PERFORMANCE OF KENAF FIBRE REINFORCED CONCRETE UNDER STATIC AND DYNAMIC LOADINGS

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To my beloved parents father and mother

Thanks for your support

I am very proud to have all of you

~~~~~ Love you all ~~~~
~~~~~

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ABSTRACT

Concrete is considered as a brittle material, its enrichment with distributed short kenaf fibres is believed to increase the toughness of matrices. This is achieved by prohibiting the concrete from being cracked and propagated. Kenaf is a natural fibre has typically some benefits such as being renewable, eco-friendly, biodegradable and locally accessible as compared to other types of fibres used for concrete reinforcement. This study was conducted experimentally to investigate the characteristics of kenaf fibre reinforced concrete (KFRC) materials and to determine the performance of kenaf fibre reinforced concrete beams under static and dynamic loadings. The basic concrete materials used in the study are 10 mm aggregate, ordinary portland cement and clean water. Mixing procedures were evaluated to produce KFRC materials with different chopped fibre lengths (10 mm, 15 mm, 20 mm, 25 mm and 30 mm) and fibre volume fractions (0.5%, 1%, 1.5% and 2%). At the preliminary stage, the alkaline treatment test was carried out on the kenaf fibres. Then, the raw materials and concrete properties were investigated by a series of physical and mechanical property tests on fresh and hardened concrete to identify the optimum characteristics of fibre length and content to be used in the concrete mixture. The study also investigated the structural behaviour of KFRC beams, in which the samples were undertaken by monotonic bending load and repeated bending load tests under four points loading system until failure. The load-deformation behaviour of the beams was observed and monitored during testing. Results from the study of alkaline treatment on kenaf fibres found that the best condition was 5% NaOH in three hour emerging time. The study also found that the optimum length of kenaf fibres was 20 mm and the optimum volume fraction yields the value of 1%. From the KFRC beam tests, it was found that the KFRC beams exhibited better performance as compared to normal concrete beams. The best static and dynamic behaviour was observed for the beam using KFRC in tension zone and plain concrete in compression zone, with the ultimate bending load of 5.9% higher than normal concrete beam after the flexural test and 15.6% higher than normal concrete beam after the repeated load test. By observation, the number of crack formation in tension zone increased by 40% and crack spacing was less by 15% as compared to normal concrete beams. The total energy absorption from the load-deflection behaviour of KFRC beams until ultimate failure was 77% higher than normal concrete beams. The relationships between KFRC material and structural performance against fibre lengths and volume fractions have been developed based on the non-linear numerical models and proposed for the analysis and design of KFRC. Conclusively, KFRC material and structure exhibit appreciable tensile, flexural, and impact strength under static and dynamic loadings compared to normal concrete.

ABSTRAK

Konkrit ialah bahan rapuh, pengayaan dengan gentian kenaf pendek secara agihan seragam dipercayai mampu meningkatkan pengukuhan matriks. Ini dicapai dengan mengekang konkrit daripada retak serta berkembang. Kenaf adalah gentian asli mempunyai beberapa kelebihan antaranya sebagai sumber yang boleh diperbaharui, mesra alam dan mudah diperoleh berbanding lain-lain jenis gentian yang digunakan sebagai tetulang konkrit. Kajian ini dijalankan secara eksperimen untuk menyelidik ciri-ciri konkrit bergentian kenaf (KFRC) dan menentukan prestasi rasuk konkrit bergentian kenaf di bawah pembebanan statik dan dinamik. Bahan-bahan asas konkrit yang digunakan dalam kajian ini ialah 10 mm agregat, simen portland biasa dan air bersih. Prosedur pencampuran telah dinilai untuk menghasilkan konkrit bergentian kenaf dengan panjang gentian (10 mm, 15 mm, 20 mm, 25 mm, dan 30 mm) dan pelbagai kandungan nisbah isipadu gentian (0.5%, 1%, 1.5%, dan 2%). Di peringkat awal, ujian rawatan alkali dijalankan ke atas gentian kenaf. Selanjutnya, ujian sifat-sifat fizikal dan mekanikal ke atas konkrit basah dan keras telah dijalankan untuk mengenal pasti ciri-ciri panjang dan kandungan gentian optimum yang diperlukan dalam campuran konkrit. Kajian juga dijalankan ke atas kelakuan struktur rasuk KFRC, di mana sampel rasuk diuji dengan beban lenturan monotonik dan beban lenturan berulang di bawah sistem beban empat titik hingga gagal. Kelakuan beban-ubah bentuk rasuk diselidik dan dipantau semasa ujikaji. Keputusan daripada kajian rawatan alkali pada gentian kenaf mendapati bahawa keadaan yang terbaik adalah 5% NaOH dalam tiga jam masa rendaman. Hasil kajian mendapati panjang optimum gentian kenaf ialah 20 mm dan kadar isipadu optimum ialah 1%. Daripada ujian rasuk KFRC, didapati bahawa rasuk KFRC menunjukkan prestasi yang lebih baik berbanding dengan rasuk konkrit normal. Kelakuan statik dan dinamik terbaik bagi rasuk ialah keratan konkrit KFRC dalam zon tegangan dan konkrit biasa dalam zon mampatan, dengan beban lenturan muktamad ialah 5.9% lebih tinggi berbanding rasuk konkrit normal selepas ujian lenturan dan 15.6% lebih tinggi berbanding rasuk konkrit normal selepas ujian beban berulang. Bilangan pembentukan retak di zon tegangan meningkat sebanyak 40% dan jarak retak adalah kurang sebanyak 15% berbanding dengan rasuk konkrit normal. Jumlah penyerapan tenaga dari kelakuan beban-pesongan rasuk KFRC sehingga kegagalan muktamad ialah 77% lebih tinggi berbanding rasuk konkrit normal. Hubungan antara prestasi bahan dan struktur KFRC terhadap panjang dan nisbah isipadu gentian telah diterbitkan berasaskan model berangka tak-linear dan dicadangkan untuk kegunaan analisis dan rekabentuk KFRC. Rumusannya, bahan dan struktur KFRC mempunyai kekuatan yang lebih tinggi dari segi tegangan, lenturan dan hentaman di bawah beban statik dan dinamik berbanding dengan konkrit normal.

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LIST OF ABBREVIATIONS

EFB	–	Empty Fruit Bunch
MARDI	–	Malaysian Agricultural Research and Development Institute
LTN	–	Tobacco Board of Malaysia
BS	–	British Standard
ASTM	–	American Society for Testing and Materials
DRY	–	Dry Sample
GGBS	–	Ground Granulated Blast Furnace Slag
PFA	–	Pulverized Fuel Ash
KFRC	–	Kenaf Fibre Reinforced Concrete
FRP	–	Fibre Reinforced polymer
NaOH	–	Sodium Hydroxide
PVA	–	Polyvinyl Alcohol
NFRC	–	Natural Fibre Reinforced Concrete
RC	–	Reinforced Concrete
ACI	–	American Concrete Institute
UNF	–	Unprocessed Natural Fibre
PNF	–	Processed Natural Fibre
PNFRC	–	Processed Natural Fibre Reinforced Concrete

LIST OF SYMBOLS

b	-	Beam Width
h	-	Beam Height
A	-	Section Area
L	-	Length of Beam
d	-	Height to Tension Steel Bar
d’	-	Height to Compression Steel Bar
fc	-	Concrete Cylinder Compressive Strength
fy	-	Yield Strength of Steel Flexural Reinforcement
f(cube)	-	Concrete Cube Compressive Strength
Fc	-	Concrete Force
Fs	-	Compression Steel Force
Fsd	-	Tension Steel Force
Cc	-	Concrete Compression Force
Cs	-	Steel Compression Force
T	-	Steel Tension Force
X	-	Natural Axis
Es	-	Steel Modulus of Elasticity
Ec	-	Concrete Modulus of Elasticity
E(KFRC)	-	Kenaf Reinforced Concrete Modulus of Elasticity
C	-	Compression Depth
Z	-	Tension Depth
av	-	Distance between Load and Beam Edge
M	-	Moment
Mr	-	Moment Resistance
Mu	-	Measured Ultimate Moment of Tested Beam
y	-	Location Measured From the Neutral Axis ($0 < y < c$)
g	-	Acceleration of Gravity
As	-	Compression Steel Area
As'	-	Tension Steel Area

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Natural fibres' first application dates back to 3000 years ago in Egypt. They were used in composite systems by mixing straw and clay in order to build walls. Natural fibres have increasingly been used for industrial applications such as sport equipment, automotive application and construction material for structural and non-structural elements [1–4]. Natural fibres were utilized as a part of early human development in fabric applications. A well-known natural fibre in Malaysia is kenaf fibre which has been used in bio composite in the local construction industry. Kenaf fibres have got specific features such as stiffness, impact resistance, flexibility, and modules. They are easily accessible [5–9], and are also renewable. Furthermore, kenaf fibre has other special features such as low cost, low density, less skin and respiratory irritation, less equipment abrasion, increased energy absorption, and vibration damping [5–8, 10, 11] which have caused them to be considered as an appropriate substitute for traditional materials such as rope, mats, straw. Kenaf fibres are considered hydrophilic materials [12–14]. Hydrophilic materials are known for absorption of water or moisture. Because of such property, fibre-matrix interface adhesion is improved due to interaction between cellulosic and water. In fact, the age and species of the plant can change cellulose quantity. Cellulose is a semi crystalline polysaccharide hydrophilic component composing of a linear chain of anhydroglucose units, which encompass alcoholic hydroxyl groups. Summarily, kenaf fibre is a kind of green material.

Conventional concretes are mainly composed of cement, water and aggregates. When used in large quantity, the environmental issue arising which contributes to global warming cannot be disregarded. Until recent decade, there has been an expanding interest on fibre reinforced concrete. The potentiality of natural fibres replacing synthetic fibres in composites is conceivable [15]. It is generally believed that some measures should be taken to sustain the world. Since concrete is considered as a brittle material, its enrichment with distributed short fibres is believed to increase the toughness of matrice and transferring the load between the concrete components from kenaf fibre. This is achieved by prohibiting the concrete from propagating of crack. However, reinforcing concrete with kenaf fibre improves is tensile properties and makes it resistant to dynamic and earthquake loading. The composite material has been slowly accepted locally as an alternative construction material due to its ability to sustain structural loads comparable to the existing conventional materials such as synthetic and steel fibres.

1.2 Background of the Study

Nowadays synthetic fibre reinforced concrete (FRC) such as glass, carbon, and aramid are commonly used for strengthening of RC structures due to their mechanical properties such as high modulus of elasticity, relative low extension coefficient, and corrosive resistance. However, these materials are expensive in terms of costs and material production [9]. Besides, they are also not biodegradable materials. In recent years, awareness regarding the cost and environmental impact of synthetic materials throughout their manufacture, use and end-life has increased. Furthermore, environmental problems arise when synthetic materials are used in large quantities, which are difficult to overcome. Landfill method is not considered economical, and the open burning results in air pollution, which can lead to global warming. Unlike the synthetic fibres, natural fibres are cheaper, lighter, more environmental friendly and also are available in large quantities [16]. In general, natural fibres offer high specific properties such as having low cost bing nonabrasive, renewable and environmental friendly [4]. The environmental issues examined are climate change, fossil fuel depletion, ozone depletion, eco-toxicity, waste disposal, water extraction, acid deposition, eutrophication (over enrichment of water sources), summer smog (low level ozone creation) and minerals extraction. This issue caused the increase in carbon dioxide, CO_2 gaseous which creates harmful environment and human health problems [17]. These advantages of natural fibres outweigh those of synthetic fibres. There is a universal movement toward the realization of a “Green World” and the need is great for participation in preserving the environment and making the world more affordable and safer to live in.

Recently, many researchers show interest in natural fibre reinforced concrete, and the potentiality of natural fibres in replacing synthetic fibres in composites is increasingly addressed. Natural fibres are combined with concrete matrix to form a bio composite. Natural fibres are agro-based and appear in different types based on source including leaf (pineapple fibre, sisal and henequen), bast (kenaf, jute, flax, hemp and ramie), fruit (empty fruit bunch), cotton, rice husks and rice straw [18]. The vegetable fibres contain cellulose, hemicellulose, lignin and pectin. Due to this, all natural fibres have high affinity for water and moisture which is referred to as hydrophilicity [12–14]. Kenaf fibres are also classified as cellulose fibre. In Malaysia, the National Kenaf Research and Development Program has been developed to incorporate kenaf for new industrial products. The Malaysian government has spent around RM12 million for conducting research on Kenaf-based industry in line with 9th Malaysia plan (2006–2010). In the bid to expand kenaf production, Malaysian Agricultural Research and Development Institute (MARDI) initiated research on kenaf plantation according Kenaf and Tobacco Board of Malaysia (LKTN) has developed kenaf fields and production in Kelantan and Terengganu.

Many studies have shown that the dynamic resistance can be increased substantially with the addition of randomly distributed fibres in concrete. Fibre reinforced concrete mixes were found to be more sensitive compared to respective un-reinforced matrices. Kenaf fibre with characteristics such as renewable, biodegradable, high energy absorption, resistance to dynamic loading and corrosion is the best type of natural fibre for improving properties of concrete. On the other hand, natural fibre reinforced concrete has good resistance to vibration dynamic effect. Addressing the above issues, this study is carried out to investigate features of kenaf fibre reinforced concrete (KFRC). This study is aimed at examining the potential of kenaf fibres as a fibre from natural source and the capacity of kenaf fibre reinforced concrete in structural application [19].

1.3 Statement of the Problem

In response to solving the brittle behaviour of conventional material, fibre reinforced concrete had been emerged and such materials as steel fibres and synthetics fibres are used as structural elements in concrete structures. Although, in spite of having a good resistance of tensile force, they are easily corroded when exposed for a long period of time. Past research has been done to find another alternative for replacement of steel materials because of the expensive costs and high maintenances. In case of, synthetics fibres it is found that they exhibit high cost of production [17], and not environmentally friendly [16]. Besides, they affect on humans' health such as skin and respiration problem [10]. Thus, synthetic fibres give negative impact since they are usually disposed by landfill or open burning methods. Landfill method is not economical because of the limited space for disposal nowadays whilst open burning results in air pollution and global warming.

Therefore, the natural fibre reinforced concrete composites is introduced as the sustainable material for structural elements to overcome the problems faced by using synthetics based fibres [20]. On the other hand, natural fibres do not have any negative impact to environment. In addition, researchers are seeking for green materials for composites, named as bio composites. Kenaf fibre known to be natural fibre are used as reinforcing fibre in concrete. This makes kenaf fibre an appropriate replacement to steel and synthetic material in conventional concrete.

One of the disadvantage of kenaf fibre is the hydrophilic surface which is not compatible with concrete, resulting in significant interfacial stress between matrix and fibre. This negative property of natural kenaf fibre can be resolved by chemical surface treatment method to enhance the properties of kenaf fibre and fibre matrix interface. Alkali treatment has shown to resulte in the removal of cementing materials, hemicelluloses and lignin, from the inter fibrillary regions and impurities such as oils and wax from the fibre surface leading to roughness of fibre surface, which improves the composite interface bonding via interlock between fibre and cement paste.

Reconstructing or rebuilding the reinforced concrete beam is not acceptable when it's cracked and is in an unstable position. This is due to the associated time and cost which is not economical in construction. . Thus, the inclusion of fibre in concrete is proposed in this study as an appropriate technique to resisting dynamic and static loading on concrete [21].

KFRC are recyclable materials that are designed to decompose rapidly. Therefore, KFRC offers environmental benefits, light weight concrete composite, good mechanical properties, resistance to corrosion, and good dynamic vibration behaviour. Kenaf fibre reinforced concrete is green material which has drawn the attention of the world to its potential. All the mention advantages calls for conducting research at this material to replace for the currently used fibre.

1.4 Objective of the Study

The aim objective of this study is to investigate the potential of kenaf fibre as reinforcement in concrete. The specific objectives of this study are as follows:

a) To examine the kenaf fibre characteristics for fibre reinforced concrete materials.

b) To investigate the compressive, tensile, bending, and impact properties of kenaf fibre reinforced concrete.

c) To determine the load - deformation behaviour of kenaf fibre reinforced concrete beams under short term flexural loads and repeated loadings.

d) To evaluate the analytical model of kenaf fibre reinforced concrete materials and structures under dynamic loadings.

1.5 Scope of the Study

This study involves three main phases, namely material properties, application of reinforced concrete beams behaviour and analytical process.

Material properties: The physical and mechanical properties of kenaf fibre which is supplied by the national kenaf and tobacco board (Malaysia) as long fibre are determined due to four different setting of chemical surface modifications by NaOH solution. According to ASTM C1557-03 (approved 2008) [22]. A number of 35 specimens are used to determine the average tensile properties of kenaf fibre. Also the water absorption test is conducted in order to determine the optimum water absorption of kenaf fibre. This optimum water content is essential to determine the additional water in mix design.

Application of reinforced concrete beams behaviour: This part is conducted experimentally to investigate the performance of kenaf fibre reinforced concreteto find the optimum value of length and effect volume fraction. In this study there are four different moulds of concrete cubes, prisms, cylindrical, and cylindrical with notch. The samples with different fibre length (10mm, 15mm, 20mm, 25mm, and 30mm) at 1% volume fraction of fibre are employed to investigate the optimum length of fibre. Following this test the archived optimum length is applied for different fibre volume fraction (0.5%, 1%, 1.5%, and 2%) to examine the effective percentage of kenaf fibre. Total number of composite series and specimens are 10 and at least 500 respectively. Slump, vebe time, compaction factor, density, ultrasonic pulse velocity, compressive, flexural, tensile, quasi-static splitting tensile, elastic modulus and poison ratio, dynamic tensile drop weight and flexural drop weight tests is the second phase test. In this phase different configurations and test methods to find the optimum values for Kenaf Fibre Reinforced Concrete (KFRC) material is applied. Hence, the behaviour of structural sample of KFRC beams including concrete beams without fibre contents and the once with optimum volume fraction and optimum fibre length are produced. The flexural and repeated load testing are carried out according to ASTM standards by using Universal Testing Machine. Total number of 18 beams are produced and tested. The aim of this test is to determine the flexural properties and dynamic behaviour of kenaf fibre reinforced concrete beam. Also the load, mid-span and load position deflection, tensile steel strain at the mid span and crack wide are reported as result of test for further discussion and analysis.

Analytical process: Finally, the last phase present different analytical pathways. The test results are analysed and used to propose the best guide line and procedures for KFRC material to be used in the construction industry.

1.6 Significant of Study

The significant findings of this research can help researchers:

1. To introduce the use of green materials for engineering applications is the main goal of this study. This can help to save the nature and to reduce the emission of carbon dioxide.
2. According to the environmental concerns of the man-made materials such as steel bar and synthetic fibre for reinforced concrete composites, natural material like kenaf fibres becomes the best replacing material for using reinforced fibre in concrete composite field because of their sustainability, lightness and other advantages.
3. Increasing the knowledge of RC properties by using of kenaf fibre, can encourage others to follow this kind of research to gain a sustainable material.
4. Furthermore, this study can define new application of natural fibre and also will benefit engineers and industries to use of renewable materials. This study

establishes design and construction procedure of kenaf fibre reinforced concrete to assist designer, engineer and architect.

5. Moreover, it may succour the agronomic activities and improve economic sector in Malaysia due to the demands of kenaf fibre production.
6. To investigate the mechanical and dynamic properties of kenaf fibre composite.
7. To evaluate the mechanical and dynamic properties of kenaf fibre reinforced concrete beam in structural properties.

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