CREEP AND SHRINKAGE PERFORMANCE OF KENAF BIO FIBROUS CONCRETE COMPOSITES

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DEDICATION

This thesis is dedicated to my beloved wife Eunice Seyi and children Ezekiel Oreoluwa, Emmanuel Ireoluwa and Elisha Ooreoluwa for their endless love, support, sacrifice, and encouragement.

"Thank you for all the patience and endurance during this PhD voyage."

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ABSTRACT

Fibrous Concrete Composite (FCC) is a high performance concrete that possesses an improved tensile strength and ductility with restraint to shrinkage and creep under sustained load compared to Plain Concrete (PC). As a result of global quest for sustainable, renewable and green materials to achieve a bio based economy and low carbon foot print environment, the use of fibre to produce fibrous concrete composite has continuously received significant research attention. While several researches have been conducted on metallic and synthetic fibrous concretes, they exhibit several unavoidable drawbacks and bio fibrous concrete has been proved to be a better alternative. This research investigates the creep and shrinkage performance of concrete reinforced with Kenaf bio fibre. After material characterization, concrete reinforced with fibre optimum volume fraction of 0.5% and length of 50 mm was used for the study. The fresh and hardened properties of the concrete were studied under short term quasi static loading. Thereafter, the compressive creep test, uniaxial tensile creep test and flexural creep test at 25% and 35% stress levels at creep loading ages of 7 and 28-day hydration period were conducted. The long term deformation behaviour of the Kenaf Bio Fibrous Concrete Composite (KBFCC) was observed and monitored. Results show that the compressive creep strains of KBFCC is 60.88% greater than the PC, but the deformation behaviour of the specimens shows 33.78% improvement in ductility. Also, uniaxial tensile creep response of fibrous concrete deforms at the rate of 0.00283 mm/day and 0.00702 mm/day at 25% and 35% stress level respectively, but the deformation rate becomes insignificant after 90 days due to the presence of fibre. In addition, the flexural creep test reveals that 0.064 mm/day and 0.073 mm/day deformation rate at 25% stress level of the KBFCC becomes less significant after 40 days of loading. The outcome of the morphology image analysis on the concrete composite shows that Kenaf fibres act as bridges across the cracks, which enhances the load-transfer capacity of the matrix, thus influencing the long term performance of KBFCC. Accordingly, statistical analysis shows that the CEB-FIP creep model is the best fit model for predicting compressive and tensile creep of KBFCC, while EC2 creep and shrinkage models are for predicting flexural creep and shrinkage strain of KBFCC, respectively. A creep and shrinkage prediction model is proposed based on the experimental data for better prediction of KBFCC. Conclusively, KBFCC exhibits appreciable shrinkage, tensile and flexural strength under static short term and long term sustained loads compared to PC.

ABSTRAK

Komposit konkrit bergentian (FCC) merupakan konkrit yang berkualiti tinggi yang mempunyai kekuatan tegangan dan kekangan kemuluran yang diperbaharui kepada pengecutan dan rayapan di bawah beban sekata berbanding dengan konkrit biasa (PC). Hasil daripada usaha global untuk bahan lestari, diperbaharui dan hijau bagi mencapai ekonomi berasaskan bio dan alam sekitar berkarbon rendah, maka penggunaan gentian bagi menghasilkan komposit konkrit bergentian terus mendapat perhatian yang ketara dalam bidang penyelidikan. Walaupun beberapa kajian telah dijalankan terhadap konkrit berserat metalik dan sintetik, kajian itu menunjukkan beberapa kekurangan yang tidak dapat dielakkan dan konkrit bergentian bio telah terbukti sebagai pilihan alternatif yang lebih baik. Kajian ini mengkaji prestasi rayapan dan pengecutan konkrit bertetulang dengan gentian bio Kenaf. Setelah pencirian bahan, konkrit bertetulang dengan gentian pecahan isipadu optimum sebanyak 0.5% dan panjang 50 mm digunakan untuk kajian ini. Ciri-ciri konkrit yang baharu dan keras telah dikaji di bawah beban statik kuasi jangka pendek. Seterusnya, ujian rayapan mampatan, ujian rayapan tegangan tidak berpaksi dan ujian rayapan lenturan pada 25% dan 35% tahap tekanan pada umur pengambilan rayapan 7 dan 28 hari tempoh penghidratan telah dijalankan. Tingkah laku Komposit Konkrit Bergentian Kenaf Bio (KBFCC) kepada perubahan bentuk dalam tempoh jangka panjang telah dikenal pasti dan dipantau. Keputusan ujian telah menunjukkan bahawa perubahan rayapan mampatan KBFCC adalah 60.88% lebih besar daripada konkrit biasa, tetapi perubahan bentuk tingkah laku terhadap spesimen menunjukkan 33.78% peningkatan dalam kemuluran. Selain itu, tindak balas serapan tegangan tidak berpaksi terhadap konkrit bergentian masing-masing berubah bentuk pada kadar 0.00283 mm/hari dan 0.00702 mm/hari pada tahap tekanan 25% dan 35%, tetapi kadar perubahan bentuk menjadi tidak berubah selepas 90 hari dengan kehadiran gentian. Di samping itu, ujian rintangan lenturan menunjukkan kadar perubahan bentuk pada 0.064 mm/hari dan 0.073 mm/hari dengan tahap tekanan 25% daripada KBFCC menjadi tidak ketara selepas 40 hari pembebanan. Hasil analisis imej morfologi pada komposit konkrit menunjukkan bahawa gentian Kenaf bertindak sebagai agen pengikat yang merentasi retak, yang meningkatkan kapasiti pemindahan beban matriks, justeru mempengaruhi prestasi KBFCC dalam jangka masa yang panjang. Dengan demikian, analisis statistik menunjukkan bahawa model rayapan CEB-FIP merupakan model terbaik untuk menganggarkan mampatan dan rayapan tegangan KBFCC, manakala masing-masing model rayapan dan pengecutan EC2 pula menganggarkan lenturan rayapan dan tegangan pengecutan KBFCC. Model anggaran rayapan dan pengecutan dicadangkan berdasarkan data eksperimen untuk ramalan KBFCC yang lebih baik. Secara kesimpulannya, KBFCC mempamerkan pengecutan, kekuatan tegangan dan lenturan yang ketara di bawah beban jangka pendek dan jangka panjang yang dapat menahan beban statik berbanding PC.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
ACI	-	American Concrete Institute
ARS	-	Average Residual Strength
AS	-	Australian Standard
BFCC	-	Bio Fibrous Concrete Composite
BS	-	British Standard
CEB-FIP	-	Fédération internationale du béton – International Federation for Structural Concrete
CPF	-	Compacting Factor
CPS	-	Compressive Strength
CMOD	-	Crack Mouth Opening Displacement
EC 2	-	Eurocode 2
FCC	-	Fibrous Concrete Composite
FS	-	Flexural Strength
ISA	-	Initial surface absorption
KBFCC	-	Kenaf Bio Fibrous Concrete Composite
KF	-	Kenaf Fibre
KFRC	-	Kenaf Fibre Reinforced Concrete
L-d	-	Load-deflection
MOE	-	Modulus of Elasticity
NaOH	-	Sodium Hydroxide
PC	-	Plain Concrete
RH	-	Relative Humidity
SLC	-	Slump of Concrete
SSD	-	Saturated Surface Dry
STS	-	Indirect Splitting Tensile Strength
UPV	-	Ultrasonic Pulse Velocity

VBT	-	Vebe Time
DOF	-	Degree of freedom

LIST OF SYMBOLS

k_1, k_2, k_3 =	-	Coefficients
$\varepsilon_E\ (t)$	-	Elastic strain at time t (micron)
$\varepsilon_{cr}\ (t)$	-	Creep strain at time t (micron)
$\varepsilon_s\ (t)$	-	Shrinkage strain at time t (micron)
Φ	-	Creep Coefficient
ε_{cr}	-	Creep Strain
f_{cm}	-	Mean concrete strength
t	-	Time
t_o	-	Initial time at the beginning of loading or drying
σ	-	Stress
E	-	Elastic modulus
ρ	-	Density of concrete
$f'c$	-	Characteristic cylinder strength
COV_m	-	Coefficient of variation for model prediction
K_o	-	Constant related to the elastic modulus of the aggregate
Φ_t	-	Tensile creep coefficient
M_∞	-	Water absorption at the saturation point
Mt	-	Water absorption at time *t*
n	-	Mechanism of sorption
E_t	-	Elastic modulus at age t
Φ_f	-	Flexural creep coefficient
$J_{(t,to)}$	-	Creep function

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CHAPTER 1

INTRODUCTION

1.1 General Appraisal

The usefulness of concrete in various building and civil engineering applications is incontestable. Over the years, it has so far been positively used in hydraulic structures, shotcrete, offshore structures, slabs on grade, structures in seismic regions, thin and thick repairs, architectural panels, crash barriers, precast products, footings, global transportation infrastructure systems such as network of roads, bridges, railways, airports, canals and many other applications . The reason for its widespread acceptability for use in various infrastructure productions is not far-fetched from the benefit of providing the lowest quotient among cost and strength as equated to other available materials [1–3]. Despite these applaudable qualities of concrete, two unattractive properties: low ductility and breakability possessed by concrete still makes it prone to collapse which occurs just after the creation of deformation and initial crack [1]. This adversely limits the performance of concrete over long-term when exposed to sustained loads like creep and shrinkage [4]. Hence, concrete has a poor resistance to cracking. Steel reinforcement came up as a response to cracking in concrete due to stronger tensile strength it possesses over concrete. In their study, Clarke *et al.*, [5] explained that reinforcement steel bar is saddled to carry the tensile stresses imposed on the concrete and curtail possible cracking of the concrete or cause the concrete to remain largely in compression under load by pre-stressing it.

Steel reinforcement has been successfully used in concrete over the years and it is still in use. Conversely, cracking still occurs under load and this creates a pathway for various deleterious species such as chlorides, sulphates, moisture and carbon dioxide [6]. This leads to the corrosion of the reinforcement thus affecting the durability of the concrete structures. Other substitutes apart from steel reinforcement are as well obtainable for the reinforcing of concrete to control cracking. One of such substitutes presently used is fibres [6]. The inclusion of short discontinuous randomly oriented fibres (natural, glass, steel, and synthetic) has remained a practice among others towards contributing to the improvement of the two negative properties of concrete mentioned earlier [7–12]. It has been reported by ACI [13], Mehta and Monteiro [14] that fibre inclusion offers a bridging capability once the initial crack take place afore the full parting of a beam. Also the studies of [7,15] supported this assertion of ability of fibre to provide concrete with post crack strength. The improvement of the mechanical and durability properties of concrete such as; crack opening, stiffness, crack promulgation, tensile strength and deformation characteristics such as creep and shrinkage of concrete amid others. These have given fibrous concrete favourable acceptance in becoming a widely used composite material in construction projects. Structural elements deform all the way through their lifespan (creep and shrinkage), which may possibly lead to serviceability concerns such a deflection, cracking, etc. Whereas fibrous concrete has presented substantial ductility and energy absorption aptitude in the short term, the sustainability of such properties in the long term is still undefined. These sustained loads could be as a result of mechanical stress known as creep or environmental stress from temperature and relative humidity causing the shrinkage of concrete elements. Creep is defined as the plastic deformation under sustain load. Creep strain depends primarily on the duration of sustained loading. It has been widely acknowledged that creep of concrete is greatly influenced by the surrounding ambient, admixtures and load intensity. Also creep has been seen to induce the deflection of structural member with time. Hence the study on creep of concrete is necessary to prevent failure of structure [16]. While shrinkage of concrete is described as time-dependent volume change that occurs due to a number of mechanisms. Shrinkage has been reported to occur due to the movement of water in both fresh and hardened states [17]. The creep and shrinkage of concrete element are categorised as time-dependent deformation properties of concrete.

There exist several types of fibres that is incorporated in concrete, but the most commonly used are the natural (vegetable), steel, glass, asbestos, carbon and polypropylene type of fibres [1,8,12,18,19]. These resource fibres have gains in the matrix proportioning of cement composites. Bio fibres are believed to be more environmentally pleasant to the users; this is why they are currently getting appreciable consideration for substituting the glass, synthetic and steel fibres [12,20]. Researchers [21–23] in the past years have investigated and compared the benefit and properties of natural, steel and synthetic fibre. They succinctly described natural fibres to possess many benefits than the synthetic and other type of fibres. Such advantages are low density, carbon dioxide requisitioning, low cost, recyclability, issue of sustainability, biodegradability, and competitive specific mechanical properties [24–26]. However, if the compressive and tensile strength of bio fibre concrete is to some degree lesser than the control concrete mix, its deformation behaviour displays more enhancement in ductility [11,18,22,23]. Some studies have been carried out on the properties of concrete with the bio fibres which is usually referred to as fibrous concrete from sugar cane, coconut coir, malva, hemp, ramie bast, jute, pineapple leaf, elephant grass, bamboo, akwata and sisal with encouraging results recorded [12,27–30].

1.2 Background of the Problem

In view of the current global challenges, the construction industry has been focusing on the concept of sustainability, particularly the inclusion of biodegradable fibre in concrete [31,32]. Bio fibres as being adjudged as a means of mitigating the effect of carbon footprint to the environment. This has evoked a lot of response from industries who are seeking more eco-efficient production and sustainable commerce. Bio fibres are a major renewable (CO_2 neutral) resource for bio-based economical developments. Serviceability and durability performance has been given more emphasis in the design and analysis of concrete structures. The ultimate limit state requirement is no longer the only main focus in structural design as durability and service performance are as well important for the safety, aesthetics and economic values of the structure or concrete composite. Creep and shrinkage are a usually a critical property used for evaluating buckling, stresses, cracking, deflection and failure of brittle materials such as concrete for structures under constant loads. Nevertheless, owing to the fact that the effects for under-prediction of creep and shrinkage are time-dependent, attention and provisions on these factors are often been ignored [33]. Creep and shrinkage prediction models meant for concrete structure design references are obtainable in AS 3600, CEB-FIP Model Code 1990, B3 Model, ACI-209, Eurocode 2, and BS 8110 Model concrete standard codes. These models are however mostly developed for plain concrete (PC). Therefore, there is need to examine their suitability in the prediction of bio fibrous concrete, and also to development an analytical creep and shrinkage model for the design of bio fibrous concrete such as KBFCC.

The deformation experienced in concrete structure due to tensile low strength and energy absorption low capacity problems can be controlled by replacing it with fibrous concrete. This is a sustainable substitute concrete type where long-term performance and durability are the key considerations. Remarkably, the commonly used fibre types in the production of fibrous concrete such as steel, asbestos, synthetic and glass are usually associated with high cost, corrosion, non-renewable, high specific weight and being harmful to the environment. These factors are not good for our world and the construction industry which is striving towards achieving sustainable environment. Therefore, bio fibre such as Kenaf fibre which is cheaper, environmentally friendly, could be a sustainable choice for the construction industry. To use this fibre in concrete, a detail research on its long-term performance under mechanical load (creep) or environmental load (shrinkage) is required. Recent studies revealed the immense potential and interest generated due to the application of Kenaf fibre in the construction industry, automobile industry, wood-based sector and textile industry. Consequently, the Malaysian government and some other developing nations have pursued vigorously the cultivation and various measures to promote downstream value processing of Kenaf among smallholders and estate owners [34]. Appreciable experimental and theoretical researches have been carried out to understand the mechanical properties of KBFCC [11,23,35]. Most of these studies are limited to the short-term performance of KBFCC under static mechanical loads and environmental loads [11,23,35,36]. Conclusively, it has been observed that the study on concrete composite system made from bio fibrous concrete has been of interest due to its need for the evaluation of stresses, deflection, cracking, bulking and failure of structures made from KBFCC. This will avail material engineers and structural designer’s knowledge and data on the material properties and structural behaviour pertaining to serviceability performance.

1.3 Statement of the Problem

The world's population and wealth increase in this century have heightened the rising needs for sustainable materials. These needs have become imperative due to the fact that landfills are filling up, earth climate is changing, and natural resources are diminishing. This has promulgated the recent researchers to finding alternative materials for the replacement of the use of synthetic fibre, steel fibre, and steel bar in concrete because of their unfriendliness to the environment, their ignition of environmental issues, poor recyclability, non-biodegradability, expensive costs and high maintenances and repair cost of damaged structure via corrosion of steel.

These general environmental issues are climate change, ozone depletion, eco-toxicity, fossil fuel depletion, water extraction, waste disposal, eutrophication (over-enrichment of water sources), acid deposition, summer smog (low-level ozone creation) and minerals extraction. These problems initiated the increase in carbon dioxide, CO_2 gas which generates unsafe environment and human health problems. Additionally, the emission produced during the petroleum product production (synthetic fibre) could bring about global warming and cause an increase in greenhouse effect. Bio fibres tend to be more sustainable compared to synthetic fibres. Carbon, Polypropylene and aramid based synthetic fibres have been introduced and applied in areas of construction such as buildings, bridges and pipelines. Glass fibres are produced from silica which is derived from sea sand. Continuous exploitation of sea sand for the production of glass fibres has led to other whole new complications. Sea sand will run out if its use continuously and the production of glass fibre also requires high budgets. Several fibrous concrete that is popularly used is from synthetic (Carbon, Polypropylene), steel and glass sources. Further research has to be done to advance the suitability of bio fibres as reinforcement to replace usage of synthetic (Carbon, Polypropylene), steel and glass fibre to produce more economical, light weight, degradable, environmentally friendly, bio-based economy and structural concrete composites.

Fibrous concrete composites are produced to restrain the propagation of a crack in the concrete and to improve its tensile strength and ductility/deformation properties. Bio fibrous concrete composites (BFCC) is an environmentally sustainable material. Its potential advantages which varied from using bio fibres to decreasing synthetic and steel fibres which are from petroleum and steel source, respectively. Due to the hydrophilic properties of bio fibre, this makes them unsuitable for use in concrete reinforcement and strengthening. An elaborate study to reduce the hydrophilic effect is necessary in order to utilize the positive properties accrued to Kenaf fibres in fibrous concrete production. The alkaline treatment of Kenaf fibre has been reported in the literature to inhibit the possibility of its decay over time. Despite the elaborate research on the short-term deformation behaviour of BFCC, publications directly related to long-term deformation behaviour of BFCC compressive, uniaxial tensile, flexural creep and shrinkage are uncommon. Though the usage of Kenaf fibre in concrete is however of current interest with gradual growing reports on its short-term mechanical demeanour in scholarly articles; there still exists a dearth of knowledge on the physical and mechanical performance of KBFCC. Also, for acceptability and immense application of KBFCC in engineering practice, the concrete science and industry must be provided with proof of systematic scientific study that shows and that analyse the features of BFCC on short and long-term structural performance. High on the list of main structural performance properties is creep and shrinkage of the concrete composites.

Long-term performance of KBFCC under sustained static loads (creep) and shrinkage, as well as analytical models for estimation of creep and shrinkage properties, is yet to be studied. Furthermore, studies on the cement matrix bonding interface of KBFCC is rare to find in the literature. To have a better understanding of the relationship and behaviour of KBFCC under sustained loads, a proper investigation has to be conducted. This calls for an extensive study into the long-term performance of KBFCC under sustained loads as a result of mechanical stress and environmental load commonly referred to as creep and shrinkage, respectively. Similarly, there is need to understand the cement matrix bonding interface of the KBFCC by carrying out the morphological examination of the concrete exposed to the short and long-term loading.

1.4 Aim and Objectives

The aim of this research is to investigate the creep and shrinkage performance of KBFCC. In order to achieve the above aim, the following specific objectives were formulated.

i. To examine the physical and mechanical properties of concrete containing kenaf fibre at varying fibre lengths and volume fractions.
ii. To examine the effect of Kenaf fibre on the shrinkage and creep properties of KBFCC in compression, tension and flexure.
iii. To assess the effect of mechanical loading on the microstructure characteristics of KBFCC.
iv. To evaluate the prediction model of compressive, tensile, flexural creep and shrinkage of KBFCC and propose a model for estimation of creep and shrinkage behaviour of KBFCC.

1.5 Scope of the Study

This research work is experimental and focused on assessing the long-term performance of KBFCC under shrinkage and compressive, tensile, flexural sustained loads which is within the limit of the set objectives. The scope of the study was divided into four stages:

i. Kenaf fibre characterisations, material properties testing, short-term mechanical and time-dependent properties testing of KBFCC were carried out. The optimum fibre length and volume fraction was determined from the physical and mechanical properties of KBFC tested. The optimum KBFCC mix of 0.5% fibre volume fraction and 50 mm fibre length was used in the production of specimen used for the shrinkage and creep testing. Also, the design and construction of uniaxial tensile and flexural creep specimen mould, rig, test set-up and procedures were defined.
ii. ASTM C512 [37] standard was used as a reference in carrying out the compressive creep test. The works of Babafemi [6] and Fladr [38] served as a reference to the experiment conducted on uni-axial tensile creep and flexural

creep, respectively. The shrinkage test was conducted in conformity with ASTM C157 [39].

iii. KBFCC specimen testing under long-term shrinkage, compressive creep, uniaxial tensile creep and flexural creep loading was conducted on standard size specimens. 100 mm diameter x 200 mm cylinder was used as a modification to the 150 mm diameter x 300 mm diameter given in ASTM C512 [37] for the compressive creep test. 75 mm x 75 mm x 600 mm prism and 100 mm x 100 mm x 500 mm prism were used for uni-axial tensile creep and flexural creep, respectively, as given in the work of Babafemi [6] and Fladr [38]. For the shrinkage test, the prism specimen dimension of 100 mm x 100 mm x 285 mm prism was used in accordance with ASTM C157 [39]. The tensile creep specimens were pre-cracked and the crack mouth opening displacement was determined as the creep deformation characteristic of the bio fibrous concrete. The focal variables considered are the effect of fibre inclusion in concrete (0% and 0.5% KF at 50 mm length), sustained stress loads (25% and 35%) and age at loading (7 and 28 days) on creep. For the shrinkage testing, the tested specimen where made of three different group of 25 mm, 50 mm and 75 mm Kenaf fibre length at 0%, 0.25%, 0.50%, 0.75%, 1.0%, 1.5% and 2.0% fibre volume fraction. The specimens were tested at drying age of (7 and 28 days). The creep and shrinkage tests were all carried out in the controlled room of 23±2^{o}C and RH of 50±4. The optimum fibre volume fraction and length was used in the prediction model analysis.

iv. The morphology of Kenaf fibre, KBFCC and their cement matrix interface of the tensile fractured surface under short term and long term mechanical load were investigated.

v. The experimental data was analysed and the relationships among different properties of KBFCC was determined. The creep and shrinkage (time-dependent deformation properties) prediction model codes evaluated in this study are from ACI-209, CEB-FIP 1990 Model Code, Eurocode 2 (EC 2), and Australian Standard 3600 (AS 3600). The best prediction model code for KBFCC was identified after evaluation.

1.6 Thesis Organization

The thesis was presented in seven chapters. Chapter 1 presents a general appraisal and a brief description of the background problem. In addition, the chapter also spelt out the aim and objectives, scope and limitation, research hypothesis, the significance of research and the research approach.

Chapter 2 is concerned with the critical review of the relevant and related literature.

Chapter 3 provides the materials and the chronological sequence of the methodology that is employed for successful completion of the research using appropriate standard and modification where necessary in conducting the tests.

Chapter 4 reveals the characterisation of the constituent materials, comprising the physical properties and chemical composition. The treatment of Kenaf fibre and its water sorptivity characteristics and mechanical test are discussed. This chapter also descried the effect of Kenaf fibre geometry (length) and volume fraction on fresh and hardened concrete properties. Parameters studied in this chapter include workability regarding the slump, compacting factor, Vebe of concrete, and fresh density. Also, the relationship between some data is developed to establish a correlation. It also presents the results obtained and discussion made on the evaluation of mechanical and durability properties. Tests falling in this class include; flexural, modulus of elasticity, compressive, water absorption (porosity), tensile strength, and shrinkage. The optimum content and length of the fibre meant to be used in the production of the creep and further shrinkage study was determined and presented.

Chapter 5 deals with the evaluation of the morphologies of the KBFCC. Also, the microstructure characteristics of the fibre matrix interface of KBFCC exposed to sustained loading was examined and discussed in this chapter. The scanning electron micrograph (SEM) results are presented and discussed in this chapter.

Chapter 6 focuses on the creep and shrinkage performance of KBFCC. The evaluation, statistical analysis, determination of best prediction model code for prediction of creep and shrinkage of KBFCC.

Chapter 7 presents the conclusion of this thesis by stating the outcomes and, successes of the study and the contribution of the research to the existing information. Recommendations are made for further research in related areas to improve the properties of concrete using Kenaf bio fibre for the production of a green and sustainable concrete.

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