INFLUENCE OF OIL PALM FIBER AND STEEL FIBER INCLUSION ON PROPERTIES OF CONCRETE

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INFLUENCE OF OIL PALM FIBER AND STEEL FIBER INCLUSION ON PROPERTIES OF CONCRETE

by

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ABSTRAK

Tandan buah kosong (EFB) adalah sisa yang tertinggal setelah buah kelapa sawit diekstrak dan minyak sedang diproses. Serat kelapa sawit (OPF) boleh didapati dari kumpulan vascular tandan buah kosong. Kemasukan OPF ke dalam campuran konkrit sebagai pengganti separa untuk serat keluli (SF) dalam konkrit yang bergentian dapat membantu mengurangkan sisa supaya persekitaran yang lebih hijau dapat dihasilkan. Penyelidikan ini mengkaji pengaruh kemasukan serat kelapa sawit dan serat keluli kepada sifat konkrit. OPF dengan panjang 3-5cm dan SF dengan panjang 10mm-16mm dan diameter 0.2mm telah digunakan dalam penyelidikan ini. Enam (6) kumpulan campuran yang berbeza telah disediakan, iaitu Mix A (kawalan), Mix B (1% SF, 0% OPF), Mix C (0.75% SF, 0.25% OPF), Mix D (0.5% SF, 0.5% OPF), Mix E (0.25% SF, 0.75% OPF) dan Mix F (0% SF, 1.0% OPF). Sifat konkrit segar iaitu kebolehkerjaan dan sifat konkrit yang telah mengeras iaitu ketumpatan, kekuatan lenturan, kekuatan tegangan pembelahan dan kekuatan tegangan langsung telah dinilai menggunakan kaedah yang berbeza. Hasil yang diperoleh menunjukkan bahawa kemasukan serat ke dalam campuran konkrit mengurangkan kebolehkerjaan campuran konkrit secara beransur-ansur akibat kekurangan kecairan compuran konkrit disebabkan campuan serat. Selain itu, Mix B dengan 1.0% kemasukan SF menunjukkan peningkatan sifat mekanikal manakala Mix F dengan 1.0% kemasukan OPF menunjukkan pengurangan sifat mekanikal berbanding konkrit biasa. Sebaliknya, Mix C dengan kombinasi 0.75% SF dan 0.25% OPF menunjukkan peningkatan sifat mekanikal berbanding konkrit biasa tetapi tidak dapat mencapai yang sama seperti Mix B.

ABSTRACT

Empty fruit bunches (EFB) are the waste that is left after the fruit of oil palm is extracted and the oil is being processed. Oil Palm Fiber (OPF) can be obtained from the vascular bundle of EFB. Inclusion of OPF into the concrete mix as partial replacement for Steel Fiber (SF) in fiber reinforced concrete can help to reduce the waste produced for a greener environment. This research studies the influence of the inclusion of OPF and SF to the properties of concrete. OPF of length 30-50mm and SF with a length of 10mm-16mm and diameter of 0.2mm is used in this research. Six (6) different batches of mixes were prepared, namely Mix A (control), Mix B (1% SF, 0% OPF), Mix C (0.75% SF, 0.25% OPF), Mix D (0.5% SF, 0.5% OPF), Mix E (0.25% SF, 0.75% OPF) and Mix F (0% SF, 1.0% OPF). The properties of the fresh concrete, which is the workability and hardened concrete, which is the density, compressive strength, flexural strength, splitting tensile strength and direct tensile strength were assessed using different methods. The results obtained show that the inclusion of fiber to concrete mix reduced the workability of the concrete mix gradually as the fluidity of concrete mix is decreased by the fiber. Besides that, Mix B with 1.0% of SF inclusion shows increase in mechanical properties while Mix F with 1.0% of OPF inclusion shows reduction in mechanical properties compared to plain concrete. On the other hand, Mix C with combination of 0,75% of SF and 0.25% OPF shows increase in mechanical properties compared to plain concrete but cannot achieve the same as to Mix B.

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LIST OF ABBREVIATIONS

BS	BRITISH STANDARD
EFB	EMPTY FRUIT BUNCHES
EN	EUROPEAN NORM
MS	MALAYSIA STANDARD
OPF	OIL PALM FIBER
SF	STEEL FIBER
SFRC	STEEL FIBER REINFORCED CONCRETE

CHAPTER 1

INTRODUCTION

1.1 Overview

Concrete is now one of the most consumed materials, second only to water, almost three tonnes used for a person per year on the planet (Gagg, 2014). Portland cement, water, fine aggregate, and coarse aggregate are the principal components of concrete. Concrete is cheap, able to be used in a wide range of applications; additionally, it also can be designed to have a high compressive strength which is one of its advantages (Liu and Liu, 2016). However, concrete possesses unwanted traits as a brittle material which is link to its low strain capacity and tensile strength. Consequently, steel reinforcement bars are used in the concrete to resist the tensile and shear stresses that are imposed on to the concrete (Behbahani *et al*., 2011).

Research and experiments were carried out to resolve the shortcomings of concrete and to enhance the properties of concrete. The utilization of fiber has been proven to enhance the mechanical properties of the concrete and its durability (Zhang *et al.*, 2018). Fiber reinforced concrete can be obtained with the inclusion of randomly oriented fibers to Portland cement concrete. As stated by the American Concrete Institute (ACI) committee 544, there are four classifications of fibers which are steel fibers, synthetic fibers including carbon fibers, glass fibers and natural fibers. Each classification of fibers possesses properties that are distinct from each other (Algihwel and Sultan, 2018).

Steel fiber reinforced concrete (SFRC) are used in various different application such as highway and air-field pavements, hydraulic structures, shotcrete, refractory concrete, precast and conventional reinforced concrete member (Behbahani *et al*., 2011).

From past studies, the addition of steel fibers in Portland cement concrete resulted in the compressive strength, tensile strength and flexural strength to increase (Liu and Liu, 2016; Mohod, 2012; Kavade and Warudkar, 2017). However, steel fibers (SF) are considered not cheap, as reduced labour cost is the cost saving way for SFRC (Bill, 2017).

The oil palm industries had produced lignocellulosic biomass such as oil palm trunks, oil palm fronds, empty fruit bunches (EFB) and palm pressed fibres. The lignocellulosic biomass aids in the strengthening of building materials' bonding or structure (Ismail and Hashim, 2008). With the amount of waste that is produced by the oil palm industries, it may cause a significant disposal issue (Abdullah and Sulaim, 2013). After the fresh fruit of oil palm is being processed, it is left with EFB. In 2007, EFB contributes 18.02 million tonnes of wastes from the oil palm industry (Goh *et al.*, 2010). Oil palm fibers (OPF) is a kind of natural fiber that could be utilized to enhance concrete performance. OPF can be obtained from the vascular bundle of the empty fruit bunch (Lee *et al.*, 2018). According to past studies, addition of oil palm fiber to concrete has increased the performance of concrete (Ahmad and Mohd Noor, 2008; Ismail and Hashim, 2008; Lee *et al.*, 2018).

1.2 Problem statement

Malaysia has abundance of oil palm plantation. As reported in December 2018, Malaysia has a total oil palm plantation area of 5.849 million hectares. Besides that, the second largest palm oil producer in the world is Malaysia (Tan, 2019). Thus, Malaysia oil palm industry generated a huge amount of palm biomass wastes such as oil palm trunks, oil palm fronds, EFB and palm pressed fibres. These biomass waste materials reflect that Malaysia has a strong supply of natural fibre that has high tensile strength (300-600 N/mm^2), density (1200 kg/m^3), and lignin content (23.03%) (Lee *et al.*, 2018).

OPF from EFB is one of a kind of reinforcing materials. It is non-harmful and renewable, furthermore, it can be attained at a low price as there are quite many well-established technology available to extract OPF from EFB (Musa *et al*.,2018).

As to maximize the use of the OPF to reduce the waste produced for a greener environment, incorporating OPF as a partial replacement for SF in SFRC may be one of the keys to the solution. Besides providing resolution to waste reduction, partial replacement of OPF for SF in SFRC can reduce the use of SF, resulting in cost reduction for materials. Therefore, further study and investigation are required to explore the potential of OPF as fiber reinforcement in concrete with the aim of maximizing the use of OPF.

1.3 Objectives

The objectives of the study are:

1. To study the effect of oil palm fiber and steel fiber inclusion on the properties of concrete.
2. To investigate the influence of oil palm fiber and steel fiber when used in combination on properties of concrete.

1.4 Scope of work

Laboratory works were conducted for this research to study the influence of oil palm fiber and steel fiber inclusion on the properties of the concrete. Six (6) batches of concrete mix with different amount of fiber were prepared for this experiment. One of the prepared concrete mixes was the control mix in this experiment. The other 5 different batches have different proportions of fiber (1% SF/0% OPF, 0.75% SF/0.25% OPF, 0.5% SF/0.5% OPF, 0.25% SF/0.75% OPF, 0% SF/1.0% OPF). The workability of the concrete mixes was evaluated by carrying out the slump test. After that, the concrete mixes were moulded into different samples namely cubes, beams, cylinders and dumbbells. The concrete specimens were cured in water temperature. The mechanical properties of the concrete specimens were then assessed by conducting compressive strength test, flexural strength test, splitting tensile strength test and direct tensile strength test.

1.5 Dissertation outline

This dissertation comprises of four additional chapters and are organised as follows:

Chapter 2: Literature Review

This chapter sums up the significant literature, as well as previously carried out studies pertaining to the use of steel fiber and oil palm fiber on the properties of the concrete.

Chapter 3: Methodology

This chapter describes the procedure of the laboratory works that were conducted in this research. It consists of procedures of mixing of materials, preparation of moulds, curing of concrete specimens and the testing of the specimens.

Chapter 4: Results and Discussion

This chapter shows the comparison and analysis of the results that were obtained from the laboratory work. Data was presented in the form of tables and graphs. Besides that, discussion of the results obtained were also provided and comparison was made with related previous work.

Chapter 5: Conclusions and Recommendations

This chapter concludes the crucial findings and achievement of the objectives of this research. Recommendations for further research are also presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Over the past decades, there is a vast number of research that had been conducted to determine the advantages and the performance of fiber reinforced concrete. Fibers that have been used to in the related research works range from steel fiber (Fu *et al.*, 2014), glass fiber (Bishetti *et al.*, 2019), synthetic fiber (Zhang *et al.*, 2014) and natural fiber (Harle and Vaibhav Dhawale, 2014).

Each type of different fiber has its unique properties in terms of physical, mechanical and chemical such as tensile and compressive strength of the fiber, ductility of the fiber, its elongation to failure, etc. The different properties of the fiber itself will affect the properties of the fiber reinforced concrete that is produced (Algihwel and Sultan, 2018). From past studies, it is reported that the compressive strength, tensile strength, ductility, and the pattern of the cracks of the concrete and the fracture strength of the concrete can be enhanced with the inclusion of fibers. The appearance of cracks on the concrete can be delayed with the inclusion of fiber which shows the benefit of the fiber (Fitzgerald, 2000; Norambuena-Contreras *et al.*, 2015).

Fiber can either be used as primary or secondary reinforcement in concrete. As fiber worked as primary reinforcement, it is used in the products that are thin-sheet, where reinforcement bars are not used and the matrix contains a higher content of cement than the normal concrete. Concrete that used fiber as primary reinforcement has an increase in strength and toughness. Besides that, cracking that is caused by the change of temperature or humidity can be controlled with fiber that is used as a secondary reinforcement for concrete. Furthermore, it also provides post-failure integrity when spalling or overload by accident happens (Filho *et al.*, 1999; Bentur and Mindess, 2007). Adding various fibers as reinforcement for cement matrix has been proven to sustain a fast transmission of micro cracking when stressed and able to withstand loading after the initial cracking, thus improves the toughness of the concrete (Yurtseven, 2004).

It has been addressed that composite material containing fiber including fiber reinforced concrete has a limit in strength that is influenced by the volume of fiber used, the aspect ratio of the fiber which is the ratio of the length to the diameter of the fiber used and the interaction between the matrix and the surface of the fiber. (Kim, Naaman and El-Tawil, 2009). For fiber reinforced concrete, increasing the amount of fiber included in concrete will result in the weakening of the mechanical properties of the cement matrix in the stage of elastic response when subjected to loading (Trejbal *et al.*, 2019). Therefore, the amount of fiber to be included in the concrete mix should be smaller. Contrarily, crack bridging occurs where the acting stress is transferred across the crack by the fiber when the matrix limit of proportionality is exceeded, and the crack has done damage on the matrix. This made sure the whole material retains its macroscopic integrity. The number of fiber and the adhesion between its surface with the cement matrix will have an impact on the amount of stresses that are being transferred (Trejbal *et al.*, 2019).

Fiber reinforced concrete can be mixed through many methods. The fibers should be mixed with a uniform dispersion to avoid the segregation of fiber or the balling effect of fiber. Most of the balling effect occurs when the fibers are added to the concrete mix. The balling effect tendencies will increase when the percentage of fiber included to the concrete mix increases, the aspect ratio of the fiber increases as well as when the aggregate size and quantity increase. This will thus decrease the workability of the concrete mix (Ragavendra *et al*., 2017). According to past experience, a range of 0.4 to 0.6 of water cement ratio are required (Bentur and Mindess, 2007). Generally, fiber reinforced concrete mix has a higher cement factor, higher content of fine aggregate and coarse aggregate that is smaller compare to the conventional concrete (Wafa, 1990).

2.2 Type of fiber

Different types of fibers, vary of different sizes, in the form of natural and manmade, have been integrated into cement-based matrices such as cement paste, mortar or concrete. Choices of the fibers that are used vary from commercially notable ones such as polypropylene or carbon which are the synthetic organic, steel or glass which are the synthetic inorganic, cellulose or sisal which are the natural organics to asbestos which is the natural inorganic (Ozerkan *et al.*, 2013). Despite the majority of the developments which used ordinary Portland cement, cement with high alumina content or cement with the inclusion of additives such as slag, fly ash, silica fume are used to enhance the durability of the concrete composite, or to reduce the chemical interactions between the cement matrix and the fibers to minimal (Bentur and Mindess, 2007). Figure 2.1 shows the general classification of fiber.

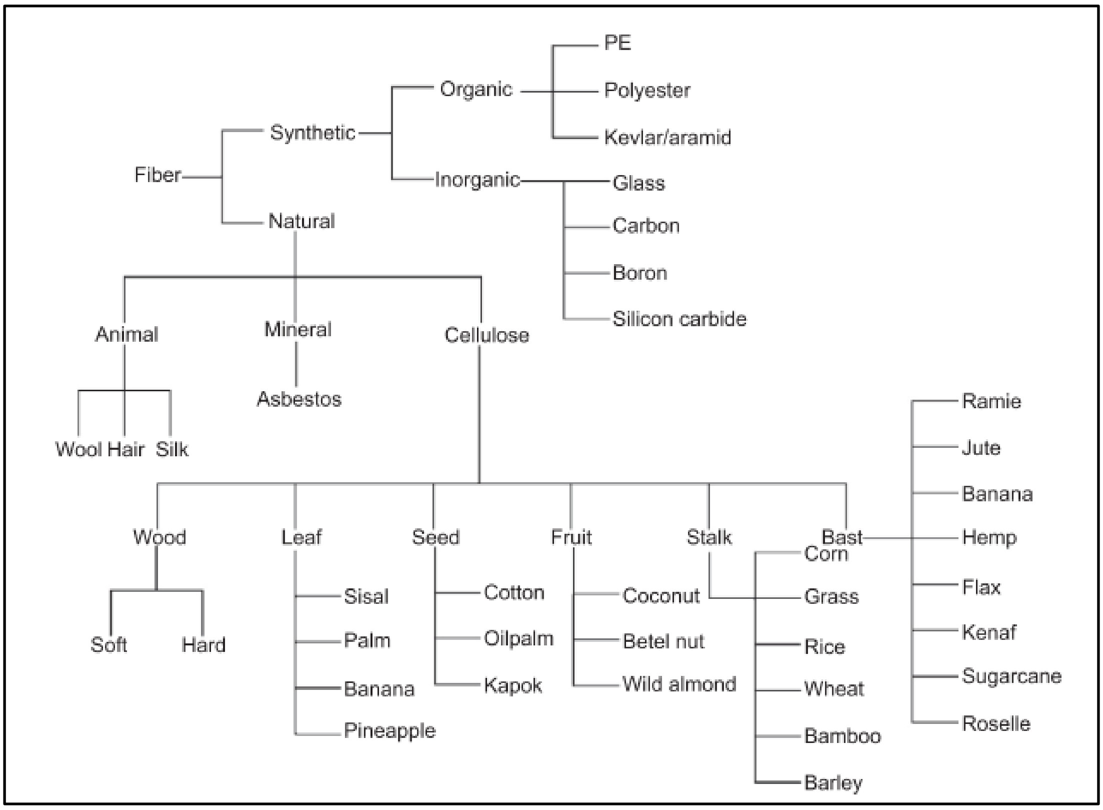

Figure 2.1: Classification of fiber
(Patel and Parsania, 2017)

Of all of the usage of fibers, synthetic fibers have accounted for almost half of it with the application in different fields (Jamir *et al*., 2018). In the early 60s, SFRC was being developed; during the late 70s, polymeric fibers were commercially used; in the 80s, glass fibers were widely used while in the 90s carbon fibers were attracting much more attention. Even though many developments were made on incorporating organic synthetic fibers into FRC, it is not a feasible alternative for steel and glass fibers. As an example, a high modulus poly aramid was developed, however, be a replacement as primary reinforcement, it will be at a high cost (Fangueiro *et al*., 2008).

The use of whether treated or untreated natural fibers to reinforced cement-based composite is widely applied in various applications worldwide. The natural fibers are obtained from different parts of different plants. For instance, fibers such as ramie, kenaf, hemp, jute and flax are acquired from the stem of plants, pineapple, banana and sisal are acquired from the leaf of plants and kapok and cotton are acquired from the seed of plants. Natural fibers are composites made up of cellular structure that consists of a different percentage of cellulose, hemicellulose and lignin which consist of various layers (Filho *et al.*, 1999; John *et al.*, 2005). Natural fibers have high tensile strength but low elastic modulus, yet, their properties have high dissimilarity causing the fiber-cement composite to have unpredictable properties (Li *et al*., 2006).

2.2.1 Steel fiber

The inclusion of SF in concrete dated back to 1950’s to 1960’s. In the beginning, only SF that are straight were used. Even though there is an enhancement on the toughness and ductility of the concrete, there are problems with the workability of the cement mix. The solution to the encountered problem is the arrival of SF that are deformed and the usage of superplasticizer. Steel is the most widely used fiber form as concrete reinforcement today, second only to asbestos fiber (Yurtseven, 2004).

In the recent years, there are efforts made to enhance the shape of SF as to increase the bond between the cement matrix and fiber, furthermore to promote the fiber to be well dispersed in the concrete mix (Pająk and Ponikiewski, 2013). As provided by ASTM A 820, there are 4 general classifications of SF when it comes to manufacturing products. The manufacturing products are melt extracted, cold drawn wire, cut sheet and other fibers (Labib, 2018). Figure 2.2 shows the general type of SF that are used in concrete.

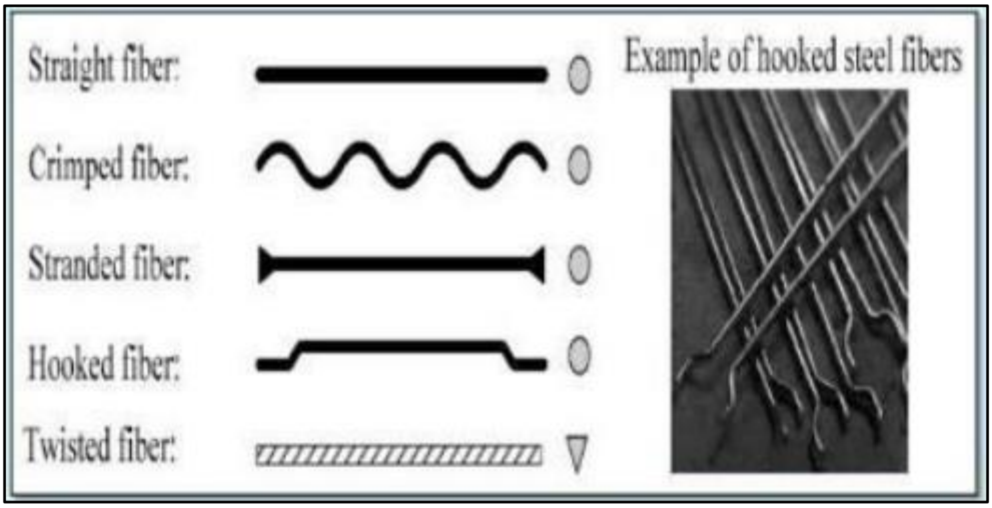

Figure 2.2: General type of steel fiber used in concrete
(Nipurte *et al.*, 2018)

The type of SF and the technique of manufacturing affect the general properties of SF which has tensile strength ranging from 280-2800 MPa and an ultimate elongation of 0.5% to 3.5%.

2.2.2 Oil palm fiber

The waste from oil palm plantation ranges from the shell of the oil palm, EFB fiber, oil palm mesocarp fiber, oil palm trunk fiber and oil palm frond fiber (Dungani *et al.*, 2013). The cellulose and hemicellulose of the OPF are bonded in the form of lignin matrix, same as most of the natural fibers. In other words, they are called lignocellulosic fibers. Figure 2.3 shows the different types of OPF that can be extracted from different parts of the oil palm tree (Nadlene *et al.*, 2016).

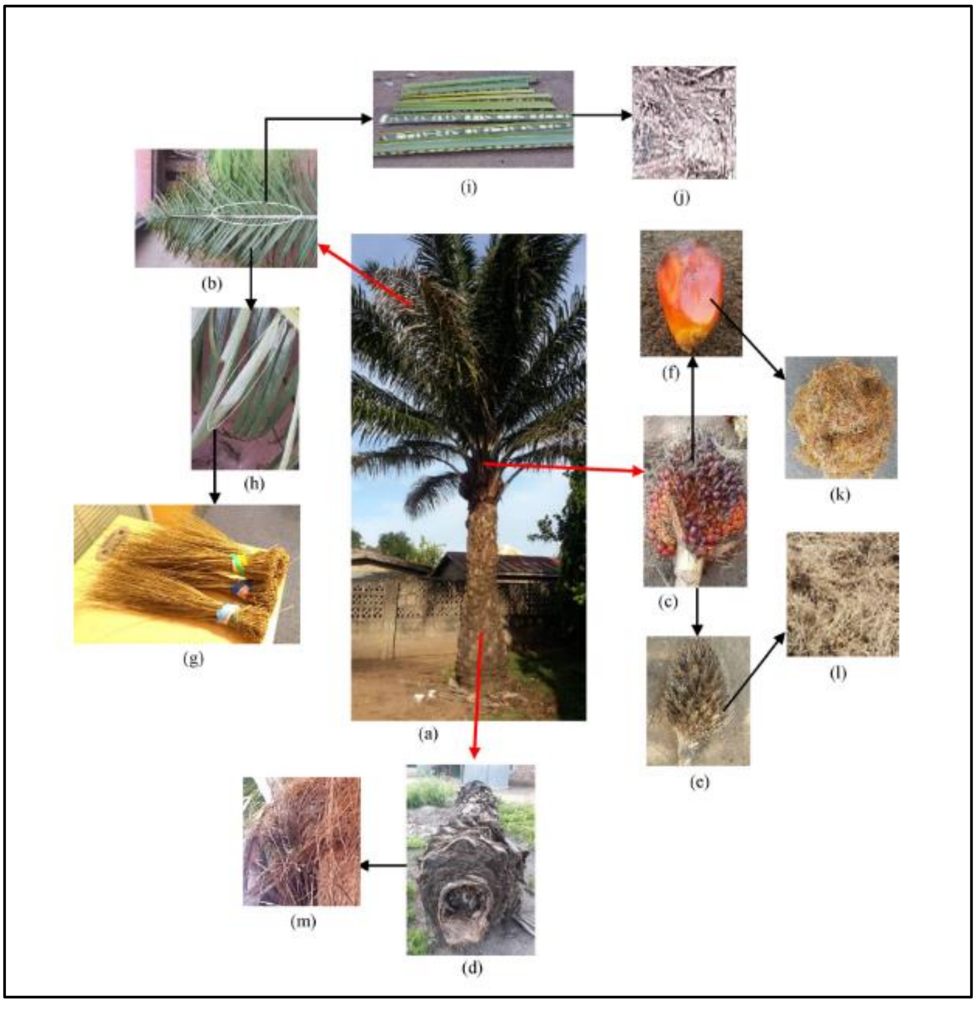

Figure 2.3: Different types of OPF: (a) oil palm tree; (b) leaf; (c) fruit; (d) trunk; (e) EFB; (f) dissected oil palm fruit; (g) oil palm broom fibers; (h) oil palm leaflet; (i) oil palm frond; (j) oil palm frond fibers; (k) oil palm mesocarp fibers; (l) EFB fibers; (m) oil palm trunk fibers.
(Momoh and Osofero, 2020)

EFB fibers are the residues of the fresh fruit bunch where the fruit are removed, and the oil is being processed. It is worth noting that EFB fiber varies from the oil palm mesocarp fiber although some research believed otherwise. The properties of the fiber that is reported may misguide engineers for them trying to use them for construction. The study used bunch fiber and fruit fiber in combination to form EFB fiber. It is reported from the study that one fruit bunch yields and average 400 g of EFB fiber *(Sreekala et al*., 1997). Annually, there are nearly 12 million tonnes of this fruit bunch that ready to be disposed by the oil palm refineries (Khalil *et al.*, 2012). It was reported that 4.4 tonnes of EFB fiber per hectare require to be disposed as wastes per year from oil palm refineries (Kelly-Yong *et al.*, 2007). Besides being discarded as waste, they may be used as fuel to generate electricity for oil palm plantation mills.

The extraction of EFB fiber is done by retting. For instance, mechanical retting which is hammering of EFB fiber, chemical retting which is immersion and boiling of EFB fiber in chemical, steam retting or microbial retting (Patel and Parsania, 2017). The most environmental friendly way to extract EFB fiber is by mechanical retting because the other retting processes may cause pollution to the water bodies (Shinoj *et al.*, 2011). After crushing the fresh fruit bunch, fruit shell and the husk of the oil palm, EFB are sieved to eliminate impurities. It is then loosened, washed to reduce oil content, dried to reduce moisture content and cut into desired length of fiber (Ahmad and Mohd Noor, 2008).

The main chemical compositions of EFB fiber are cellulose, hemicellulose, hollocellulose, lignin, and ash (Nadlene *et al.*, 2016). Table 2.1 illustrates the percentage of compositions of EFB fiber based on different research.

Table 2.1: The compositions of EFB fiber by percentage from different research (Momoh and Osofero, 2020)

Composition / Source	Cellulose	Hemicellulose	Holocellulose	Lignin	Ash
	Percentage (%)				
(Lertwattanaruk and Suntijitto, 2015)	-	-	47.7	24.5	6.99
(Shibata et al., 2008)	65	-	-	19	2
(Or *et al.*, 2017)	38.3	35.3	-	22.1	1.6
(Ismail and Yaacob, 2011)	59	2.1	-	25	3.2
(Bahari, 2010)	-	24	65.5	21.2	3.5
(Koba and Ishizaki, 1990)	-	20.8	-	28.5	5.6
(Khalil et al., 2012)	43-65	17-33	68-86	13-37	1-6

Strength of fiber is a vital factor for the inclusion of fiber in concrete. The length of fiber plays an important role that determines the bonding of fiber and the cement matrix, and the distribution of stress of the composite (Khalil *et al.*, 2008). Besides that, it is reported that the l/d which is the aspect ratio of the fiber plays a significant role in the final properties of the composite. The physical properties of the OPF in terms of the length, diameter, lumen width and density have significant effects on the composite materials' physical and mechanical properties (Hassan *et al.*, 2010; Shinoj *et al.*, 2011; Jawaid and Abdul Khalil, 2011). As OPF has low specific gravity, it is able to give a high strength-to-weight ratio when used in plastic material (Hariharan and Khalil, 2005). As reported, the optimum length of EFB fiber is 30 mm (Musa *et al.*, 2017).

The mechanical properties of the fiber include the tensile strength of the fiber, young's modulus, and the breaking elongation of the fiber. The properties are correlated to the internal structure and the composition of the fiber. Generally, the higher the cellulose content of the fiber will result in higher tensile strength and young's modulus of the plant fiber (Aji *et al.*, 2009). Table 2.2 shows the summary of the physical and mechanical properties of EFB fiber based on the work by some previous researchers.

Table 2.2: Physical Properties and Mechanical Properties of EFB fiber
(Momoh and Osofero, 2020)

Properties / Source	Diameter (mm)	Length (mm)	Density (g/cm^3)	Breaking elongation (%)	Tensile strength (MPa)	Young's modulus (GPa)
	Value					
(Danso, 2017)	0.23	17	4.0	-	19	12
(Obilade and Olutoge, 2014)	0.02	30	-	4	21.2	0.5-2
(Ismail and Yaacob, 2011)	0.25-0.6	100-280	1.3	30	21	-
(Khalil et al., 2012)	0.008-0.3	0.89-1.42	0.7-1.55	2.5-18	50-400	0.57-9
(Or *et al.*, 2017)	-	-	-	14	248	2.0
(Ahmad and Mohd Noor, 2008)	0.02-0.07	-	1.03	-	-	-
(Patel and Parsania, 2017)	0.15-0.5	-	0.7-1.55	4-18	50-500	0.6-9
(Yousif, 2010)	0.35	20	-	0.3-16.2	50-55	0.57-0.59

2.3 Application of steel fiber reinforced concrete

The applications of SFRC are so diverse that categorization is complicated. Stairways, pavements, airport pavements, slabs, tunnel linings, shotcrete, refractory elements, and various types of concrete repair are among the applications. Through the accumulated research conducted on SFRC, the application of SFRC can be further expanded. However, the addition of SF to concrete at approximately 1% may almost double the price. Therefore, SFRC is only limited to special application to save cost (Yurtseven, 2004). Figure 2.4 shows the typical application of SFRC.

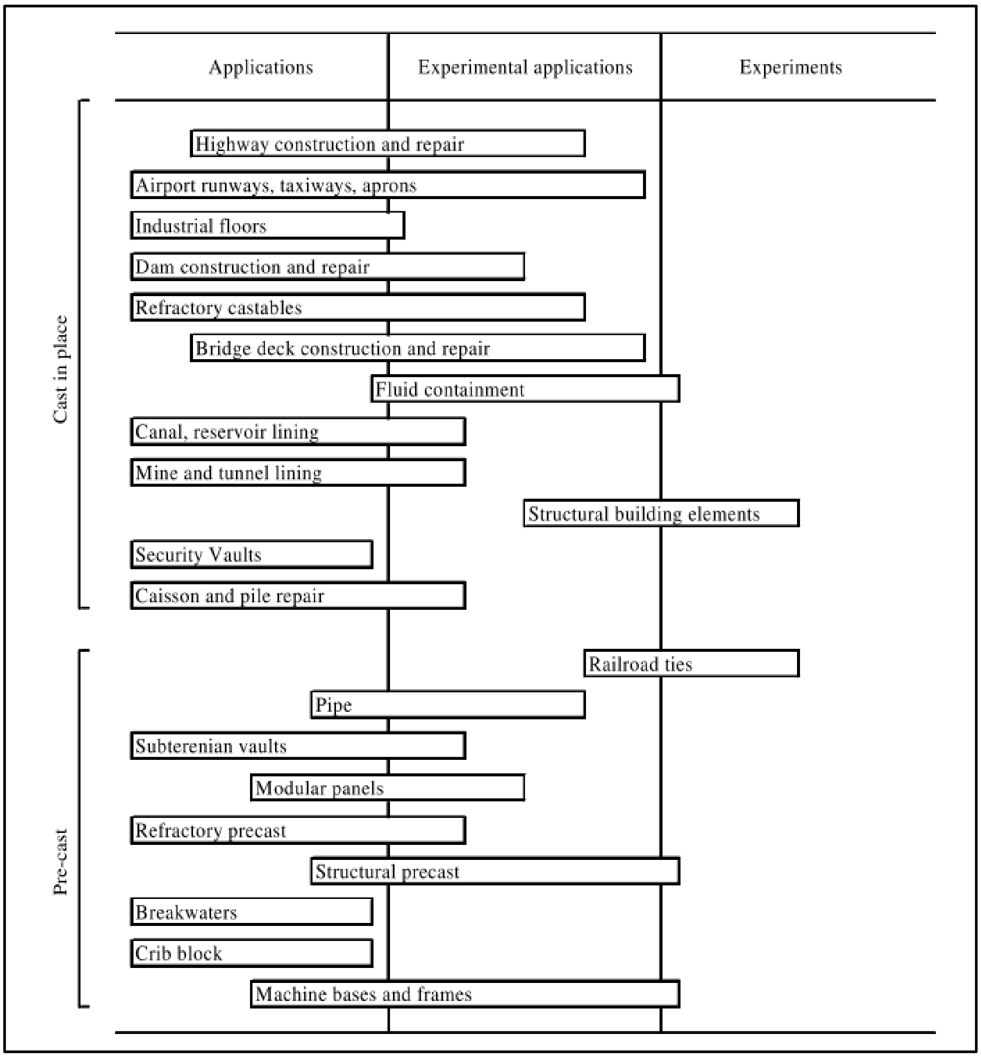

Figure 2.4: Typical application of SFRC
(Yurtseven, 2004)

One of the examples of the application of SFRC is on water resources and hydropower engineering. In water resources and hydropower engineering, pump pipe is an integral component. SFRC pump pipe is widely used as it has many advantages compared to the pure steel tube. One of the advantages is because it is free of corrosion as pure steel may get corroded over time. Besides that, the transportation and installation of SFRC pump pipe is more convenient and its costing for maintenance is somewhat lower (Liu and Liu, 2016). In Czech Republic, SFRC was used to produce sewage pipe with various sizes. The traditional way of producing sewage pipe is by adding reinforcement cage that is formed by welding spiral wires to longitudinal wires, to concrete. The reinforcement that is added to the concrete is used to prevent the pipe from getting damage when being manipulated or transported. There are several types of fibers that were incorporated to concrete for testing and SFRC was proven to be the most efficient (Kohoutková and Broukalová, 2017).

Another application of SFRC is on the bridge engineering. SFRC is good in resisting crack, fatigue, impact, shrinkage, has good flexural properties and toughness. The excellent properties of SFRC makes is suitable as other material for bridge deck, but at the same time reducing the thickness of the surface layer. This does not only save the cost of material, SFRC also reduces the cost for maintenance and extends the bridge deck’s service life (Liu and Liu, 2016).

Besides being applied for water resources and hydropower engineering and bridge engineering, SFRC also being applied for structural engineering. In power transmission, there are experimental research showing that the beam-column node to be an important part. As the part usually required a big force, it will get damaged easily. Furthermore, seismic action will cause destruction to the node and cause a further degree of damage to the node. Joining the node with a stirrup is the traditional way of enhancing the node's seismic intensity, as stirrup improves the tensile strength of the node. Although this method proves to be effective, it is not convenient to construct it. If SFRC is used for the nodes, it can enhance the seismic activity significantly (Liu and Liu, 2016).

Few projects around the world have been applying SFRC for structure. One of the examples was at a machinery warehouse at Western Australia. As the location of the warehouse is in the region of Australia that has the most severe cyclonic wind, the footing of the warehouse was designed to resist high wind load. Originally, the design was constructing the conventional way, however, the transporting of reinforcing cage is very costly and time consuming. Therefore, the design was changed to SFRC. As the design moment capacity of the SFRC is more than the design moment required, the contractor chose to replace the conventional reinforcement with SFRC. Consequently, construction became simpler, and the construction time got sped up. Besides that, the contractor was able to save cost on the transportation, fabrication and placement of the originally designed conventional reinforcement (Ng and Nyan, 2017).

2.4 Sustainability of empty fruit bunch

There are several technologies that have been developed and available for making full use of EFB which is the residue of oil palm industry. Even though with the availability of these technologies, most of them from the oil palm industry do not have official instruction from the authorities to choose which technology to put money into to counter the problem of disposal of EFB (Abas *et al.*, 2011), as a result, most of them chose to dispose it the old way. Therefore, the authorities should play an important role and provide helpful information regarding the technologies available and create proper guidelines for the oil palm millers so that the issue of disposal of EFB can be reduced which directly reduced the impact made on the environment. This helps the boost of the recycling industry as well as bringing additional benefits to the oil palm millers and the whole nation (Chiew and Shimada, 2013).

Table 2.3: Process flow of recycling technologies for EFB
(Chiew and Shimada, 2013)

Technology Options	Reference Flow
Ethanol Production	Pre-treatment (Shredding + washing) → Saccharification → Fermentation → Distillation → Wastewater treatment * Replacement of gasoline
Methane Recovery	EFB handling → Shredding → Mixing with temperature 328 K → Methane collection → Wastewater treatment * Replacement of electricity generated supply to national grid
Briquette Production	EFB handling → Shredding → Dehydration → Briquetting * Replacement of electricity of hardcoal used in power plant's boiler
CHP Plant	Pre-treatment (Shredding + washing) → Combustion → Ash disposal * Replacement of electricity generated supply to national grid
Composting	Pre-treatment (Shredding) → Windrowing → Turning for aeration (1-3 times/week) → Spraying POME and adding microbes → Sampling → Bagging → Wastewater treatment * Replacement for chemical fertilizer

MDF Production	Pre-treatment (Shredding) → Mechanical Pulping → Drying → Blending fibers with resin and wax → Forming → Pressing → Sanding → Wastewater treatment * Replacement for hardwood and residue wood
Pulp and Paper Production	Pre-treatment (Shredding) → Chemical Pulping → Bleaching → Refining → Paper making → Wastewater treatment * Replacement for fiber extracted from hardwood

The technologies that were considered using EFB as feedstock to reduce the disposal of EFB are using EFB as biofuel and material. These include the production of ethanol, recovery of methane, production of briquette, combined heat and power plant, composting, medium density fiberboard production and production of pulp and paper. Table 2.3 shows the flow of the process of recycling EFB. Although the development of recycling EFB is well established, a sustainable system that is used to commercialize the technologies that are developed should also be focused (Chiew and Shimada, 2013).

The OPF is a biodegradable material that is non-hazardous, extracted from EFB which considered a waste after fresh fruit is extracted from oil palm. OPF is stable and versatile, can be transformed into a variety of dimensional grades to suit unique applications which varies from control of erosion, production of mattress cushion, stabilization of soil, landscaping, manufacturing of brick, production of paper and more. Besides that, OPF can be applied as filler in composites of thermoplastic and thermoset that are widely used in furniture and components of automobile (Abdullah and Sulaim, 2013).

2.5 Hybrid fiber reinforced concrete

Hybrid refers to the mixing of different types of materials, while hybrid fiber reinforced concrete refers to mixing of two or more types of fibers to the concrete mix (Panzera *et al*., 2013). The mixing of fibers can provide an improved characteristic which cannot be obtained from any of the fiber alone. For a well-designed hybrid fiber reinforced concrete, the fibers will interact positively and the result will exceed the original performance of the individual fiber (Navilesh *et al.*, 2017).

The combination of different fiber to concrete is applied to optimize the overall system to attain synergy where it can be classified into three groups. The first group contains one type of fiber is stiffer and stronger that can provide more strength, while the other type of fiber is more ductile and flexible, which leads to better toughness in condition of opening of crack and high strains. The second group contains one type of fiber which is small that can bridge microcracks which results in increase in the tensile strength, while another type of fiber that is larger, that it delays the spread of the macro cracks, that increases the overall toughness of the concrete. The third group contains one type of fiber that provides the overall strength and toughness to the hardened concrete while another type of fiber provides a short term performance on the fresh concrete mix for better transportation and placement (Bentur and Mindess, 2007).

There has been previous research that has been conducted on hybrid fiber reinforced concrete that uses natural fiber as one of the fibers. One of the research works was conducted on structural behavior of hybrid fiber reinforced concrete that contains alkali resistant glass fiber and coir fiber. The result obtained from the research shows that the hybrid fiber reinforced concrete has increased in both ductility and resistance against impact compared to plain concrete (Vishaul *et al*., 2020). Furthermore, a study was done to investigate the influence of hybrid fibers containing SF and coir fiber on the mechanical and rheological properties of concrete. From the study, it is concluded that the hybrid fiber reinforced concrete has a lesser workability than the plain concrete. It also shows the optimum percentage of fiber inclusion, which is 2% by the weight of the cement increases the mechanical properties of the concrete in terms of compressive strength, flexural strength and tensile strength (Das *et al.*, 2020). Another similar research was done on hybrid fiber reinforced concrete with the use of steel fiber and coir fiber. As concluded in the research, the addition of fiber to concrete decreases its workability. However, the inclusion of hybrid fibers to the concrete enhances its mechanical properties, which shows an increase in compressive strength, flexural strength and splitting tensile strength. Moreover, a research was conducted on the study of impact resistance of hybrid fiber reinforced concrete which contain 3 types of fibers which are sisal fiber, steel fiber and polypropylene fiber. The conclusion obtained from the research shows that sisal fiber reinforced concrete had the least performance. Even though the steel-sisal hybrid fiber reinforced concrete has a better performance than sisal fiber reinforced concrete, steel-polypropylene hybrid fiber reinforced concrete at 1.5% fiber inclusion shows superior result (Naraganti *et al*., 2019).

2.6 Performance of concrete

This topic discussed the performance of the concrete based on research carried out by different researchers.

2.6.1 Workability

The workability of a concrete mix can be explained as the level of effective work needed for achieving full compaction. It is the compactability, consistency and mobility that characterize the properties of fresh concrete. Compactability is the elimination of the voids and segregation from a concrete mix. Consistency is the degree of fluidity of the concrete mix whereas mobility is the capability of the fresh concrete mix to flow into a mould or formwork. It can be affected by different kind of factors such as the water content, the water/cement ratio, the size and the shape of aggregate, admixtures and others (Rawarkar and Ambadkar, 2018).

The addition of fibers to concrete mix decreases the fluidity of the concrete mix, that causes bad impact towards the workability of the concrete mix. A negative impact on the workability of the concrete mix results in difficulties when undertaking mixing, handling, and placement of the fresh concrete. During the process of mixing, fibers tend to ball together causing the homogeneity to reduce and the performance of the fiber reinforced concrete to decrease. While during the placement of the fresh concrete for casting of the relevant elements will require more time as there is lack of fluidity (De Figueiredo and Ceccato, 2015). All fiber reinforced concretes are required to achieve uniform distribution of fibers so that the fibers provide good efficiency as reinforcement in the concrete. Besides that, the interaction between the fibers included and the cement matrix plays a major role as well. It is essential for every fiber to be fully coated with