, due to uncertainties in current design practices over the ability of natural fiber to be used as reinforcement in structure, the need for an extensive research programme is necessary. Most research are studies on the use of steel fibers in concrete, and is it rare to find studies on natural fibers, especially kenaf fiber (Lee, 2007; Rabalais, 1992; Aruntas *et al.*, 2008; Mohammadi *et al*., 2006; Torrijos *et al*., 2007; Magendran, 2007; Huzaifa, 2008; Julie, 2012; Isa, 2015). No natural fiber has emerged to dominate the marketplace. In this study, particular interest was paid to the use of kenaf fibers as concrete reinforcement.

1.2 Problem Statement

Sustainability is an important issue today in business and society. Sustainable construction may include element management, energy use, low carbon emissions from the use of concrete alternatives, the optimized use of carbon high materials, proper site planning and construction, and the recycling or reuse of natural resources (Tan, 2012).

In Malaysia, there is increasing demand, in both the private and public sectors to understand sustainable construction practices. In order to promote sustainable concepts, green materials have been developed and have attracted global attention.

There is currently a great deal of interest in developing natural organic fiber materials in cement composites. Among the most promising of such materials are biofibers. Biofibers have many advantages compared to other types of fibers such as their renewability, recyclability, and biodegradability (Hafizah *et al.*, 2011). In order to completely evaluate the potential of biofiber for new applications, a comprehensive and detailed study of their fundamental properties is important.

Cement concrete lends itself to a variety of innovative designs as they can be cast into any desired shape. It possesses many desirable properties like high compressive strength, high stiffness, low thermal conductivity, and low electrical conductivity. However, it also has low tensile strength, limited ductility, and little resistance to cracking (Bergman *et al.,* 2010).

In order to overcome concrete weaknesses, it is essential to use conventional steel reinforcement or the inclusion of a sufficient volume of certain fibers. The randomly distributed fibres in the concrete redistribute tensile force and interrupt the propagation of cracks, improving post-cracking ductility (Faezah, 2012). With this mechanism, concrete becomes ductile and catastrophic failure can be prevented. Natural fibre in reinforced concrete is able to enhance tensile strength, flexural strength, modulus of elasticity, shrinkage, fatigue life and resistance to impact and abrasion (Nurulhuda, 2008). In addition, fibres in the tension zone contribute to flexural stiffness and fibers in the compression zone delay disintegration and enabling beams or columns to develop greater overall ductility during failure, which substantially increases energy absorption capabilities (Sellers *et al*., 1999). However, fibre reinforced concrete is not meant to be a replacement for steel reinforcement for heavy loading applications. This is because of its inferior strength compared to conventional steel reinforcement bars.

In the 1960s, steel, glass and synthetic fibers such as polypropylene fibers were utilized with concrete, and research into new fiber reinforced concrete continues today. The above statement tells us that the investigation of materials and methods is needed to satisfy community needs.

There is still a lack of applications for natural fiber reinforced concrete in the construction industry. This may be caused by a lack of information on natural fiber reinforced concrete in the construction sector, especially in Malaysia. Consequently, natural fiber reinforced concrete is not popular in civil engineering despite its advantages compared to conventional cast-in-situ concrete. Natural fiber reinforced concrete will be accepted in the construction industry only after its characteristic properties are thoroughly investigated and well understood. (Lim, 2006)

The natural fiber used in this study is kenaf fiber. Kenaf has advantages compared to other cellulosic fiber crops since it has short plantation cycle, flexibile environmental requirements, and requires less pesticides and herbicides. Kenaf fiber has superior properties such as high tensile strength, light weight, renewability, biodegradability, and affordability (Elsais *et al.*, 2011). The Malaysian government is interested in replacing tobacco plants with kenaf plants. Kenaf cultivation reveals that natural fibers could reduce CO_2 emissions.

The weaknesses of kenaf fiber as composite reinforcement is that its fibers are hydrophilic attract water, while matrix materials are typically hydrophobic and repel water. This difference in hydrophility makes wetting the fiber with a polymer matrix during the fabricating process difficult. The solution to this problem are surfaces treatment that improve interactions between the fibre and matrix material.

In order to assess the effectiveness of alkaline treatment on the kenaf fiber surface as well as the effect of kenaf fiber on the mechanical properties of concrete and reinforced concrete structures, a set of experimental tests were carried out. There is currently, no information about kenaf fiber applications in load-bearing structures. The use of kenaf fibers in a concrete matrix was carried out only for no-structural elements. Kenaf fiber can be used in combination with conventional reinforcing bars to improve concrete properties. Therefore studies on the load-bearing structure behaviour of KFRC beams using through experiments and theoretical analysis might be the best way to collect data in the process of preparing a universal standard for kenaf fiber design and construction. It is necessary to check the properties of the material, to determine the performance of KFRC and the optimum content of kenaf fiber before the material can be broadly used as a building material.

1.3 Objectives

The aim of the study is to investigate Kenaf fiber properties and their performance in concrete and reinforced concrete. There are five objectives for this study:

1. To characterise the physical and mechanical properties of kenaf fibers.
2. To investigate the effects of kenaf fibers on the properties of fresh and hardened concrete.
3. To observe the optimum characteristics of kenaf fiber reinforced concrete for structural applications.
4. To determine the load-deformation behaviour of reinforced concrete beams by employing kenaf fiber reinforced concrete.
5. To evaluate the analytical models of kenaf fiber reinforced concrete for reinforced concrete elements.

1.4 Scope of Study

The study was conducted experimentally to evaluate and develop kenaf fiber reinforced concrete based on requirements for availability, economical, recyclability, energy use, and environmental considerations. Before kenaf fiber reinforced concrete can be introduced to the marketplace and widely used as a building material, the properties of the material and methods used to handle the material must be carefully studied. This study mainly focuses on the development of standard mixtures for kenaf fiber reinforced concrete using various fiber parameters (fiber volume, fiber fraction, and fiber length) based on laboratory testing on fresh and hardened concrete.

The study was divided it into four stages as shown in below:

Stage I :	For kenaf fiber, the tests conducted were density test, water absorption test, weight loss and Scanning Electron Microscope (SEM) test.
Stage II:	For fresh concrete, the tests conducted were slump, compacting factor, and Vebe time test.
Stage III:	For hardened concrete, the tests conducted were compressive strength, splitting tensile strength, flexural strength, static modulus of elasticity in compression, and equivalent of compressive strength.
Stage IV:	For reinforced concrete beam, the test conducted was a four-point bending test.
Stage V:	Analytical models and theoretical analysis of KFRC beams were proposed and evaluated, then compared to experimental results.

1.5 Significance of Study

To develop kenaf fiber reinforced concrete as a material in the construction industry, the significance of this study is as follows:

i. The development of kenaf fiber reinforced concrete as a sustainable green material would be beneficial for the construction industry.
ii. The study of kenaf fiber chemical treatments provides information on the properties of kenaf fiber in concrete applications.
iii. Kenaf fiber reinforced concrete can cause the industry to improve concrete properties and building life time.

iv. The study of kenaf fiber reinforced concrete on load-bearing structure can provide information for a universal standard for kenaf fiber design and construction.

1.6 Outline of Thesis

There are 7 chapters in this thesis and each chapter gives information related to the research objectives. An outline of this thesis is shown below:

i. **Chapter 1**: This chapter presents the introduction study background, problem statement, objectives, study scope, and study significance.

ii. **Chapter 2**: This chapter presents the literature review. It covers brief explanations regarding natural fibers, kenaf fiber, kenaf fiber chemical treatments, and natural fiber reinforced concrete.

iii. **Chapter 3**: This chapter presents information on material specifications, equipment and the experimental procedures used in this study.

iv. **Chapter 4**: This chapter describes the results for kenaf fiber properties (physical and mechanical) and concrete trial mixes.

v. **Chapter 5**: This chapter describes the results for kenaf fiber reinforced concrete. Fresh and hardened concrete properties are discussed.

vi. **Chapter 6**: This chapter describes the results of the performance of KFRC beam structures under flexural loads and also make a comparison to the theoretical analysis.

vii. **Chapter 7**: A summary of the major findings of the study together with some recommendations for further work is given in this chapter.

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