STRUCTURAL BEHAVIOUR OF KENAF FIBER AS PART SHEAR REINFORCEMENT IN OIL PALM SHELL REINFORCED CONCRETE BEAMS

SAYED JAVID AZIMI

Thesis submitted in fulfilment of the requirements for the awards of the degree of Master of Civil Engineering (Concrete Structure)

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JULY 2015

ABSTRACT

This thesis presents the structural behaviour of kenaf fibre as a part of shear reinforcement in oil palm shell reinforced concrete (OPS-RC) beams. The main objective of this research was to improve the structural properties of OPS-RC beams by incorporation of kenaf fiber for improving the structural properties of oil palm shell reinforced concrete (OPS-RC) beams. This investigation was carried out by using two methods; experimental and consequently numerical modelling. Experimentally five beams by incorporation of kenaf fiber with two shear reinforcement arrangements and three different amount of kenaf fiber were considered in this study. The first beam were constructed with full shear reinforcement and without fibre (SI = 0 % and with V_f = 0 %) denoted as a control beam. Meanwhile, two beams with full shear reinforcement (SI = 0 %) and with fibre volume fraction of V_f = 1 % and V_f = 2 % and two more beams with reduction of shear reinforcement (SI = 100 %) with fibre volume fraction of V_f = 1 % and V_f = 2 % were constructed respectively. The beam specimens were tested under four-point flexural test. Consequently numerical modelling with finite element method (FEM) software, Abaqus for calibration and validation of experiment results was considered. First, sensitivity analysis (mesh and time) was conducted to acquire the best correlation with the experimental result. Then, the experiments results of two beams with SI = 0 % and with V_f = 0 % and V_f = 1 % were used for calibration in FEM modelling investigation. Once satisfactory results were obtained parametric studies on key parameters with three shear reinforcement arrangement (SI = 0 %, SI = 50 % and SI = 100 %) and together with six volume fraction (V_f = 0 %, V_f = 0.5 %, V_f = 1 %, V_f = 1.5%, V_f = 2 % and V_f = 2.5 %) of kenaf fiber were carried out. The results comparison showed that there is a good agreement between the experimental test and nonlinear finite element analysis NLFEA results. Generally this investigation demonstrated up to 37 % improvement on structure properties of OPS-RC beam by addition of kenaf fiber.

ABSTRAK

Tesis ini membentangkan sifat struktur rasuk OPS-KFRC. Objektif utama kajian ini adalah untuk mengkaji potensi gentian kenaf untuk meningkatkan sifat struktur rasuk konkrit bertetulang yang telah ditambah tempurung kelapa sawit (OPS-RC). Tambahan lagi, potensi gentian kenaf sebagai tetulang ricih dengan meningkatkan jarak rakap dalam rasuk dianggap dan disahkan untuk kesesuaian struktur bahan yang dicadangkan. Penyelidikan ini dijalankan melalui dua kaedah iaitu eksperimen dan pemodelan berangka. Kerja-kerja ujikaji memberi tumpuan kepada lima rasuk melalui penggabungan serat kenaf dengan dua susunan tetulang ricih dan tiga perbezaan jumlah gentian kenaf. Rasuk pertama dihasilkan dengan susunan tetulang ricih penuh dan tanpa gentian (SI = 0 % dan dengan V_f = 0%) dijadikan sebagai rasuk kawalan. Sementara itu dua rasuk dengan susunan jarak tetulang ricih penuh (SI = 0 %) dengan peratusan jumlah gentian kenaf V_f = 1 % dan V_f = 2 % dan dua rasuk lagi jarak tetulang ricih dikurangkan (SI = 100 %) dengan peratusan jumlah gentian kenaf V_f = 1 % dan V_f = 2 % dihasilkan. Kerja-kerja ujikaji telah dijalankan dengan menggunakan ujian empat titik lenturan pada rasuk disokong mudah. Oleh yang demikian pemodelan berangka dengan kaedah perisian FEM Abaqus penentukuran dan pengesahan keputusan eksperimen dipertimbangkan. Pertama, analisis kepekaan (jejaring dan masa) yang dijalankan sehingga memperoleh korelasi terbaik dengan keputusan ujikaji. Kemudian, keputusan ujikaji untuk dua rasuk yang menggunakan SI = 0 % dengan V_f = 0 % dan V_f = 1 % digunakan sebagai penentukuran dalam kajian model FEM. Sebaik sahaja keputusan yang memuaskan diperolehi kajian parametrik pada parameter utama dengan tiga susunan tetulang ricih (SI = 0 %, SI = 50 % dan SI = 100 %) dan bersama-sama dengan enam peratusan jumlah gentian kenaf (V_f = 0%, V_f = 0.5%, V_f = 1 %, V_f = 1.5 %, V_f = 2 % dan V_f = 2.5 %) dapat dijalankan. Hasil perbandingan menunjukkan bahawa terdapat perubahan yang baikdi antara ujian ujikaji dan keputusan analisis NLFEA. Secara amnya penyiasatan ini menunjukkan peningkatan yang ketara pada sifat struktur rasuk OPS-RC dengan penambahan serat kenaf.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Mε	Micro strain
D	Depth ratio
L_f	Length of fibres
D_m	Density of fibres
E_m	Modulus of elasticity fibres
ΔL	Elongation of fiber
WA	Water absorption of fibres
T	Tensile strength of fiber
f_t	The concrete tensile strength
f_{tu}	The post-cracking residual tensile stress
ε_{t0}	Cracking strain
ε_{tu}	Ultimate (post-cracking) strain
T1	The tensile zone
C	Compressive zone
L	The span length of the specimen
f_{fck}	Characteristic compressive strength
σ_{tu}	Ultimate tensile strength
τ_u	The average ultimate pull-out bond strength of fibres
E_{ct}	Tensile elastic modulus for FRC composite
V_f	Volume fraction of the fibres
L_f	Fibre length

σ_1	Compressive stress
ε_1	Compressive strain
f_{ct}	Concrete tensile strength
f_{cm}	Concrete mean cylinder strength
f_c	Compressive strength of concrete
ε_{tu}	Ultimate compressive strain
f_{ctm}	Peak tensile strength
P	Static point load
SI	Stirrup spacing increased
P_y	Yielding load
$P_{y,0}$	Yielding load of the control specimen
P_{max}	Maximum load carrying capacity
$P_{max,0}$	Maximum load carrying capacity of the control specimen
P_u	Ultimate load
δ_y	Deflection at yield
$\delta_{p,max}$	Deflection at maximum load
δ_u	Ultimate deflection
M	Ductility ratio
μ_0	Ductility ratio of the control specimen
E_a	Energy absorption
$E_{a,0}$	Energy absorption of the control specimen
P_y	The longitudinal reinforcement yield stress
SI	Increment in the shear reinforcement spacing
MPa	Mega Pascal

LIST OF ABBREVIATIONS

OPS-KFRC	oil palm shell kenaf fiber reinforced concrete
OPS-RC	oil pal shell reinforced concrete
OPSC	oil palm shell concrete
FEM	finite element method
OPS	oil palm shell
LWAC	lightweight aggregate concrete
OPS-LWC	oil palm shell lightweight aggregate concrete
KFRC	kenaf fibre reinforced concrete
NRC	normal reinforced concrete
LWC	lightweight concrete
LVDT	linear variable displacement transducers
SRF	shear retention factor
NLFEA	non-linear finite element analysis
ASTM	American Society for Testing and Materials
EC-2	Euro code two

CHAPTER 1

1.1 BACKGROUND

Lightweight concrete (LWC) as the name demonstrates, is essentially a concrete that is produced with a density lower than 2000 kg/m^3 (Arisoy, 2002). Structural lightweight concrete is an important and versatile material as it is used in a number of applications, namely multi-storey building frames, floors, and bridges. The very notion on the utilisation of LWC has increased over the years due to its many benefits. Almousawi (2011) for instance illustrated that if the production of LWC with adequate strength and ductility is achieved, the construction cost may significantly be reduced owing to its low weight of dead load of structure. Teo et al. (2006) suggests that one of the justifications of utilising LWC is to reduce the dead load of the concrete structure. Therefore, this will in turn decreases the impact of dynamic loads on the structure, reduces the dimension of all structure members apart from significantly reducing the amount of reinforcement. Moreover, Hassanpour et al. (2012) also suggests that LWC is considered as a high thermal insulation material as it provides better heat insulation as well as good fire resistance properties comparable to normal weight concrete (NWC). Oil Palm Shell (OPS) is a waste material from the agricultural sector that are available in a copious amount in tropical regions (Mannan and Ganapathy, 2004). Since 1984s OPS as a lightweight aggregate for producing lightweight aggregate concrete (LWAC) practiced in Malaysia. Teo et al. (2006) further opines that with the density of OPS ranging between 500 kg/m^3 and 600 kg/m^3 wich is about two times lighter than normal sand aggregates the production of concrete with a density of less than 1900 kg/m^3 is possible. The desired traits of OPS further encourages the replacement of ordinary sand aggregate with OPS for the production of structural LWAC.

Previously, different types of fibres have successfully been used in concrete structures such as steel fiber, synthetic fiber, glass fiber and natural fiber as reported by

Shao et al. (1995). From a structural standpoint, the primary reason for adding fiber is to improve structural properties of concrete through the fiber ability. Fiber bridging over the cracks leads to increase shear, moment, ductility, punching resistance, stiffness and reduce cracks widths. Short randomly distributed fibres acts as a multi-dimensional reinforcement and enhances the bond between the matrix that in turn increases the tensile strength and structural integrity of the concrete (Hassanpour et al., 2012). Shear resistance of concrete structure increase by transferring the tensile strength of fibre across shear crack and fibres prohibit the excess of diagonal tensile cracking. Additions of fibres within concrete structure caused to distribute the impact of dynamic load to entire structure reduce the concentration of the breaking force and minimize the human causalities in earthquake prone areas (EI-Hacha et al., 2004; Dawood and Ramli 2012). Furthermore, fibres act as crack arrestors and reduce the crack width which caused to increase the durability of concrete structure Furlan et al. (1997). Besides, numerous investigations indicated that by the incorporation of different types of fibres significantly increases the shear strength of concrete structures and transforms the failure mode from shear to bending (Brooks, 2006; and Furlan et al. 1997). Furthermore, fibres may also be used as a replacement of shear reinforcement in beams and other structural applications as remarked by Syed Mohsin (2012).

The utilisation of natural fibres as building materials in reinforced concrete by enhancing its ductility, flexural strength, toughness, cracking behaviour, and impact resistance was conceived by Lewis and Premalal, (1979). Owing to low density, high specific strength as well as economic nature of natural fibres, it has received wide attention by researchers in the applications of lightweight and high strength concrete (Deka et al., 2013). Moreover, reinforced steel is high-cost materials that comes from non-renewable resources but natural fibres, on the other hand, comes from renewable resources and are abundantly available. Jumaat et al. (2009) carried out a laboratory investigation on kenaf fibre reinforced concrete (KFRC) and found that it is a promising "green construction material" for various structural applications. Futhermore, Elsaid et al. (2011) further argues that the structural properties of KFRC are comparable to ordinary reinforced concrete (NRC).

1.2 PROBLEM STATEMENT

Lightweight aggregate concrete (LWAC) is an important economic and versatile material; nonetheless, it has low tensile strengths and a subsequently reduced shear resistance. As the LWAC has lower modulus of elasticity, the structure deflects more and has a lower rate of loading in cracking than typical concrete structure. Oil palm shell (OPS) is considered as a waste material, and Malaysia alone produces over 4 million ton of OPS annually. Due to the vast quantities production of these wastes, it has created a significant disposal problem. In general, the past research mentioned OPS as coarse aggregate have been found useful for making lightweight aggregate concrete (LWAC) and more than 20 % dead load of construction would be decreased by replacing sand aggregate with OPS. However, the brittleness effect of OPS-LWAC has yet to be fully mitigated in the concrete industry. At present, lightweight aggregate concrete has gain the construction industry interest due to the benefits offered by this lightweight concrete in terms of reduction in member size, longer spans, improved fire resistance, smaller foundations and better thermal properties. Conversely, their limited ability to absorb earthquake energy raises concerns due to brittle behaviour. Several investigations in the past on the incorporation of different types of fibres in the mix in order to mitigate the brittle behaviour of LWAC has been reported.

The incorporation of natural fibres in concrete as a viable replacement of conventional steel fibers is of immense interest as it is more economical and environmental friendly in promoting “green” structures. Akil et al. (2011) revealed that the tensile strength of kenaf fibre is between 400-550 MPa, which is higher than other natural fibres, such as sisal and jute. Therefore, kenaf fiber is capable of improving the structural properties of OPS-RC. However; study on kenaf fibres added to OPS-RC structures has yet been published. Therefore, it is essential to investigate the potential advantages of kenaf fiber in order to enhance the structural properties of OPS-RC beams. Hence, the present research aimed to study the behaviour of OPS-RC beams upon the inclusion of kenaf fibres and to determine the potential of kenaf fibres as part of the shear reinforcement in the beams. This research investigates the following key structural behaviour and design issues:

(i) Strength: Load at yield and maximum load carrying capacity
(ii) Ductility: maximum displacement/displacement at yield.
(iii) Cracking: patterns and locations
(iv) Failure modes of the beam.

1.3 RESEARCH OBJECTIVES

The overall aim of this research is to investigate the advantages of kenaf fiber in OPS-RC beams and its potential to serve as part of shear reinforcement.

The specific objectives of the present work are:

(i) To study the behaviour of OPS-RC beams with three fibre volume fractions (V_f = 0 %, V_f = 1 %, V_f = 2 %) of kenaf fibre experimentally, in terms of load-deflection behaviour, cracking pattern and failure mode.
(ii) To investigate the behaviour of OPS-KFRC beams numerically, in terms of load-deflection curve, strength, ductility and cracking pattern.

1.4 SCOPE OF WORK

The main concentration of this research is on two variables, volume fraction of fibre (V_f) and stirrups spacing increments (SI). Also, the following limitation of research work has been identified for both the experimental test as well as numerical modelling:

1.4.1 Experimental

(i) Five OPS-KFRC beams tested under four-point bending test.
(ii) The load is applied through a single stroke of 300 kN and the distance between the two loading points is 400 mm.
(iii) The dimension of the beam is 1500 mm long, 150 mm high and 150 mm wide.

(iv) The structural design of the control beams is designed according to the Eurocode-2 and designed to fail in shear.

(v) Based on the load design, the tension reinforcement is 2H16; the compression reinforcement is 2H12 whilst for the shear reinforcement the diameter 6 mm and stirrups spacing for the control beam is 100 mm.

(vi) Two arrangement of shear reinforcement stirrups spacing of 100 mm (SI = 0 %) and stirrups spacing of 200 mm (SI = 100 %) are considered.

(vii) The length of kenaf fiber considered is 30 mm, and its diameter varies between 0.1 mm and 2 mm

(viii) Three different volume fraction (V_f = 0 %, V_f = 1 %, V_f = 2 %) of kenaf fibre used in concrete mixture.

(ix) The size of oil palm shell (OPS) considered is between 10 to 15 mm.

(x) The concrete compressive strength is designed for 20 MPa.

1.4.2 Numerical Modelling

(i) A three-dimentional (3D)-Non-Linear Finite Element Analysis (NLFEA) is performed on the numerical modelling by means of a commercial FEA package, Abaqus.

(ii) Calibration and validation of the numerical modelling on two beams with full shear reinforcement SI = 0 % (stirrups spacing = 100 mm) together with two-volume fraction of fiber V_f = 0 % and V_f = 1 % is carried out.

(iii) Parametric studies on three arrangements of shear reinforcement (SI = 0 %, SI = 50 % and SI = 100 %) together with six fibre volume fraction (V_f = 0 %, V_f = 0.5 %, V_f = 1.5 %, V_f = 2 %, V_f = 2.5 %) were considered.

1.5 THESIS OUTLINE

This thesis consists of six chapters that are organised as below;

(i) Chapter one presents the introduction of the study.

(ii) Chapter two presents previous experimental studies regarding structure properties of FRC, application and advantages of natural fibre, lightweight concrete and as well as numerical modelling of FRC with NLFEA software Abaqus.

(iii) Chapter three presents the method of how the case studies for both the experimental work and then numerical modelling by means of Abaqus are carried out.

(iv) The experimental results of the structural behaviour (i.e. strength, ductility, crack propagation, strain and mode of failure) of OPS-KFRC beams, are presented in chapter four.

(v) Chapter five deals with the numerical modelling of this work namely the load-deflection curves, kinetic energy plots, tensile stress-strain relations as well as cracking patterns (i.e. principal strain contours, principal strain vectors and deflected shapes).

(vi) Chapter six provides the conclusion as well as recommendation for future research work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This section presents the structural properties of normal weight concrete (NWC), lightweight concrete (LWC), and fibre reinforced concrete (FRC). The background regarding modelling of FRC by means of finite element method (FEM) has also been included. A number of publications (Altun and Aktaş 2013; Hassanpour et al. (2012)) suggest that LWC behaves in a similar manner to normal weight concrete (NWC). Concrete is known to have a very high compressive strength but has a very low tensile strength that causes cracks in the tension zone. Therefore, steel reinforcement and different types of fibres are added in the concrete structures to solve the aforementioned problem as demonstrated by Naaman et al. (1993). The addition of fiber in lightweight concrete has proven to enhance the structural properties of LWC (Ashour et al, 1992). The following sections summarises the existing researches conducted in NWC, LWC, FRC, OPS-LWAC and natural FRC.

2.2 NORMAL CONCRETE

Concrete is one of the most popular construction materials that composed mainly of water, cement, aggregate, and as well as often additive like super plasticizers, fly ash and silica fume are included into the mixture to acquire the desired physical properties (Neville and Brooks, 1987). By chemical process (hydration) after mixing of materials concrete becomes hard and this hardening process takes different period due to inclusion of different types of material (Ezeldin and Balaguru, 1992). Aitcin (2000) stated that concrete is the most popular construction material. Because of new development in technologies, concrete has new improved material properties in several ways such as strength, durability, ductility, density. Yet, concrete will have to improve more to adapt to the environment by using natural materials mixed with it. Concrete has a relatively low tensile strength (compared to other building materials), low ductility, and susceptible to cracking. The weight of concrete is also high compared to its strength. Piyamaikongdech, (2007) illustrated, one of the major problems in design and execution of buildings is the considerable weight of dead load. Using lightweight natural and artificial materials is of interest as an effective solution in order to reduce the dimensions of the supporting structure, minimize the earthquake force on the building and finally to increase the speed, facilitate the execution and economize the project. In this regard, it is necessary to carry out special studies in the field of using suitable lightweight concrete, which allow the execution of buildings with lower weights (Gao, et al., 1997).

2.2.1 LIGHTWEIGHT CONCRETE

Lightweight concrete (LWC) is concrete produced with a density lower than 2000 kg/m^3. The use of LWC in the concrete industry is still limited owing to its ductility and brittleness (Arisoy, 2002). Nonetheless, if the production of LWC with adequate strength and ductility is attainable, construction costs will be significantly reduced. Teo et al. (2006) opines, that LWC may be utilised to reduce the dead load of a concrete structure that decreases the effect of dynamic loads on structure apart from reducing the dimension, as well as the amount of reinforcement used. In addition Hassanpour et al. (2012) stated, LWC possess high thermal insulation and provide better heat resistance as compared to normal weight concrete. Lightweight concrete mixes are also often used due to its weight saving properties that are a significant factor in the construction industry.

2.2.2 Lightweight Aggregate Concrete

Structural lightweight aggregate concrete (LWAC) is defined as concrete that is made with lightweight aggregates and has a compressive strength in excess of 17 MPa. Zhang et al. (1991) reported; that there are two types of lightweight aggregate namely natural and manufactured lightweight aggregates. Natural lightweight aggregates can be combined with two different types viz. naturally existent and unprocessed by-product that is obtained from waste material. Examples of natural lightweight aggregates are diatomite, pumice, scoria, volcanic cinders, and oil palm shell (OPS). Whilst, examples of unprocessed-by product natural lightweight aggregates are furnace clinker, furnace bottom ash and wood particles. Manufactured aggregates, on the other hand, are made from clay and shale or crushed fuel ash. The use of lightweight (LWAC) can be traced to as early as 3,000BC. The pumice is still used today in certain countries, such as Germany, Italy and Japan (Chandra and Berntsson, 2002). In some places, like Malaysia, oil palm shells (OPS) are used for making LWAC. As the aggregate comprise about 70 % of the volume of concrete, a reduction in density is most easily achieved by replacing all or part of the normal weight aggregate with a lighter weight material. To achieve a concrete density of less than 2000 kg/m^3 with all of the aggregate replaced by a lightweight material, the particle density of the lightweight aggregate must be also be less than about 2000 kg/m^3 Shideler (1957). The structural LWAC provides up to 30 % dead load reduction, which makes it suitable practical construction material in many applications. The use of lightweight aggregate concrete as a structural material is profoundly significant as it reduces the dead load of the structural members. Reduction of dead loads allows the designers to decrease the size of the foundation that provides cost effective. The utilization of lightweight aggregate in concrete not only reduces the weight of the structure but also provides better thermal insulation and improved fire resistance Chandra and Berntsson (2002). The use of LWAC is limited due to its inadequate ductility. Furthermore, the strain capacity of LWAC is higher than that achieved by NWC and elastic modulus is generally about 30 % less than NWC. The lightweight aggregate used to produce LWAC is usually weaker than cement matrix, as it has a lower modulus of elasticity which causes to faster rate of crack opening in reinforced concrete members as compared to normal weight concrete (Altun and Aktaş, 2013). A number of researchers (Sari and Pasamehmetoglu, 2005; Alengaram et al., 2013; and Shafigh et al., 2013) used super plasticizer to increase workability during the production of lightweight aggregate concrete. High water absorption of lightweight aggregate can lead to segregation and thus results in lightweight aggregate concrete that are more brittle than gravel aggregate concrete. Therefore, the addition of super plasticizer is vital to improve the flow ability of lightweight aggregate concrete mixture containing low water content. The structural performance of LWAC under loading is observed to be the same as ordinary reinforced concrete (NRC). There have been many LWAC structures successfully designed and constructed in the past, and hitherto no structural problem has been reported (Hoffman et al., 1998). It can be concluded, LWAC has gain the construction industry interest due to the benefits offered by this LWAC in terms of reduction in member size, longer spans, improved fire resistance, smaller foundations and better thermal properties.

2.2.3 Oil Palm Sell (OPS) in LWAC

Oil palm shell (OPS), as shown in Figure 2.1, is a waste material from the agricultural sector, and a vast amount of it is available in tropical regions Basri et al (1999). OPS is obtained after the oil extraction in the factory from the fresh fruit bunch and it is generally composed of different shapes such as roughly parabolic or semi-circular, elongated, flaky and other irregular shapes (Teo et al., 2006b). Malaysia alone produce over 4 million tonnes of OPS every year, and it can be utilised as a coarse aggregate for the producing structural lightweight concrete as reported by Shafigh et al. (2011). Teo, et al. (2007) reported that the density of OPS is two times lighter than normal sand aggregate, which suggests the possiblly to produce with OPS-LWAC with a density less than 1900 kg/m^3. Yew et al. (2015) stated, density of OPSC is varies in the range of 1868–1988 kg/m^3. In a past studies, the enhancement of mechanical properties of OPSC is dependent on the density, aggregate content, crushed or uncrushed particle size of OPS and heat treatment on OPS aggregate and Other factors include water-cement ratio and incorporation of cementations materials (silica fume, fly ash and ground granulated blast furnace slag). The influence of density on the compressive strength of OPSC can be observed from previous studies. Alengaram et al. (2013) showed that with a density of about 1900 kg/m^3, a compressive strength of 37 MPa with the addition of silica fume (SF) can be produced. Furthermore, Shafigh et al. (2013) have successfully produced OPSC with compressive strength of up to 53 MPa for a density of about 2000 kg/m^3.

Okpala et al. (1990) described that OPS has a water absorption capacity of 21.3 % and porosity of 37 %, which exhibits that high porosity could have affected the

CHAPTER 1

1.1 BACKGROUND

Lightweight concrete (LWC) as the name demonstrates, is essentially a concrete that is produced with a density lower than 2000 kg/m^3 (Arisoy, 2002). Structural lightweight concrete is an important and versatile material as it is used in a number of applications, namely multi-storey building frames, floors, and bridges. The very notion on the utilisation of LWC has increased over the years due to its many benefits. Almousawi (2011) for instance illustrated that if the production of LWC with adequate strength and ductility is achieved, the construction cost may significantly be reduced owing to its low weight of dead load of structure. Teo et al. (2006) suggests that one of the justifications of utilising LWC is to reduce the dead load of the concrete structure. Therefore, this will in turn decreases the impact of dynamic loads on the structure, reduces the dimension of all structure members apart from significantly reducing the amount of reinforcement. Moreover, Hassanpour et al. (2012) also suggests that LWC is considered as a high thermal insulation material as it provides better heat insulation as well as good fire resistance properties comparable to normal weight concrete (NWC). Oil Palm Shell (OPS) is a waste material from the agricultural sector that are available in a copious amount in tropical regions (Mannan and Ganapathy, 2004). Since 1984s OPS as a lightweight aggregate for producing lightweight aggregate concrete (LWAC) practiced in Malaysia. Teo et al. (2006) further opines that with the density of OPS ranging between 500 kg/m^3 and 600 kg/m^3 wich is about two times lighter than normal sand aggregates the production of concrete with a density of less than 1900 kg/m^3 is possible. The desired traits of OPS further encourages the replacement of ordinary sand aggregate with OPS for the production of structural LWAC.

Previously, different types of fibres have successfully been used in concrete structures such as steel fiber, synthetic fiber, glass fiber and natural fiber as reported by

Shao et al. (1995). From a structural standpoint, the primary reason for adding fiber is to improve structural properties of concrete through the fiber ability. Fiber bridging over the cracks leads to increase shear, moment, ductility, punching resistance, stiffness and reduce cracks widths. Short randomly distributed fibres acts as a multi-dimensional reinforcement and enhances the bond between the matrix that in turn increases the tensile strength and structural integrity of the concrete (Hassanpour et al., 2012). Shear resistance of concrete structure increase by transferring the tensile strength of fibre across shear crack and fibres prohibit the excess of diagonal tensile cracking. Additions of fibres within concrete structure caused to distribute the impact of dynamic load to entire structure reduce the concentration of the breaking force and minimize the human causalities in earthquake prone areas (EI-Hacha et al., 2004; Dawood and Ramli 2012). Furthermore, fibres act as crack arrestors and reduce the crack width which caused to increase the durability of concrete structure Furlan et al. (1997). Besides, numerous investigations indicated that by the incorporation of different types of fibres significantly increases the shear strength of concrete structures and transforms the failure mode from shear to bending (Brooks, 2006; and Furlan et al. 1997). Furthermore, fibres may also be used as a replacement of shear reinforcement in beams and other structural applications as remarked by Syed Mohsin (2012).

The utilisation of natural fibres as building materials in reinforced concrete by enhancing its ductility, flexural strength, toughness, cracking behaviour, and impact resistance was conceived by Lewis and Premalal, (1979). Owing to low density, high specific strength as well as economic nature of natural fibres, it has received wide attention by researchers in the applications of lightweight and high strength concrete (Deka et al., 2013). Moreover, reinforced steel is high-cost materials that comes from non-renewable resources but natural fibres, on the other hand, comes from renewable resources and are abundantly available. Jumaat et al. (2009) carried out a laboratory investigation on kenaf fibre reinforced concrete (KFRC) and found that it is a promising “green construction material” for various structural applications. Futhermore, Elsaid et al. (2011) further argues that the structural properties of KFRC are comparable to ordinary reinforced concrete (NRC).

1.2 PROBLEM STATEMENT

Lightweight aggregate concrete (LWAC) is an important economic and versatile material; nonetheless, it has low tensile strengths and a subsequently reduced shear resistance. As the LWAC has lower modulus of elasticity, the structure deflects more and has a lower rate of loading in cracking than typical concrete structure. Oil palm shell (OPS) is considered as a waste material, and Malaysia alone produces over 4 million ton of OPS annually. Due to the vast quantities production of these wastes, it has created a significant disposal problem. In general, the past research mentioned OPS as coarse aggregate have been found useful for making lightweight aggregate concrete (LWAC) and more than 20 % dead load of construction would be decreased by replacing sand aggregate with OPS. However, the brittleness effect of OPS-LWAC has yet to be fully mitigated in the concrete industry. At present, lightweight aggregate concrete has gain the construction industry interest due to the benefits offered by this lightweight concrete in terms of reduction in member size, longer spans, improved fire resistance, smaller foundations and better thermal properties. Conversely, their limited ability to absorb earthquake energy raises concerns due to brittle behaviour. Several investigations in the past on the incorporation of different types of fibres in the mix in order to mitigate the brittle behaviour of LWAC has been reported.

The incorporation of natural fibres in concrete as a viable replacement of conventional steel fibers is of immense interest as it is more economical and environmental friendly in promoting “green” structures. Akil et al. (2011) revealed that the tensile strength of kenaf fibre is between 400-550 MPa, which is higher than other natural fibres, such as sisal and jute. Therefore, kenaf fiber is capable of improving the structural properties of OPS-RC. However; study on kenaf fibres added to OPS-RC structures has yet been published. Therefore, it is essential to investigate the potential advantages of kenaf fiber in order to enhance the structural properties of OPS-RC beams. Hence, the present research aimed to study the behaviour of OPS-RC beams upon the inclusion of kenaf fibres and to determine the potential of kenaf fibres as part of the shear reinforcement in the beams. This research investigates the following key structural behaviour and design issues:

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The present research centres on both experimental work and numerical modelling. The experimental work focuses on the addition of kenaf fiber in OPS-RC reinforced concrete beams under laboratory conditions. The results obtained from the experimental work were used to calibrate the numerical model before further parametric studies are carried out. Figure 3.1 shortly explains the methodology of this research.

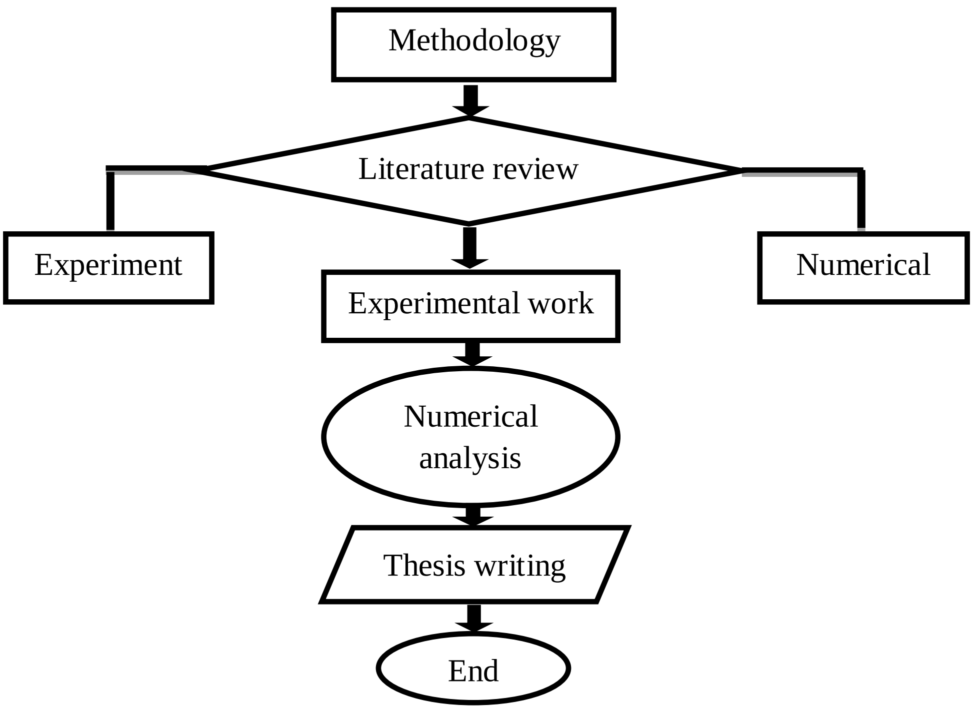

Figure 3.1: Research methodology

3.2 EXPERIMENTAL WORK

The experimental work begins with the preparation of the OPS-KFRC beam materials. The main materials used in this investigation are OPS as aggregate and kenaf as fiber into the mixture. The OPS were provided from a local factory and the kenaf fiber provided by the supplier whilst other required materials are readily available in the laboratory. Formwork and reinforcement (primary reinforcement and stirrups) were prepared for five beams. Consequently, three types of mixtures with three various volume fractions of fibres (V_f = 0 %, V_f = 1% and V_f = 2 %) prepared, for casting of beams. The concrete beams were removed from the wood forms after seven days of the casting time. This was followed by the curing process of the OPS-KFRC beams by covering them with wet bags as well as by watering them daily. Two strain gauges positioned at the middle of shear span of beams by 45 degrees and one strain positioned at the bottom of mid-span of the beam for shear strain and bending strain respectively. The mid-span displacement was measured by positioning linear variable differential transducers (LVDT) at the centre of each beam. Subsequently four points bending test for all beams were arranged and tested. Finally, the influence of kenaf fiber towards the OPS-RC beam under laboratory condition was studied.

3.2.1 Concrete Mixture

Table 3.1 shows three sets of concrete mixture proportions for all the five beams. The mixtures have different volume fraction of kenaf fiber prepared namely, V_f = 0 %, V_f = 1 %, and V_f = 2 % respectively. In this investigation, the OPS aggregates were used as full replacement for the conventional aggregates in the customised manufactured lightweight concrete. All mixes possess 510 kg/m^3 cement, 848 kg/m^3 sand, 308 kg/m^3 OPS and 1.4 litres super-plasticizer per 100 kg cement with a water/cement ratio of 0.4. This mix proportion was selected throughout the entire investigation.

Table 3.1: Proportion of materials for OPS-KFRC beams (Teo et al. 2006)

Concrete (OPS)	**Mix 1**	**Mix 2**	**Mix 3**
Ingredients	kg/m^3	kg/m^3	kg/m^3
Ordinary Portland Cement	510	510	510
Fine aggregate (sand)	848	848	848
Coarse aggregate (OPS)	308	308	308
Super plasticizer (SP)	20.4	20.4	20.4
Water	204	204	204
Kenaf fiber (%)	0	1	2
W/C ratio	0.4	0.4	0.4

Figure 3.2 shows a flowchart of experimental work adopted for the laboratory investigation. Firstly, formworks were prepared for all five beams. Then, concrete mixtures with three different fiber volume fractions V_f = 0 %, V_f =1% and V_f = 2 % of kenaf fiber and two distinct arrangement of shear reinforcement, full shear reinforcement SI = 0 % (i.e. shear reinforcement spacing = 100 mm) and reduced in shear reinforcement SI= 100 % (i.e. shear reinforcement spacing = 200 mm) were prepared. The beam with full shear reinforcement without fibre (SI = 0 % and V_f = 0 %) denoted as a control beam which is designed to fail in shear based on Eurocode-2 (refer to Appendix-A). Subsequently, the curing process was performed for 56 days until the OPS-KFRC beams are fully hardened as suggested by Teo et al. (2006). Finally, a four-point bending test was conducted on all the beams. The load-deflection curves, load strain curves, as well as the failure mode of the beams, are plotted.