STUDY ON LIGHTWEIGHT CONCRETE WITH COCONUT SHELL AND KENAF FIBRE

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A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering(Civil)

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

The construction industry has been facing difficulties due to the rising costs of construction materials, but one possible solution is to use lightweight concrete, which can provide more cost-effective options. To make this type of concrete more sustainable and environmentally friendly, the mix can be enriched with coconut shell and kenaf fibre. Coconut shell is a commonly found waste material in Malaysia that can be utilised to create lightweight concrete, while kenaf fibre is abundant and easy to obtain in Malaysia. After conducting a compressive strength test and splitting tensile strength test, it was found that by combining coconut shell and kenaf fibre in the concrete mix, the resulting product can meet the minimum strength and density requirements for structural lightweight concrete which is 17 MPa and below 2000kg/m^3 as specified in Eurocode 2. The study's results show that coconut shell is a suitable lightweight aggregate for structural lightweight concrete, and kenaf fibre can enhance the concrete's tensile strength.

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LIST OF SYMBOLS / ABBREVIATIONS

mm	millimeter
cm	centimeter
MPa	MegaPascal
π	Pi
Al_2O_3	Aluminium Oxide
CaO	Calcium Oxide
C_3A	Tricalcium Aluminate
C_4AF	Tetracalcium Aluminoferit
C_2F	Dicalcium Ferrite
C_2S	Dicalcium Silicate
C_3S	Tricalcium Silicate
CO_2	Carbon Dioxide
CSC	Coconut Shell Concrete
Fe_2O_3	Iron Oxide
HDPE	High Density Polyethylene
LDPE	Low Densty Polyethylene
MgO	Magnesium Oxide
SiO_2	Silicon Dioxide
SO_3	Sulphur Trioxide
UHMWPE	Ultra-High Molecular Weight Polyethylene

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The construction industry has been facing challenges due to the increased costs of construction materials, prompting developers to explore options to maintain affordable building costs. One such option is lightweight concrete, which offers several benefits over traditional concrete. Firstly, lightweight concrete can significantly reduce the structure's dead load by up to 20% to 30% during the design stage due to its substantially lower mass (Pirzad, 2017). This weight reduction can also lead to lower costs for load-bearing structures. Additionally, using lightweight concrete can help reduce energy consumption for heating and cooling buildings. Furthermore, the reduction in mass can enhance construction site productivity by improving the speed of implementation and reducing the reliance on highly skilled labour.

Several materials can be used to design lightweight concrete, including lightweight aggregates such as sawdust, fly ash, expanded polystyrene beads, straw, expanded clay or shale, and more. Another option is to replace the coarse aggregate with coconut shell, which has been shown to produce lightweight concrete with sufficient compressive strength to meet the requirements for structural lightweight concrete under full water curing conditions (Gunasekaran, Kumar and Lakshmipathy, 2011). Furthermore, coconut shell is a common solid waste in tropical countries, including Malaysia. Therefore, the possibility of using coconut shell as an aggregate in concrete can help to reduce solid waste in Malaysia and helps to produce cost-effective concrete due to the low price of coconut shell in a tropical country.

Another option to improve concrete's mechanical properties is adding kenaf fibre to the concrete mix. Among various fibre options, kenaf fibre is one of the more affordable. Furthermore, its ability to reduce cracking and enhance durability makes it an excellent material for lightweight concrete structures. Using kenaf fibre can help produce inexpensive green concrete with outstanding durability and less cracking propagation in concrete applications (Sadiqul Hasan et al., 2015a). Overall, lightweight concrete and alternative materials such as coconut shell and kenaf fibre can provide a cost-effective and sustainable solution for the construction industry.

1.2 Importance of the Study

This study aims to understand the possibility of replacing coconut shells with coarse aggregate and adding kenaf fibre to the concrete mix to produce structural lightweight concrete. Using natural fibres and agricultural waste as alternatives for concrete is not only of interest due to cost reduction but also from an environmental perspective. The ability of kenaf plants to absorb carbon dioxide and provide suitable fibres for concrete mix makes it an environmentally-friendly choice that can help reduce greenhouse gas emissions (Baghban and Mahjoub, 2020). Moreover, kenaf fibre costs relatively lower than other types of fibres, making it a more cost-effective option for producing lightweight concrete.

The findings of this study will be significant for the construction industry, as it will provide an alternative solution to conventional concrete by utilising natural fibres and agricultural waste as replacement materials. This approach can potentially reduce the cost of concrete production while promoting sustainability and environmental responsibility. Furthermore, using coconut shell and kenaf fibre in concrete mix design can reduce the environmental impact of the concrete output and contribute to the development of green building practices.

Overall, this study's importance lies in the potential to produce a cost-effective and environmentally-friendly solution for the construction industry. Using natural fibres and agricultural waste can reduce the environmental impact of concrete production while promoting sustainable building practices. In addition, the results of this study can help design lightweight concrete structures that meet the strength requirements while reducing the overall environmental impact of the construction industry.

1.3 Problem Statement

Previous studies have focused on evaluating concrete's compressive and flexural strength, incorporating coconut shells as an aggregate (Gunasekaran and Kumar, 2008; Shelke et al., 2014; Palanisamy et al., 2020). However, adding kenaf fibre to the concrete mix may further enhance the mechanical properties of coconut shell concrete (CSC). Despite the potential benefits of incorporating kenaf fibre, there is a lack of research on replacing coconut shell aggregate and adding kenaf fibre in the concrete matrix, particularly in Malaysia. Therefore, this study aims to fill this gap by investigating the design mixture of coconut shell and kenaf fibre to produce high-strength concrete with improved mechanical properties.

The findings of this research project will be significant for the construction industry, as it will provide a more cost-effective and environmentally-friendly solution for producing lightweight structural concrete. By incorporating kenaf fibre, this research project aims to enhance the mechanical properties of coconut shell concrete and provide an alternative solution to conventional concrete. The results of this study can help design lightweight concrete low-rise structures that meet structural requirements while promoting sustainability and environmental responsibility in the construction industry.

1.4 Aim and Objectives

This study aims to provide the possibility of lightweight concrete with coconut shells and kenaf fibre. The objectives of the study are as follows:

1. To study the performance of coconut shell and kenaf fibre in lightweight concrete
2. To compare the performance of CSC and CSC with kenaf fibre
3. To evaluate the possibility of using CSC and CSC with kenaf fibre as a structural lightweight concrete

1.5 Scope and Limitation of the Study

This study's scope is to determine the performance of the design mix for kenaf fibre-reinforced CSC. The different concrete mix's performance will be analysed after the compressive and splitting tensile strength tests are conducted. It was important to evaluate that the compressive strength of CSC and density of CSC had achieved the requirement for structural lightweight concrete. A comparison between CSC and CSC with kenaf fibre will be studied to understand the effect of added kenaf fibre on CSC. Analysis of the result of the compressive strength test and splitting tensile test of CSC and CSC with kenaf fibre will be done to understand the behaviour of the lightweight concrete. The limitation of this study is that the bonding properties between kenaf fibre, coconut shell and cement mix cannot be done. Pull-out tests will not be done to determine the bonding between each material in the concrete mixture. A flexural test was not conducted due to the machinery breakdown. Moreover, the durability of concrete that tests the concrete under various load conditions over time will not be tested because the time needed to conduct it is insufficient.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the main focus is concrete, lightweight concrete and its mix proportion, such as replacing aggregate or adding a different type of fibre. The type of Portland cement used in this study will be Type 1, ordinary Portland cement. The replacements for lightweight aggregate and fibre types will be studied and previous research related to coconut shell and kenaf fibre will be discussed in detail.

2.2 Concrete

Concrete is one of the most used construction materials in the world. Cement, water, and fine and coarse aggregate are the primary materials used to form a concrete block. While producing concrete, it had to undergo two stages: setting and hardening. The concrete setting state can be differentiated into two types which are initial and final setting time. In the initial setting time, the formation of escalating cement paste resulted in cement loss of parts of its plasticity and began to turn stiff. The cement paste will lose all its plasticity during the final setting time and eventually proceed to the hardening stage. Concrete cannot achieve any strength in the setting stage but will start to retrieve strength in the hardening stage (Shan Somayaji, 2000).

Concrete is a non-combustible material that excels in compression (Wit, 2011). On the contrary, concrete is a brittle and tension-weak material. Some materials can be put into the concrete to enhance its performance. For instance, concrete contains artificial and natural fibres and steel bars such as tension and compression bars or shear links. Additionally, cracking typically occurs both before and after hardening. Plastic shrinkage cracking and thermal cracking are two different types of concrete cracking that can occur. The specific types and causes of cracking are detailed in Figure 2.1. Construction or formwork movement causes cracks to appear before hardening, whereas unintentional overload, alkali-aggregate interaction, and cement carbonation cause cracks to occur after hardening. Plastic shrinkage and cracking can be caused by construction or formwork movement, whereas thermal cracking and drying shrinkage can be caused by inadvertent overload, alkali-aggregate reaction, or cement carbonation (Larosche, 2009).

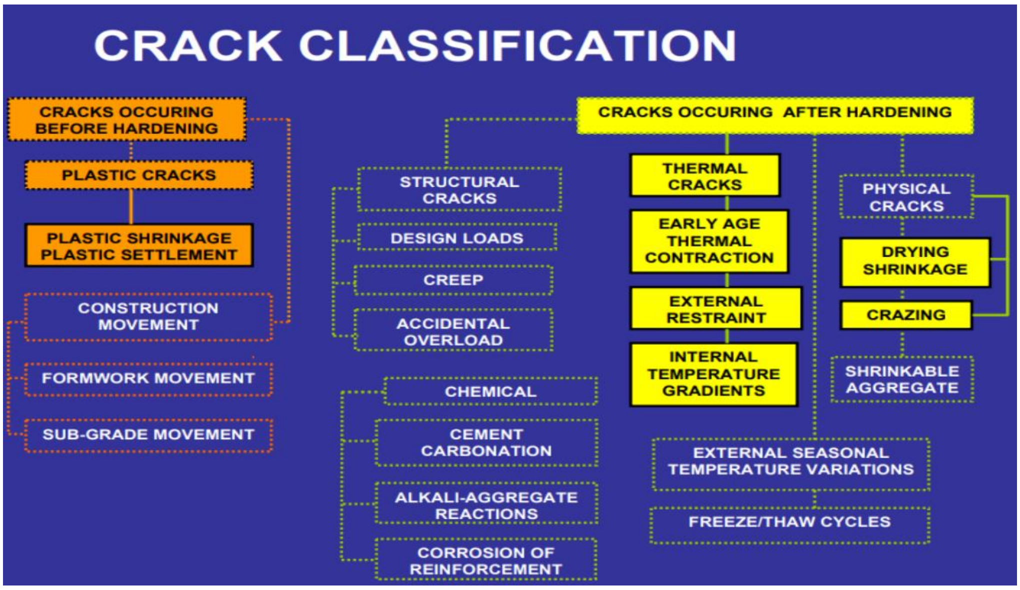

Figure 2.1: Types and Reasons for Cracking (Stanley, 2009)

Concrete cracking reduces the concrete's ability to support weight, reduces its durability, and causes corrosion of the reinforcement bar in the concrete due to chloride ions entering the concrete through the crack. However, concrete cracking could be minimised or reduced in specific ways. For instance, the amount of cement used in the concrete can be diminished, and the use of mineral admixture or fibres added to the concrete(ACI Committee 224, 2001).

2.2.1 Aggregate

Fine and coarse aggregate are the two main types of aggregate. Fine aggregate includes both manufactured sand and natural sand. Fine aggregate shall be graded from 0.075 mm to 4.75mm in accordance with ASTM C33-06. When fine aggregate passes the sieve with a size of 0.075 mm, but ASTM C33-06 suggests mineral admixture or more cement, excessive bleeding or workability difficulty occurs. The reason for this is to reduce bleeding or workability issues. Blast furnace slag in air-cooled conditions and gravel with or without crush are examples of coarse aggregates. The size of coarse aggregate should be greater than 4.75 mm, according to ASTM C33-06. Most structural components have a maximum size of 40 mm. When exposed to a humid atmosphere or moist ground, coarse aggregates should not contain material that reacts 10 with the alkali. Therefore, the concrete expanded due to the material's reaction to the alkali. The alkali-aggregate reaction occurs when a material reacts with an alkali (ASTM C33-06, 2006). Aside from that, the concrete's compressive strength will increase due to the increase in aggregate size. This can be proven in the study of Fedder Musa and Aziz bin Saim (2017).

2.2.2 Ordinary Portland Cement

Al-Khateeb (2013) conducted a study on the chemical analysis of ordinary Portland cement. Ordinary portland cement is a common concrete raw material in powder form. When combined with water, it can bind the coarse and fine aggregate. When cement is mixed with water, it undergoes the hydration process, releasing heat. The term for this is an exothermic reaction. The chemical equation of cement hydration is cement + Water (H_2O) → Calcium Silicate Hydrate (C-S-H) gel + Calcium Hydroxide ($Ca(OH)_2$). The four types of chemical compounds in ordinary Portland cement are dicalcium silicate (C_2S), tricalcium silicate (C3S), tetra calcium aluminoferit (C_4AF) and tricalcium aluminate (C_3A). C_2S will result in a low permeability of concrete due to more C-S-H generated and less capillary. So, chemicals such as chloride or sulfate ions hardly penetrate the concrete. This will prevent steel corrosion. The difference between dicalcium silicate and tricalcium silicate is that dicalcium silicate gives the later strength of the concrete, while tricalcium silicate gives the early strength of the concrete.

Sulphoaluminate will be formed in tricalcium aluminate when the sulphate attacks the cement paste during the hardening process. This results in separation or disruption. When calcium hydroxide reacts with sulphoaluminate, mono-sulfate and ettringite are formed. Monosulfate and ettringite have the chemical formulas C_4ASH_{11} and $C_6AS_3H_{32}$. Ettringite is classified into two stages: early and late. The early stage of ettringite is soft and suitable for static cement. The later stage of ettringite remains in the concrete permanently and expands. This will cause damage to the concrete due to breakage or internal stress, which is undesirable. The later stage of ettringite formation is referred to as delayed ettringite formation. One way it is formed is when sulphate reacts with undissolved mono-sulfate. The percentage of these four chemical compounds in the cement can be calculated by using the formula in the ASTM 150-07 as shown in Tables 2.1 and 2.2 for Aluminium Oxide (Al_2O_3) / Iron Oxide (Fe_2O_3) ≥ 0.64 and Al_2O_3/ Fe_2O_3 < 0.64.

Table 2.1: Calculation for Chemical Compounds in Percentage for Al_2O_3/ Fe_2O_3 ≥ 0.64 (ASTM C150-07, 2007)

Type of chemical compound	Formula
Tricalcium Silicate (C_3S)	4.071 x CaO –7.600 x SiO_2-6.718 x Al_2O_3-1.430 x Fe_2O_3 -2.852 x SO_3-5.188 x CO_2
Dicalcium Silicate (C_2S)	2.867 x SiO_2-0.7522 x C_3S
Tetracalcium Aluminoferit (C_4AF)	3.043 x Fe_2O_3
Tricalcium Aluminate (C_3A)	2.650 x Al_2O_3-1.692 x Fe_2O_3

Table 2.2: Calculation of Chemical Compounds in Percentage for Al_2O_3/ Fe_2O_3 < 0.64 (ASTM C150-07, 2007)

Type of chemical compound	Formula
C_4AF +Dicalcium Ferrite (C_2F)	2.100 x Al_2O_3-1.702 x Fe_2O_3
C_2S	2.867 x SiO_2-0.7522 x C_3S
C_3S	4.071 x CaO –7.600 x SiO_2-4.479 x Al_2O_3-2.859 x Fe_2O_3 -2.852 x SO_3-5.188 x CO_2

2.3 Lightweight Concrete

The adjective “lightweight” from lightweight concrete refers to various types of low specific-weight concrete. The weight can be reduced using specific types of lightweight aggregates with noticeably lower specific gravity than traditional aggregate types such as gravels, rushed stones, or air-entraining admixture added to the concrete (Chandra and Berntsson, 2002). In Eurocode 2 and ASTM C330, structural lightweight concrete refers to concrete with a mean cylinder compressive strength of at least 17 MPa and a unit weight of at least 800 kg/m^3. Non-structural lightweight concrete consists of a compressive strength of fewer than 17 MPa.

2.4 Lightweight Aggregate

The development of lightweight aggregate concrete has received significant attention in recent years. This type of concrete offers numerous benefits, including reduced building costs, simplified construction processes, and the advantage of being an environmentally friendly building material. Traditionally, concrete is a three-phase composite material that consists of cement paste, aggregate, and an aggregate/cement paste interface. However, in many cases, the aggregate component is the weakest link in the concrete composite. Therefore, the strength of the aggregate has a direct impact on the strength of the resulting concrete. Additionally, the water-cement ratio and the pore characteristics of the hardened cement paste also play crucial roles in determining the integrity of the concrete. Therefore, it is widely recognised that the contributions of aggregate strength and the pore size characteristics of the interfacial zone are the most critical factors to consider in improving concrete performance (Lo, Tang and Cui, 2007).

Lightweight aggregates that can be used as a substitute for traditional aggregates can be differentiated into natural or artificial lightweight aggregates. The availability of various physical and mechanical properties of lightweight aggregate allowed lightweight aggregate to be fabricated with different densities and strengths. Lightweight aggregate is defined as aggregate with a density of less than 2000 kg/m^3 or a dry loose bulk density of less than 1200 kg/m^3. Expanded aggregate, which retains air within an aggregate's structure, allowed aggregate densities close to 2600 kg/m3 to have a lower density of less than 2000 kg/m^3. This aspect of noticeable divergence between different densities, particle versus dry loose bulk, is concerned with the interaction between distinct types shaped of the same nominal size to the apparent percentage of interstitial voids. For a given volume, the number of spherical particles is more packed compared to a higher random density than the same-sized irregular or angular particles (Lclarke, 1993). Figure 2.2 shows the relationship of particle density versus dry loose bulk density to determine the characteristic of a particle on the effect of interstitial void on lightweight aggregates.

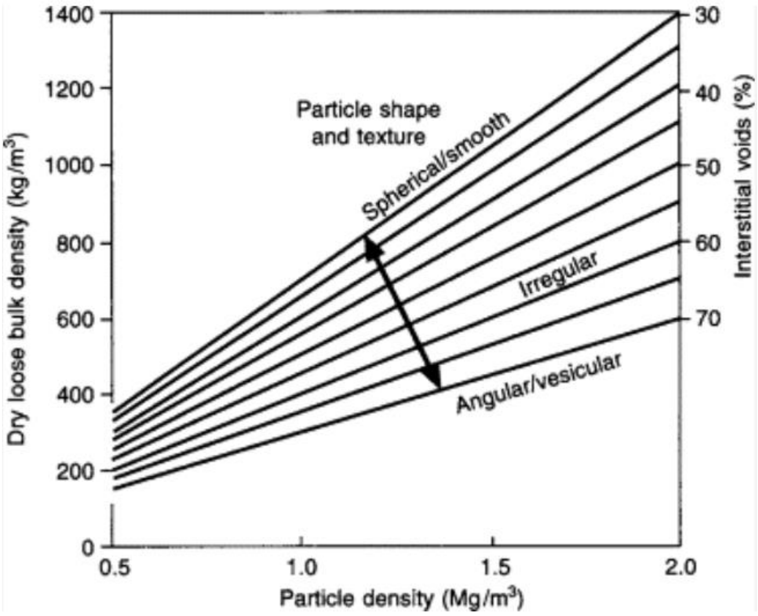

Figure 2.2: Relationship of particle density versus dry loose bulk density determines the characteristic of a particle on the effect of interstitial void on lightweight aggregates (Lclarke, 1993).

2.4.1 Vermiculite

Vermiculite comprises a combination of complex hydrated aluminium and magnesium silicate. Vermiculite is formed when mica disintegrates, releasing lime and absorbing water. When heated to 800-1100 ^{o}C, vermiculite splits into tiny strips. These disperse water, curl up and swell to form a light porous mass suitable for use as an aggregate in lightweight concrete or as a loose insulator (Berge, 2001).

Figure 2.3: Vermiculite from Tamilnadu Minerals (Naveen Kumar et al., 2020)

Naveen Kumar et al. (2020) investigated using vermiculite in a lightweight concrete block. Vermiculite is used as a replacement for coarse aggregate. The average particle size of the vermiculite used is around 3mm to 6mm. Figure 2.3 shows the vermiculite used in their study. Three different trial mix rations are used, which are 1:1:2, 1:1.5:1.5 and 1:2:1. Their experimental test results show that the trial mix ratio of 1:1.5:1.5 provides the best result achieving split tensile strength of 3.35 kN/mm^2. The compressive strength of the lightweight vermiculite concrete block is around 5N/mm^2 after 28 days—the results of the compression strength test results show that it is adequate for load-bearing wall structures. Due to the strength of the lightweight vermiculite concrete block not exceeding 17 N/mm^2, it can be concluded that it is a non-structural lightweight concrete block.

2.4.2 Expanded Perlite

Perlite is an igneous mineral of silicon, aluminium, oxygen, and water. Expanded perlite is formed by heating perlite to temperatures above 870 °C. It turns plastic, and internal steam escapes under pressure from the mineral (Aguilar-Garib et al., 2013).

Expanded perlite can be mixed with Portland cement to produce lightweight concrete. The performance of this type of lightweight concrete is studied (Ji et al., 2015). A different volume ratio of expanded perlite to Portland cement from zero to twelve was applied to study the effect of the substitution of expanded perlite in a concrete mix. Three times of compression test was done to determine the strength of expanded perlite lightweight concrete, and the final experiment result will be the mean of the test values. Figure 2.4 shows the strength of lightweight concrete with different proportions of expanded perlite. From the figure, we can notice that the compressive strength and thermal conductivity had reduced with the increasing substitution of expanded perlite added to the concrete matrix. The relationship of replacing expanded perlite in the concrete mix can be differentiated into two parts: samples with a bulk density of more than 1300 kg/m3 and otherwise. Although replacing expanded perlite reduces the strength of lightweight concrete, bulk density and thermal conductivity have improved. From their study, we can conclude that expanded perlite is suitable for thermal insulation and lightweight structural aggregate replacement for coarse aggregate.

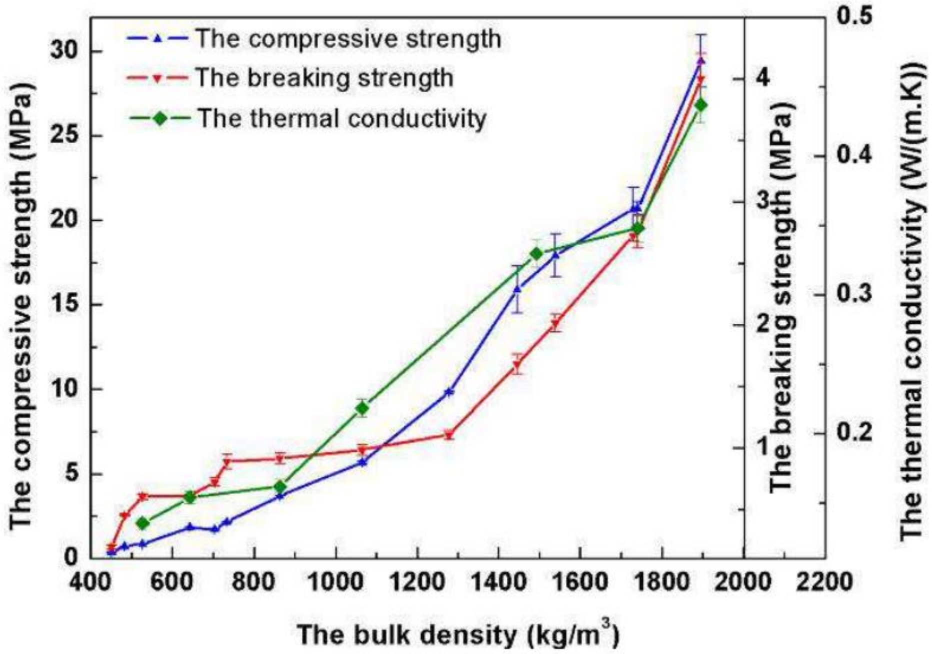

Figure 2.4: The strong performance of lightweight concrete with different proportions of expanded perlite (Ji et al., 2015)

2.4.3 Expanded Glass

The glass will be broken and fed into a mill to produce a fraction smaller than 3 mm glass. Structure-shaping, gas-forming, and melting-point-reducing agents add to the expanded glass production. A ball mill will be used to mill the mixture to a 50– 120 nanometer size. The powder and addictive solution will be mixed in a rotary furnace at a temperature of 750 to 950 ^{o}C to allow for the automatic production of raw pellets. The pellets will melt and increase in volume up to 2-10 times their original book. Then, the pellet will be heated on a belt drier to remove the water content. After that, the granulate will be mixed with additive, preventing cohesion of melted glass grains and fed into a drier (Nemes and Józsa, 2006).

Adhikary, Ashish and Rudžionis (2021) conducted a study on expanded glass lightweight concrete. Expanded glass aggregates are good in thermal insulation and a good material for producing thermal insulating cement composite. The aggregate size of expanded glass aggregates will affect the mechanical properties such as bulk density size, strength and water absorption. Expanded glass aggregates are typically granule-shaped, with bulk densities ranging from 120 to 400 kg/m^{3,} depending on size. Expanded glass aggregates are commonly utilised to prepare lightweight concrete, foamed concrete, and mortars. Expanded glass aggregate is a porous material which absorbs more water than conventional aggregates. Therefore, incorporation of expanded glass aggregates For density around 1600 to 2000 kg/m^3, compressive strength of 18 to 27 MPa can be achieved. However, the concentration of expanded glass aggregate in the concrete mixture will affect the carbonation risk because of the aggregate's permeability. Therefore, concrete mix with full replacement of expanded glass aggregate will surely be carbonate.

2.4.4 Apricot Shell

The use of an apricot shell as a substitution for conventional aggregate in lightweight aggregate concrete was studied (Wu et al., 2019). Five different percentage of apricot shell replacement (0%, 25%, 50%, 75%, 100%) for conventional aggregate is studied. During the slump test, it is found that increasing apricot shell content in the concrete mixture will reduce the slump height. Moreover, increasing apricot shell content in concrete will decrease the concrete density with a minimum density of 1762 kg/m^3 for full replacement of apricot shell. Figure 2.5 shows the compressive strength of concrete with different apricot shell content.

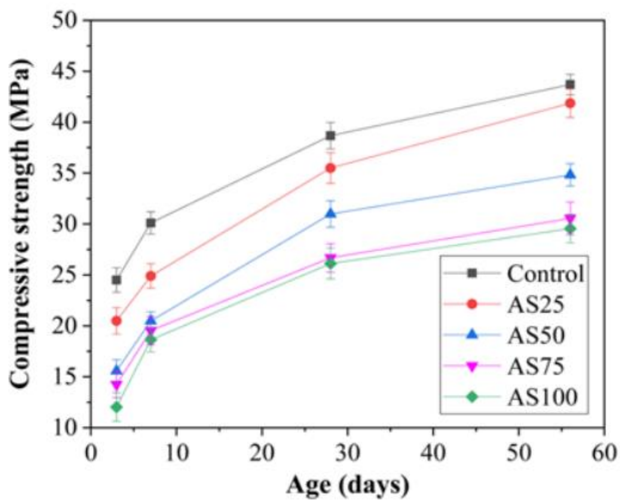

Figure 2.5: Compressive strength of concrete with different apricot shell content (Wu et al., 2019)

The comparison was made to the control concrete. The 28-day compressive strength of 100 per cent apricot shell content had lowered to 26.1 MPa. Adding apricot shell content also reduces the modulus of elasticity and the tensile strength of the concrete. The concrete strain also increases with the increasing volume of the apricot shell added, resulting in a faster creep rate. However, although the overall performance of apricot shell concrete had reduced, based on the result obtained, we can conclude that apricot shell as a potention substitution for coarse aggregate in lightweight concrete is feasible because it achieves the minimum standard and requirement for lightweight concrete.

2.4.5 Wood Chipping

Wood chipping can partially substitute fine aggregate in the concrete mix to produce lightweight concrete. Before mixing with cement, wood chipping must be treated by soaking it in water to ensure the occurrence of cement hydration. Concrete with high content of wood chipping will have better workability and air content. However, the strength of concrete reduces by adding wood chipping (Mohammed, Abdullahi and Hoong, 2014).

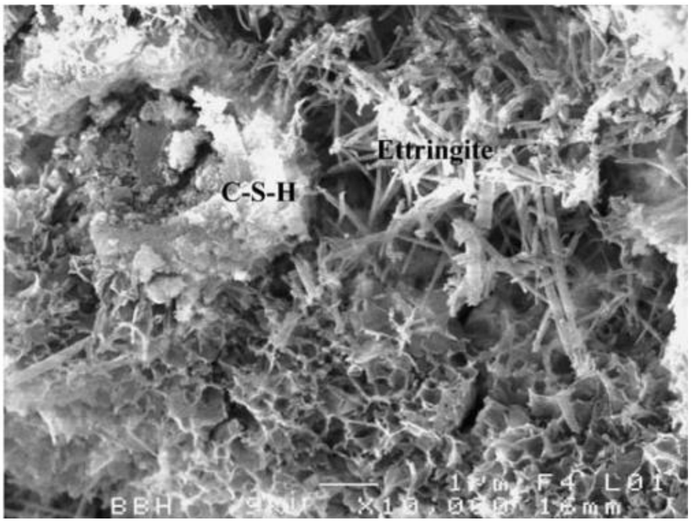

Figure 2.6: Ettringite needles developed on cement matrix’s surface (Coatanlem, Jauberthie and Rendell, 2006)

To further improve the performance of wood chipping lightweight concrete, treatment of wood chipping can be done by soaking in a sodium silicate solution other than water before mixing it with the cement paste (Coatanlem, Jauberthie and Rendell, 2006). Figure 2.6 shows the development of ettringite needles on the cement matrix's surface. The reaction between sodium silicate solution and wood chipping help in developing ettringite needles on the cement matrix's surface. This can improve the bonding properties between cement and wood chipping. However, they failed to present the pozzolanic effect they expected to achieve.

2.4.6 Peach Shell

Peach shell is one option that can be used as a replacement for average weight aggregate. Wu et al. (2020) researched choosing agricultural waste, which is peach shells, to produce lightweight concrete. Their study used crushed pebbles as average weight aggregate, whereas peach shell was the replacement. Before adding the peach shell to the concrete mixture, it should be washed to eliminate residual dust and dried before crushing it in a crushing machine. Crush peach shell aggregate will have a flaky shape with a smooth inner surface and a rough and irregular outer surface. The crush peach shell aggregate is controlled to a maximum size of 4.75 mm by sieving. Before mixing the peach shell aggregate with cement, it was immersed in water to ensure it is saturated with water and the dry surface condition was met.

The increase in the replacement of peach shells to normal-weight aggregate will reduce the concrete's overall strength and modulus of elasticity. However, their lab test concluded that concrete with peach shell proportion below 50% could match the minimum properties and standard for lightweight concrete.

2.4.7 Palm Shell

Malaysia is one of the largest palm plantation owners in the world. One possible approach to utlisize this type of abundant agriculture is using palm shells as lightweight aggregate in a concrete matrix (Mannan and Ganapathy, 2002).

Hamada et al. (2020) studied using oil palm shells to replace aggregate in concrete cement. The compressed palm shell is sieved within 2.36 to 9 mm to prepare the suitable aggregate size to add to the concrete mix. Palm shell aggregate has an irregular shape with rough and angular edges. Due to the low workability of the palm shell, superplasticiser is added to the concrete mixture.

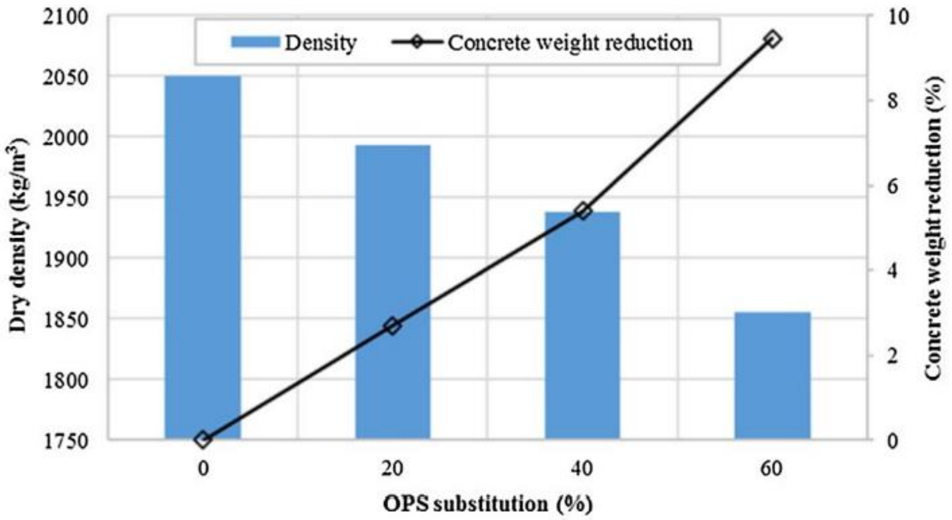

Figure 2.7: Relationship between the proportion of palm shell substitution versus dry density of concrete(Hamada et al., 2020)

Figure 2.7 shows the relationship between the proportion of palm shell substation versus the dry density of concrete. We can notice a significant dry density reduction when the replacement percentage of palm shells added to the concrete increase. Their lab result concluded that the compressive strength of palm shell lightweight concrete varies from 16 MPa to 54 MPa based on the different percentages of palm shell substitution. In addition, the spitting tensile strength varies from 1.78 MPa to 10.99 MPa, and flexural strength ranges from 2.6 MPa to 18.48 MPa. Based on the result, palm shells could be used as one of the aggregate substitutions for lightweight concrete.

2.4.8 Coconut Shell

In Malaysia, coconut shells are one of the agricultural solid waste. Coconut shells have a greater capacity to retain moisture than crushed stone aggregates because they are mostly made of wood and organic material. Because coconut shell absorbs a lot of water, aggregates will be presoaked in potable water and mixed with concrete mix under saturated surface dry condition. This is to ensure the occurrence of concrete hydration (Shelke et al., 2014).

Kaur and Kaur (2012) also suggested that the utilisation of coconut shells in cement concrete can play a significant role in reducing waste and pollution. There is a pressing need to promote waste products as construction materials for low-cost housing, as this could encourage housing developers to invest in these materials for house construction. In recent years, the construction industry has identified various natural and artificial lightweight aggregates that have replaced conventional aggregates, reducing structural members' size. This development has brought about a significant change in the construction of high-rise structures using lightweight concrete. Although coconut shells are not commonly used in construction, they are often discarded as agricultural waste. However, coconut shell concrete can be utilised in rural areas and regions where coconut is abundant and may also be used where conventional aggregates are expensive. Furthermore, coconut shell concrete is classified as structural lightweight concrete.

Table 2.3: CSC's compressive strength and density (Gunasekaran and Kumar, 2008)

	Compressive strength, N/mm^2				
Mix Type	**3-days**	**7-days**	**28-days**	**Fresh concrete density, kg/m^3**	**Hardened concrete density at 28-day (SSD condition), kg/m^3**
CSC	10.2	14.9	19.1	1975-2110	1880-1930

Gunasekaran and Kumar (2008) researched replacing coconut shells as aggregate in lightweight concrete. Table 2.3 shows CSC's compressive strength and density. After 28 days under saturated surface dry conditions, the compressive strength of the concrete is 19.1 N/mm^2 which is more than 17 N/mm^2. This shows that CSC is sufficient to be classified as structural lightweight concrete. Moreover, the aggregate impact value and crushing value of coconut shell aggregate were much lower compared to the crushed stone aggregate, indicating that these aggregates have good absorbance to shock.

Palanisamy et al. (2020) studied the permeability of lightweight self-consolidating coconut shell concrete. Self-consolidating concrete could flow and compress without any disturbance. The drawback of self-consolidating concrete is the cost of the chemical admixtures, and the high powder content is high. To reduce the cost, coconut shell aggregate is recommended. The workability of coconut shell lightweight self-consolidating concrete satisfied the requirement, which possessed good fluidity, deformability and the ability to pass and fill. The compressive strength in 28 days for 75 per cent replacement for coconut aggregate is more than 21.72 MPa, exceeding the required strength (17 MPa) for structural lightweight concrete. The density for 75 percent replacement and a full replacement is 1825 kg/m^3 and 1740 kg/m^{3,} respectively, lower than the minimum density requirement (2000 kg/m^3).

Gunasekaran, Kumar and Lakshmipathy (2011) researched the mechanical and bonding properties of CSC. Pull-out tests of 400 kN capacity were prepared to evaluate the bonding properties. Each concrete specimen will be in cylinder form with a 100 mm diameter and a height of 200 mm. Plain and deformed bars with different diameters, such as 8, 10, 12, and 16, are included in the specimen. The reinforcement was positioned in the middle of each specimen, with both ends given a 25 mm unbonded length. A plastic sheathing was fastened to the reinforcement to provide the unbonded lengths. A 150 mm short embedment length was chosen to prevent the reinforcement from yielding under pull-out load. Plastic sheets were immediately used to cover the specimen after casting to avoid excessive evaporation, which will be moulded after 24 hours. Figure 2.8 shows the pull-out test for CSC. Formula 2.1 shows the bond strength calculated. Formula 2.2 shows the theoretical bond strengths followed by the formula in BS 8110.

$$\iota = F/(\pi \times d \times l) \qquad (2.1)$$

where

ι = bond stress (N/mm^2)

F = Applied load (N)

d = nominal bar diameter

l = embedment length

$$f_{bu} = \sqrt[\beta]{f_{cu}} \qquad (2.2)$$

where

f_{bu} = theoretical bond strength (N/mm^2)

β = bond coefficient (0.28 and 0.50 for MS bars and RTS bars, respectively)

f_{cu} = compressive strength of concrete

Figure 2.8: Pull-out test for CSC (Gunasekaran, Kumar and Lakshmipathy, 2011)

The theoretical bond strength, as per BS8110, is 1.36 N/mm^2. The experimental bond strength obtained for concrete with plain bars are varied from 3.56 to 7.49 N/mm^{2,} whereas concrete with deformed bars will varied from 4.22 to 9.84 N/mm^2. In their experiment, all of the plain bar-embedded concrete failure due to the bar was pulled out from the concrete. On the contrary, the deformed bar-embedded substantial loss is due to the cracking of the concrete cover and the sudden failure from the formation of longitudinal cracks, which is because a deformed bar with well-distributed mechanical anchorages possessed a better grip on concrete. Therefore, the CSC experiment bond strength is higher than the theoretical value. CSC bond strength is generally similar to other lightweight concrete's bond strength.

Pordesari et al. (2021) conducted a comparative study on using coconut shells as a partial replacement for coarse aggregate compared to oil palm shells and average coarse aggregate. Their research findings revealed that coconut shell concrete (CSC) could achieve a maximum strength of 40.8 MPa after 28 days, with a splitting tensile strength of 3.7 MPa. It should be noted, however, that the superior mechanical properties observed in their study are attributed to the use of superplasticiser and fly ash as admixtures and the partial replacement of coarse aggregate. Hence, it is essential to note that comparing the results of this study with previous studies on CSC may not be appropriate since previous studies did not use similar admixtures in their concrete mix and replaced all coarse aggregate with coconut shell aggregate, which could have resulted in less satisfactory outcomes.

2.5 Fibre Reinforced Concrete

Fibre-reinforced concrete is a composite material composed of concrete and short discrete, randomly oriented fibrous material. Due to the shortcomings of concrete, such as micro-cracks that form during curing or a lack of tensile strength, fibre can be added to improve its performance. Counting fibre into the concrete matrix can increase the tensile strength and durability of the concrete. The volume of fibres, orientations and aspect ratio of threads, and stiffness of the relative fibre matrix are all factors that can affect the properties of fibre-reinforced concrete (Zheng and Feldman, 1995).

2.5.1 Boron Fibre

It is a fibre created through Chemical Vapour Decomposition (CVD). It is a method of depositing material produced by the substrate and growing with it. Thick filament will be formed in this process. The deposit material's structure determines the boron fibres' modulus and strength. During the manufacturing process, the reaction of Boron Trichloride ($2BCl_3$) (g) + Hydrogen ($3H_2$) (g) +

Boron (2B) (s) + Hydrogen Chloride (6HCl) (g) occurs. Because high temperatures are required in the CVD process, carbon or tungsten wire in fine form can be used as the substrate material (Debnath, Maity and Ray, 2016). Table 2.4 shows the properties of boron fibre.

Table 2.4: Properties of Boron Fibre(Joyce, 2003)

Properties	**Description**
Temperature of melting	2040^{o}C
Coefficient of thermal expansion	8.3x10-6 ^{o}C -315 ^{o}C
Young modulus	380-400GPa
Tensile strength	3-4GPa
Density	2.34g/cc

2.5.2 Steel Fibre

Steel fibre has various shapes, including melt extract, straight and deformed types. The aspect ratio of steel fibre, length to diameter, is one way to differentiate it. Aside from that, the volume fraction of steel fibre added to the concrete determines the behaviour of SFRC. When the percentage adds less than 1%, the steel fibre usually acts as a pavement reinforcement or plastic shrinkage controller. Some concrete performance, such as flexural strength or impact resistance, can be improved for a percentage of 1% to 2%. A structure's blast or impact resistance can be improved by adding more than 2% steel fibre (Behbahani et al., 2011).

With verification, steel fibre can effectively replace conventional shear reinforcement. Replacing traditional shear reinforcement appears promising because it could save time and make placement easier in highly reinforced structures. It has been reported that incorporating some steel fibre into concrete can significantly improve shear capacity. Furthermore, steel fibre can allow for greater energy dissipation, transforming the fragile shear mechanism into a better flexural mechanism with improved ductility (Cucchiara, la Mendola and Papia, 2004).

2.5.3 Carbon Fibre

Wet, melt, and dry spinning create carbon fibre from polymers like rayon or lignin. Then, carbonisation, oxidation, and surface treatment were performed to develop carbon fibre. Carbon fibre has low density, electrical and thermal conductivity in good condition, and good creep resistance. Carbon fibre is typically used as chopped and tape or filament winding. Carbon fibre has been used in various industries and fields, including automotive, medical, civil and aerospace engineering, and so on. Helmets, ailerons, and pallets are some examples of applications. Carbon fibre has advantages and disadvantages, including high durability, abrasion resistance, and high cost or thermal conductivity (Balias et al., 2015).

Chen and Chung (1993) studied concrete reinforced with short carbon fibres. 0.5 per cent of carbon fibres to the weight of cement is added to the concrete mix. After 28 days of curing, compared with unreinforced concrete, the flexural strength had an increment of 85 per cent, an increment in flexural toughness of 205 per cent, and a compressive strength increment of 22 per cent. The minimum fibre needed to provide sufficient strength to the concrete is 0.1 per cent. This shows that carbon fibre is very effective in increasing flexural toughness.

2.5.4 Aramid Fibre

The aramid fibre is classified into two types: meta and para. The meta-aramid fibre's properties make it resistant to heat or melt, and it will not ignite. Its applications include car racer and firefighter clothing. On the contrary, the advantages of para-aramid fibre include high heat resistance and elasticity (Prasad et al., 2014). Figure 2.9 shows the chemical structure of aramid fibre.

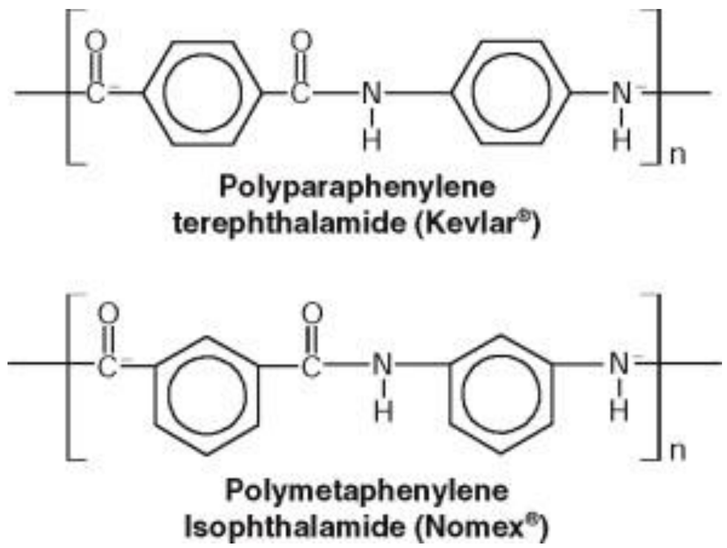

Figure 2.9: Para and Meta Type of Aramid Fibre (Prasad et al., 2014)

2.5.5 Polyethylene Fibre

Polyethene fibre comes in a variety of forms, including Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), and Ultra-High Molecular Weight Polyethylene (UHMWPE). The polymer material is the polyethene family. The polymerisation of ethylene monomer can result in the production of polyethene (PE). LDPE can be produced by polymerisation under free radical conditions. In this process, a peroxide initiator is used. The carrier bag and sack for heavy-duty applications are made of LDPE. HDPE is produced during ionic polymerisation. Carbon molecules are formed in a linear chain, and an organometallic catalyst is used. HDPE is used in the manufacture of fishing nets and carrier bags.

Furthermore, Low Molecular Weight Polyethylene (LMWPE) is a low melting temperature or strength material. It is used in candle making and automotive wax. When the molecular weight of PE is 1 million Da, it can be classified as UHMWPE. The advantages of this PE are its low density and chemical resistance. However, the viscosity of the melt or the natural draw ratio makes UHMWPE challenging to manufacture. PE fibre is alkali or acid in non-oxidising conditions, brittle and tough at low and room temperatures. Because of the PE fibre-resistance advantage to chemicals, chemical plants use it, and it can also be used for water piping (Deitzel, McDaniel and Gillespie, 2017).

Kobayashi and Cho (1981) studied the flexural behaviour of concrete reinforced with polyethene fibre. They found that the increment in polyethene fibre reduces the first crack strength. However, the useful load is maintained when deflection increases significantly after the first crack. When the fibre content reaches roughly 3%, its maximum value is higher than the first-crack strength.

2.5.6 Wool Fibre

The primary source of wool fibre, such as vicuna or wool fleece, is sheep or rabbit follicles. There are various types of amino acids found in wool fibre. For instance, serine or cysteine. Some treatments, such as bleaching or carbonising the wool, are required to improve the performance of the wool fibre resource. Scouring or carbonisation is necessary to remove contamination from the wool, such as dirt or grease. Wool fibre can be used in various applications, including clothing and upholstery. Wool fibre has several advantages, including being a renewable resource that does not pollute the environment and has low flammability. On the contrary, wool fibre's disadvantages are that it will shrink in size (Johnson et al., 2003).

2.5.7 Sisal Fibre

Sisal fibre can be obtained from the leaves of the agave sisalana plant, and one leaf can yield up to 1000 fibres. There are three methods for extracting sisal fibre from the leaves of the sisal plant. For example, boiling, retting, and the mechanical method. The sisal plant's leaves can be boiled to produce clean fibre. The purpose of retting is to break the chemical bond of the sisal leaves with water. As a result, the pith separates from the fibre. The disadvantages of this method are that it takes a long time and the fibre quality is poor.

Furthermore, a machine is known as Raspador is used to extract the fibre from sisal leaves. The sisal fibre is strong. The disadvantage of this fibre is that as the temperature rises, the toughness or strength of the sisal fibre decreases. Sisal fibres are used in various applications, including carpet and rope. Sisal fibre's tensile strength and modulus are 100-700 MPa and 9-40 GPa, respectively (Saxena, 2011).

2.5.8 Pineapple Leaf Fibre

Pineapple leaf fibre can be obtained from the pineapple plant. Scrapping is the first step in extracting pineapple fibre, followed by retting. A machine is used in the scrapping process. The machine is made up of three parts. The first component is known as the feed roller, and its function is to remove the waxy layer on the leaf. The upper layer of the leaf is scratched in the second part, known as the scratching roller. The serrated roller is the final component. Its purpose is to allow the leaves to be crushed and divided into several pieces for retting purposes (Asim et al., 2015).

Odusote and Kumar (2016) studied the mechanical properties of glass fibre and pineapple leaf fibre. The results showed that the glass fibre had higher ultimate tensile strength, young modulus, and elongation than the pineapple fibre. However, as the percentage of pineapple leaf fibre increased, the value of these three parameters increased. This indicated that as the fibre percentage increased, the pineapple fibre became stiffer and more tension-resistant.

2.5.9 Kenaf Fibre

The kenaf plant's ability to grow under various weather circumstances to a height of more than 3 m and a width of 3-5 cm in three months has made it a famous cellulose source with economic and ecological advantages. Moreover, kaf fibre can be extracted from the kenaf plant (Akil et al., 2011).

Elsaid et al. (2011) conducted a study on the properties of kenaf fibre-reinforced concrete. Kenaf fibres were retted, dried and cut into 25 to 38 mm lengths. Several pretreatment procedures were carried out to ensure that the fibres were in a state that would allow them to be mixed into a concrete mixture. Mechanical separation is accomplished by blowing air through a series of metal combs while the fibre bundle is passed through them to achieve fibre opening.

To strengthen the bond between kenaf fibres and the inorganic concrete mixture, chemical pretreatments are used. Anti-microbial treatment prevents fibre degradation and enhances fibre-reinforced concrete's durability. To maintain the workability of fresh concrete, more water needs to be added to the concrete mixture to allow for the fibre's water absorption.

The experiment results show that the strength of kenaf fibre-reinforced concrete is comparable to plain, non-air entrained concrete with a similar water-to-cement ratio at lower fibre concentrations. On the contrary, the compressive strength will be marginally less strong at greater fibre contents. This is because kenaf fibre provides ductility to the concrete, which exhibits better energy absorption and results in a more well-distributed cracking pattern.

From the splitting tensile test, the tensile strength is similar to conventional concrete. Additionally, the outcomes of the flexural testing demonstrate that kenaf fibre concrete will have a ductile failure mode as opposed to traditional concrete and will possess toughness that is roughly three times that of conventional concrete. Finally, the results show that kenaf fibre can increase concrete's durability more cheaper than other fibre types.

In a study by Lam and Yatim (2015), the impact of different fibre contents and fibre lengths on the mechanical properties of kenaf fibre-reinforced concrete was investigated. Their research indicates that using short fibres and higher fibre content leads to decreased compressive strength. Furthermore, kenaf fibre-reinforced concrete's flexural strength and indirect tensile strength positively correlated with fibre length and content. Based on their findings, it is recommended to use a volume and length of kenaf fibre equal to or less than 0.75% and 50mm, respectively, to enhance the concrete's performance.

Sadiqul Hasan et al. (2015) conducted a study to evaluate kenaf fibre-reinforced concrete's properties in fresh and hardened states based on the volume of kenaf fibre added to the concrete mix. According to their research, adding 1% of kenaf fibre to the concrete blend provides higher strength and toughness compared to adding 3% and 5% of the fibre. They concluded that kenaf fibre is a superior option for constructing lightweight concrete structures because of its exceptional crack resistance and toughness compared to synthetic, steel, or polypropylene fibres.

2.6 Summary

The use of coconut shells as a coarse aggregate replacement for lightweight concrete is suitable based on previous research (Gunasekaran and Kumar, 2008; Shelke et al., 2014; Palanisamy et al., 2020). In addition, kenaf fibre is excellent in providing ductility to the concrete with the approximate amount added into the cement matrix.

However, there are no studies about the performance of the combination of coconut shell and kenaf fibre to produce a high-strength structural lightweight concrete and study the optimum proportion mix for it. Hence, further research on the combination of coconut shell aggregate incorporated with kenaf fibre in concrete cement mix will be reviewed not only to aim to reduce the cost of concrete but also to produce sustainable and environmentally friendly concrete.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will describe the material used, the process of mixing and casting, and the laboratory test performed in this study. First, the raw materials will be fine and coarse aggregate, coconut shell, kenaf fibre, water and ordinary Portland cement. Next, the raw materials will be mixed, and a slump test will be done to test the fresh concrete's consistency. Finally, the hardened concrete will be cured with water after dmolding and performed tests such as compressive strength and splitting tensile tests. Figure 3.1 shows the overview of the casting work.

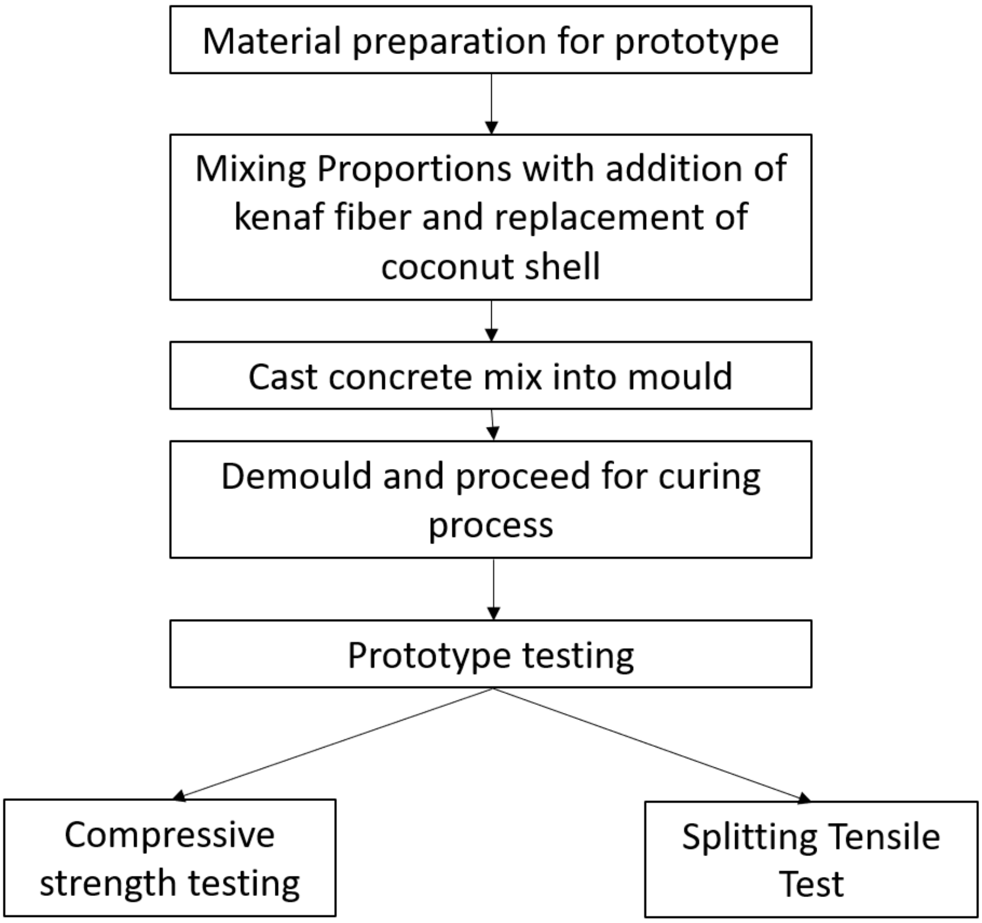

Figure 3.1: Overview of casting work

3.2 Material

Materials used in this experiment work will be ordinary Portland cement, water, coconut shell aggregate, fine aggregate and kenaf fibre.

3.2.1 Ordinary Portland Cement

The type I ordinary portland cement was used in this study based on the ASTM C150-07. This type of cement was used for general uses. The types of concrete that use type I Portland cement will provide sufficient strength for the lightweight concrete. Table 3.1 shows the type I Portland cement composition used in this study. The maximum C3A that can contain in type I cement is 15% (Baghchesaraei and Baghchesaraei, 2012). Figure 3.2 shows the ordinary portland cement used in this study.

Table 3.1: Compound in Type I Portland Cement

Compound	**Percentage(%)**
C_3S	55.0
C_2S	19.0
C_4AF	7.0
C_3A	10.0
Free Calcium Oxide (CaO)	1.0
Sulphur Trioxide (SO_3)	2.9
Magnesium Oxide (MgO)	2.8
Ignition loss	1.0

Figure 3.2: Ordinary Portland Cement

3.2.2 Aggregates

The aggregates used in this experiment are coarse aggregate, fine aggregate and coconut shell aggregate. The size of the coconut shell aggregate was controlled at an average size of 25mm. Coconut shell aggregate will be submerged in water for 2 hours and let dry to a saturated surface dry condition before mixing into the mix proportion to ensure that the coconut shell aggregate does not absorb the water. Fine aggregate was passed through 4.75mm and retained on a 75 µm sieve. Figures 3.2 and 3.3 show the coconut shell aggregate and fine aggregate used in this study.

Figure 3.3: Coconut Shell Aggregate

Figure 3.4: Fine Aggregate

3.2.3 Water

The water used for the casting of concrete will be potable water. Water that won't hurt people or concrete is known as potable water. If non-potable water is utilised, concrete will be harmed. The source of the potable water came from the municipal water system (ASTM C1602-06,2006).

3.2.4 Kenaf Fibre

Kenaf fibre will be added during the casting of concrete. First, t length of kenaf fibre will be cut into lengths of approximately 50mm to provide maximum mechanical properties to concrete(Lam and Yatim, 2015). Next, it will be washed and treated with a 6% sodium hydroxide solution to soften the fibre. After treating the fibre, the fibre will be washed and rinsed to eliminate excess chemical solution. Figure 3.4 shows the kenaf fibre before treatment.

Figure 3.5: Kenaf Fibre

3.3 Mixing Proportion

According to the study from Gunasekaran, Kumar and Lakshmipathy (2011), the optimum mixing ratio for cement, fine aggregate, and coarse aggregate(coconut shell aggregate) will be 1:1.47:0.65 with a water-cement ratio of 0.42 will be used to satisfy the optimum wood to cement ratio. The amount of kenaf fibre added to the mix will be differentiated into two types, which are 0% and 1%. Table 3.2 shows the mix proportion of each type of concrete specimen.

Table 3.2: Mix Proportion

Type of Concrete	**CSC**	**CSC with 1.0% Kenaf Fibre**
Cement, kg/m^3	709	709
Water, kg/m^3	298	298
Coconut Shell Aggregate, kg/m^3	165	165
Fine Aggregate, kg/m^3	870	870
Kenaf Fibre, kg/m^3	0	Depending on the volume fraction of kenaf fibre, as shown in Appendix B

3.4 Casting

A slump test will be conducted to ensure the concrete mix's consistency and quality before casting. This involves pouring the concrete mix into a slump cone in three layers and compacting each layer with a tamping rod around 25 times. After everything is compacted, the cone will be lifted to check the concrete mix's slump value; if the result is unsatisfied, the concrete mix will need to be remixed. Once the concrete mix has passed the slump test and is deemed suitable for casting, it is prepared and ready to pour into the mould. The mould must be cleaned and painted with a layer of oil before the fresh concretes are poured into the mould to ensure the concrete can be removed easily after hardening. Subsequently, the new concrete is added to the mould and formwork in three equal layers. To ensure proper compaction, a steel rod is used to tap each layer of concrete 25 times for both the cylinder and cube specimens to prevent a honeycomb formation. After that, a trowel was used to level the top layer of the concrete to produce a concrete specimen with a smooth surface.

3.5 Curing

Curing is the process of maintaining the proper moisture content and temperature in the concrete during the early stages of hardening so that chemical reactions such as cement hydration can occur at an optimal rate. Proper curing allows the concrete to gain strength, durability, and resistance to cracking and shrinkage. In accordance with the ASTM C192 standard, freshly hardened concrete will be left air-dry for 24 hours before being transferred into a water tank for water curing. The specimen will be cured for seven days and 28 days, respectively.

3.6 Testing

Slump test, compressive strength test and splitting tensile strength test will be conducted to compare the qualities of the CSC and CSC with kenaf fibre.

3.6.1 Slump Test

After all the raw materials of the concrete have been mixed homogeneously, the slump test should be conducted. The equipment required for this test includes a slump cone with a frustum shape, a steel rod, and a flat or impermeable base. As per ASTM C143, the standard dimensions of the slump cone should be a bottom diameter of 200 mm, a top surface diameter of 100 mm, and a height of 300 mm. The allowable range for changes in the diameter and size of the cone is plus or minus 3 mm. This test aims to determine the consistency of fresh concrete.

To conduct the test, the slump cone should be placed above the base and held firmly with two legs standing on the foot piece. The fresh concrete should then be added to the cone in three equal layers, each of which should be tapped with the steel rod 25 times to compact the concrete. After the three layers have been filled, the cone should be lifted without any vibration and upturned beside the concrete slump. The difference between the height of the cone and the height of the centre of the slumped concrete is called the slump value. According to ASTM C143, the recommended slump value should be between 15 mm to 230 mm. If the slump value is less than 15 mm, the concrete is not sufficiently plastic, whereas a slump value greater than 230 mm indicates that the fresh concrete lacks cohesiveness.

3.6.2 Compressive Strength Test

The maximum compressive axial load that caused the failure of the cube specimen can be obtained based on the compressive strength test (BS EN 12390-3,2009). The test will be applied on the cube specimen's 7 and 28 days of curing.

The machine used in this test is AD300/EL with a loading rate of 0.6 ± 0.2 MPa/min, which can read the strength of concrete until 3000kN in a digital condition. Below is an outline of the steps involved in conducting the compression strength test:

1. After the curing period, remove the specimen from the water and allow it to dry in an oven for two hours until it reaches the oven-dry state.
2. Position the specimen in the designated area of the testing machine.
3. Ensure that the specimen is precisely centred on the machine's base plate.
4. Gradually apply load onto the specimen until it reaches the failure point
5. Take note of the maximum load used, which caused the failure.

By dividing the area of the specimen exposed to the compressive load in mm^2 by the maximum axial load in N, computation of the compressive strength of a cube specimen will be done. Equation 3.1 shows the formula for the compressive strength of the cube specimen.

Compressive Strength in MPa, $\frac{P}{A}$ (3.1)

Where P= Maximum Axial Load (N)

A = Area of Specimen that Expose to the Compressive Load (mm^2)

Table 3.3: Compressive Strength Test

Type of Concrete	CSC	CSC with 1.0% of kenaf fibre
Size of Sample	(100x100x100)mm	(100x100x100)mm
Number of Samples for seven days Test	3	3
Number of Samples for 28 Days Test	3	3

3.6.3 Splitting Tensile Test

Indirect tensile tests, such as the splitting tensile test, can be used to determine the tensile strength of a brittle material. A cylinder specimen will be needed to evaluate the splitting tensile strength of the concrete. The failure occurred during the test when a diametral compressive force was applied over the whole length of the cylinder specimen. Tensile stress was present on the applied load, while compressive stress was around it. The splitting tensile strength was approximately 10% of the compressive strength (ASTM C496,2004).

The splitting tensile strength test was conducted in accordance with ASTM guidelines, which involved using 100 mm diameter and 200 mm long cylindrical specimens. To conduct the test, the specimen was placed in a centring jig, and bearing strips were carefully positioned along diametrically vertical planes at the top of the specimen. The bearing strip is used to ensure the stress is applied constantly over the entire length of the specimen. Therefore, the loading rate for the specimen tested will be 1.0 ± 0.2 MPa/min. The maximum diametrical load applied during the test was recorded, and the splitting tensile strength of the specimen was calculated using the formula given below:

Splitting Tensile Strength, $\sigma = \frac{2P}{\pi l d}$ (3.2)

Where P = Maximum Load that Causes the Specimen Failure(N),

l = Length of Specimen (mm)

d = Diameter of Specimen (mm)

Table 3.4: Splitting Tensile Strength Test

Type of Concrete	CSC	CSC with 1.0% of kenaf fibre
Size of Sample	(200x100)mm	(200x100)mm
Number of Samples for 28 Days Test	3	3

3.7 Summary

Cement, coconut shell aggregate, fine aggregate, water and kenaf fibre are used in this experimental study. To cast the concrete, it is crucial to mix the raw materials uniformly and conduct a slump test to determine the consistency of the fresh concrete. Following the slump test, the concrete is poured into cube or cylinder moulds and beam formwork for testing purposes. The dimensions of the cube specimen and cylinder specimen used in this study are 100 mm x 100 mm x 100 mm and 200 mm in length with a diameter of 100 mm, respectively. Cube specimens will be used for the compressive strength test, whereas cylinder specimens will be used for the splitting tensile test. According to Eurocode 2, a minimum cylindrical compressive strength of 17 MPa and density below 2000 kg/m3 must be achieved to ensure that CSC can be used as structural lightweight concrete.

CHAPTER 4

ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the data obtained from the test mentioned above. The compression test is conducted to examine the compressive strength of the concrete specimen, whereas splitting tensile strength is to evaluate the tensile strength of the concrete specimen. From the test above, we can understand the behaviour of CSC.

4.2 Slump Test

The workability of concrete is a vital aspect to consider during the construction process. From the results presented in Table 4.1, it can be observed that the slump value of the CSC and CSC with 1.0% kenaf fibre is 30mm and 25mm, respectively. This indicates that the addition of kenaf fibre has decreased the workability of the CSC. The reduction in workability can be attributed to the fact that the presence of kenaf fibre in the mix has caused the aggregates to be pushed apart, making it more challenging to achieve a desirable slump value.

Moreover, low workability can also lead to a low water-cement ratio in the concrete mix. The water-cement ratio is an essential factor affecting concrete's compressive strength, as it determines the amount of water needed to hydrate the cement particles. Therefore, a lower water-cement ratio results in a higher compressive strength of concrete. Thus, the reduced workability of CSC with the addition of kenaf fibre may positively affect the compressive strength of the concrete.

Notably, the decrease in workability due to the addition of kenaf fibre is not an uncommon observation. Similar findings have been reported by other researchers, such as Odusote and Kumar (2016), Lam and Yatim (2015) and Sadiqul Hasan et al. (2015). These studies have also reported a reduction in workability with the addition of natural fibres to concrete mixes.

Table 4.1: Slump Value of the Concrete Specimen

Type of Specimen	**Slump Value(mm)**
CSC	30
CSC with 1.0% Kenaf Fibre	25

4.3 Compressive Strength Test

Two types of cube specimens were employed to assess the compressive strength, namely CSC and CSC with 1.0% kenaf fibre. The mean compressive strength values of the respective cube specimens at 7 and 28 days are presented in Figure 4.1.

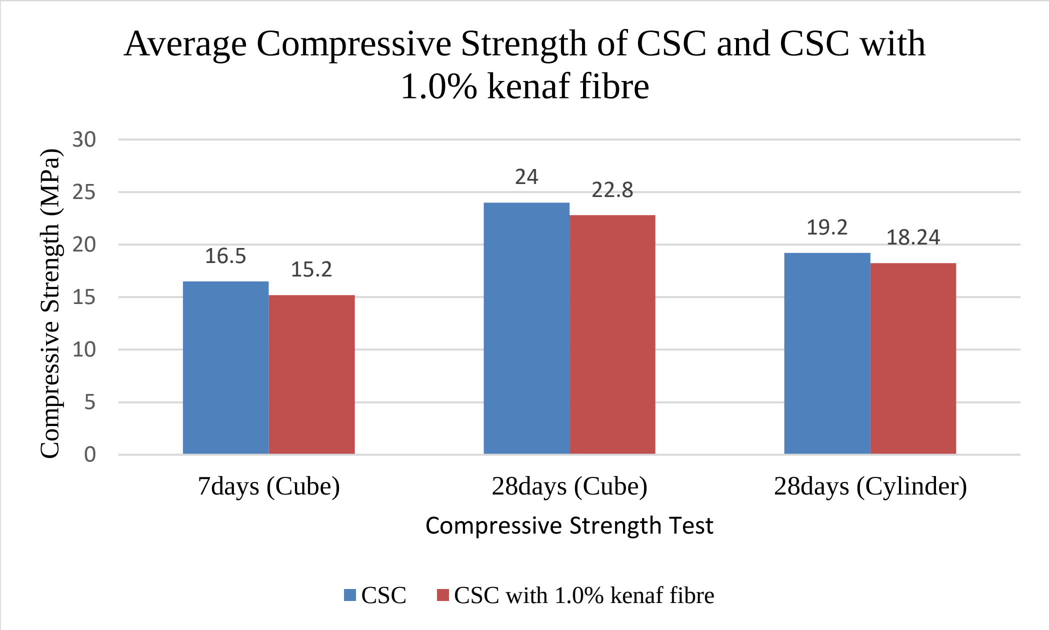

Figure 4.1: Average Compressive Strength of CSC and CSC with 1.0% kenaf fibre

After analysing the results presented in Figure 4.1, it is evident that the average compressive strength of CSC after 7 and 28 days, which is 16.50 MPa and 24.00 MPa, respectively, is greater than that of CSC containing 1.0% kenaf fibre. The addition of kenaf fibre results in a reduction of compressive strength which is consistent with the findings of other studies conducted by other researchers such as Odusote and Kumar (2016), Lam and Yatim (2015) and Sadiqul Hasan et al. (2015). According to ASTM C330 and Eurocode 2, the minimum cylinder compressive strength to be classified as structural lightweight concrete will be 17.0 MPa. Eurocode 2 shows that cylinder compressive strength can be taken as 0.8 of cube strength for cube strength below 50 MPa. From the result obtained from this study, it can be noticed that both CSC and CSC with 1.0% kenaf fibre are 19.20 MPa and 18.24 MPa, respectively, which had reached the minimum strength (17.0 MPa) to be determined as structural lightweight concrete.

Table 4.2: Comparative Study of Average Compressive Strength and Size of Coconut Shell Aggregate

Study	**Mix Proportion (Cement: Fine Aggregate: Coarse Aggregate: Water Cement Ratio)**	**Average Compressive Strength (MPa)**	**Size of Coconut Shell Aggregate (mm)**
Palanisamy et al. (2020	1:1.88:0.8:0.37	18.2	-
Gunasekaran, Kumar and Lakshmipathy (2011)	1:1.47:0.65:0.42	26.70	12.5
Tang (2023)	1:1.47:0.65:0.42	24.00	25

Nevertheless, it is worth noting that the compressive strength obtained from CSC in our study is slightly less compared to the research done by Palanisamy et al. (2020) and Gunasekaran, Kumar and Lakshmipathy (2011). Further investigation is needed to determine the underlying reasons for this discrepancy. Table 4.2 revealed the comparative study of the average compressive strength and size of coconut shell aggregate, and it can be confirmed that the particle size of coconut shell aggregate significantly impacted the compressive strength of CSC.

In a previous study conducted by Meddah, Zitouni and Belâabes (2010), the effect of particle size of coarse aggregate on concrete compressive strength was examined. The results indicated that an increase in particle size of coarse aggregate up to 12% would result in a corresponding increase in compressive strength from 3/8mm to 15/25 mm. However, the opposite trend was observed when compared to the findings of this current study. Specifically, the compressive strength of the 25 mm coconut shell aggregate obtained was 24.00 MPa, 10.2% less than the value reported by Gunasekaran, Kumar and Lakshmipathy (2011).

Another study by Ogundipe et al. (2018) investigated the size of coarse aggregate affecting the compressive strength of concrete. Their results indicated that an increment in the particle size of coarse aggregate results in a corresponding increase in the compressive strength of the concrete up to a certain point, beyond which further increases in particle size has an adverse effect on compressive strength. These findings align with our study, where it was observed that an aggregate size as large as 25 mm resulted in a decrease in the compressive strength of the CSC. Based on these observations, it can be concluded that the optimal aggregate size of coconut shell aggregate needs to be determined to obtain more satisfactory results. Further research in this area could potentially uncover more insights into the behaviour of different aggregate sizes in concrete and inform the development of guidelines for selecting the appropriate aggregate size for specific applications.

Figure 4.2: Crack Pattern of CSC

Figure 4.3:Crack Pattern of CSC with 1.0% Kenaf Fibre

The results obtained from the analysis of Figures 4.2 and 4.3 indicate that the number of cracks and the area of cracking, spalling, or crushing observed in the case of the coconut shell concrete (CSC) were higher and more extensive than those observed in the CSC with the addition of kenaf fibre. This outcome can be attributed to the low tensile strength of the CSC, which causes microcrack propagation to occur rapidly upon the application of a load. However, adding kenaf fibre has been found to enhance the tensile strength of the concrete.

As can be seen from the figures, the presence of kenaf fibre reduced the propagation of cracks and improved the ductility of the CSC. These findings suggest that including kenaf fibre in the concrete mix can significantly enhance its mechanical properties and performance under load. Therefore, it can be concluded that kenaf fibre can serve as a promising material for improving the durability and resistance of concrete structures against damage induced by external forces. Furthermore, a study by Syed Mohsin, Baarimah and Jokhio (2018) and Elsaid et al. (2011) also concluded that adding kenaf fibre can improve the durability and reduce the crack propagation of the concrete.

4.4 Splitting Tensile Test

The splitting tensile strength is calculated using equation 3.2; the results are shown in Table 4.3.

Table 4.3: Splitting Tensile Strength and Estimated Splitting Tensile Strength of CSC and CSC with 1.0% Kenaf Fibre at 28 days

Type of Specimen	**Average Splitting Tensile Strength, MPa**	**Estimated Splitting Tensile Strength, MPa**
CSC	2.50	2.69
CSC with 1.0% kenaf fibre	3.05	2.67

Table 4.3 shows that the average splitting tensile strength obtained from Concrete Specimen C (CSC) is 2.50 MPa, which is inferior to CSC containing 1.0% kenaf fibre, with an average of 3.05 MPa. Previous studies by Lam and Yatim (2015) and Elsaid et al. (2011) have indicated that the confining effect of kenaf fibre increases the splitting tensile strength of concrete specimens. Conversely, previous studies from Lam and Yatim (2015) and Elsaid et al. (2011) have indicated that the confining effect of kenaf fibre will significantly improve concrete specimens' splitting tensile strength.

ACI 318-08 proposes an equation correlating splitting tensile and compressive strengths. The equation states that the splitting tensile strength will be $0.55\sqrt{f_c'}$ in MPa, which has been modified from the original $0.67\sqrt{f_c'}$ in psi where f_c' is the cube compression strength. Table 4.6 shows that the estimated tensile strength for CSC with 1.0% kenaf fibre is lower than the recommended value by ACI 318-08. This indicates that the ACI 318-08 estimation is conservative for the kenaf fibre-reinforced concrete.

However, a comparison between CSC and the estimated splitting tensile strength proposed by ACI 318-08 reveals that the equation capable of overestimating the splitting tensile strength of coconut shell concrete. Gaedicke et al. (2016) mentioned in their study that ACI 318 did not consider the porosity of concrete, which will have a significant impact on the splitting tensile strength of concrete. Therefore, the lower splitting tensile strength results obtained from CSC in this study compared to the estimated value can be attributed to the higher porosity of CSC.

4.5 Summary

The average oven-dry density of the produced CSC and CSC mixed with kenaf fibre is 1973 kg/m3 and 1975 kg/m3, respectively, which falls below the maximum density of 2000 kg/m3 that defines lightweight concrete according to Newman and Owens (2003). Additionally, the estimated cylinder compressive strength of CSC and CSC with kenaf fibre are slightly higher than 17 MPa, measuring 19.20 MPa and 18.42 MPa, respectively. These results classify the concrete as structural lightweight concrete.

During the study, it was observed that adding kenaf fibre to CSC enhanced its tensile strength but reduced its compressive strength. However, incorporating natural fibres such as kenaf is more cost-effective than other fibres such as steel and synthetic fibres. The use of CSC mixed with kenaf fibre in producing interlocking concrete blocks and lightweight concrete wall panels for structural purposes is highly recommended due to its remarkable crack minimisation. In conclusion, the study demonstrates that adding kenaf fibre to CSC can result in an economical yet durable option for lightweight concrete production.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, this study investigated the effect of adding 1% kenaf fibre on the workability, compressive strength and tensile strength of coconut shell concrete (CSC) while satisfying the requirement of structural lightweight concrete. The results showed that the oven-dry density of CSC and CSC with kenaf fibre are within the requirement of lightweight concrete between 800 kg/m^3 and 2000 kg/m^3.

Moreover, the results showed that the addition of kenaf fibre caused a decrease in workability, which is a common observation in other studies involving the addition of natural fibres to concrete mixes. However, this reduced workability can positively affect the compressive strength of the concrete by lowering the water-cement ratio.

The compressive strength of CSC decreased with the addition of kenaf fibre, but both CSC and CSC with 1% kenaf fibre achieved the minimum compressive force required to be classified as structural lightweight concrete. The particle size of coconut shell aggregate was found to significantly impact the compressive strength of the CSC, with larger particle sizes resulting in a decrease in strength. The addition of kenaf fibre also reduced the number and extent of cracks in the concrete.

Overall, this study highlights the potential of using kenaf fibre as a sustainable and eco-friendly alternative to traditional reinforcement materials in concrete mixes. However, further research is needed to optimise the coconut shell aggregate and kenaf fibre combination to balance workability and compressive strength. Additionally, the behaviour of different aggregate sizes in concrete needs further investigation to develop guidelines for selecting the appropriate aggregate size for specific applications.

In conclusion, the study successfully evaluated the performance of CSC and CSC mixed with kenaf fibre for the production of structural lightweight concrete and compared their performance. The results indicate that

CSC mixed with kenaf fibre is a promising option for producing structural lightweight interlocking blocks and structural lightweight concrete wall panels.

5.2 Recommendation

Adding kenaf fibre to CSC decreases workability and compressive strength, but it can help reduce the number of cracks and the area of cracking, spalling or crushing. Therefore, using kenaf fibre in CSC should be considered in applications where improved durability is a priority over workability and strength.

Moreover, the particle size of coconut shell aggregate significantly impacts the compressive strength of CSC. Further research is needed to determine the optimal aggregate size of coconut shell aggregate for specific applications. The use of CSC as a structural lightweight concrete material is feasible, as it can meet the minimum compressive strength requirements according to ASTM C330 and Eurocode 2. However, further research is needed to investigate the long-term durability as coconut shell is an organic material that will decay over time.

Given that the reduction in workability due to the addition of natural fibres to concrete mixes is a common observation, it is recommended to conduct further research to investigate ways to mitigate this effect, such as modifying the mix design or using a combination of two fibre materials. In addition, future studies should consider investigating the impact of other parameters, such as curing conditions, on the performance of CSC to obtain a more comprehensive understanding of the behaviour of this material.

5.3 Further Study

To optimise the compressive strength of CSC, further research is needed to identify the optimum size of coconut shell aggregate for use in the mix. This can be accomplished by formulating various concrete mixes with different proportions of admixtures, such as superplasticiser and fly ash. Moreover, the combination of kenaf fibre with varying types of fibre can be further investigated to mitigate the negative impact of kenaf fibre on the compressive strength of CSC while maintaining and enhancing the mechanical strength and properties of the material.

Additionally, a comprehensive examination of the mechanical strength of CSC can be conducted by testing concrete mixes with partial replacement of coconut shell aggregate under the maximum density of lightweight concrete. By analysing the data gathered from these studies, researchers can improve the mechanical strength of structural lightweight concrete and help to develop more durable and sustainable construction materials. Overall, further research will lead to a better understanding of the properties of CSC and how it can be used to enhance the mechanical strength of CSC.

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APPENDICES

Appendix A: Absolute Volume Method for Mix Proportion

Materials	kg/m^3	Specific Gravity	Absolute Volume
Ordinary Portland Cement	709	3.15	0.225
Water	298	1	0.298
Water to Cement Ratio	0.42		
Fine Aggregate	870	2.63	0.331
Coconut Shell Aggregate	165	1.13	0.146
Theoretical Density=2042kg/m			Sum=1.000

Appendix B: Volume Fraction of Kenaf Fibre

Per Cube (100x100x100)mm : $134.3kg/m^3 \times 1.0/100 \times 1.0x10^{-3}m^3$

$= 1.343g$

Per Cylinder(100x200)mm : $134.3kg/m^3 \times 1.0/100 \times 1.57x10^{-3}m^3$

$= 2.108g$