PERFORMANCE OF PINEAPPLE LEAF FIBRE AS REINFORCEMENT IN OIL PALM SHELL LIGHTWEIGHT CONCRETE

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Thesis submitted in partial fulfillment of the requirements
for the award of the
B. Eng (Hons.) Civil Engineering

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

MAY 2019

ACKNOWLEDGEMENTS

First, I would like to thank my final year project supervisor, Ir. Dr. Chin Siew Choo for her patience to guide me from beginning until the completion of this Final Year Project. She always sincerely gave me valuable advices, guidance and suggestions even though she was busy but the door to her office was always open whenever I had question about my research. Thanks Dr. Chin for sparing her time to email and tell me all my mistakes in my presentation slide and steered me in the right direction. I truly appreciate the advices she gave.

Secondly, I would like to thank all the lab assistants of Faculty of Civil Engineering for their guidance and assistances during laboratory works. Whenever I needed help, they are always ready to help and try their best to fulfil requirement that needed in my research. I sincerely appreciated their efforts. Without their passionate participation and input, the laboratory work could not have been successfully conducted.

Besides, I would like to express my gratitude to my partner who took almost similar research topic as mine. I am gratefully indebted to him for his helping hands during laboratory works and his very valuable comments on this thesis. Without him, this project probably could not be completed successfully.

Finally, I must express my very profound gratitude to my parents and to my beloved one for their unfailing support and endless motivation throughout the whole process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

ABSTRAK

Konkrit dibentuk oleh agregat kasar yang tertanam dalam matriks simen yang mengisi ruang dan lompang di antara zarah agregat dan melekatkannya bersama-sama. Dalam eksperimen ini, konkrit ringan, yang lebih mampan alam sekitar dibandingkan dengan konkrit konvensional, yang menggunakan sepenuhnya simen. Konkrit ringan lebih mampan alam berbanding dengan konkrit konvensional kerana konkrit ringan mengurangkan penggunaan simen serta kuantiti agregat yang menyebabkan kemusnahan bukit menyebabkan ketidakseimbangan geologi dan alam sekitar. Konkrit konvensional adalah bahan rapuh di mana retakan struktur akan dikembangkan walaupun sebelum beban digunakan kerana kekuatan tegangan yang rendah, kemuluran terhad, dan sedikit ketahanan terhadap retak. Beban luaran akan menyebabkan penyebaran lebih banyak keretakan yang sedia ada dan akhirnya menyebabkan keretakan konkrit dan keretakan tambahan yang baru terbentuk. Oleh itu, kemasukan tetulang dalam konkrit adalah diperlukan. Gentian biasanya digunakan dalam konkrit untuk mengawal penyebaran retakan mikro, pengecutan dan untuk meningkatkan kekuatan dan prestasi konkrit. Dalam penyelidikan yang lalu, kerana pertimbangan ancaman terhadap alam sekitar, serat mesra alam diperkenalkan kepada bidang konkrit sebagai sumber alternatif serat yang akan digunakan dalam konkrit untuk meningkatkan sifat mekaniknya. Kajian utama ini adalah untuk menumpukan kepada kelakuan mekanikal serat daun nanas (PALF) dalam konkrit ringan sawit kelapa sawit dalam pecahan volum serat yang berbeza kepada jumlah konkrit 0.5 %, 1 %, 1.5 % dan 2.0 % daripada PALF berbanding dengan konkrit biasa . PALF diekstrak dan kemudian dirawat dengan natrium hidroksida dengan kepekatan 10% untuk meningkatkan ketahanan serat. Dalam kajian ini, panjang PALF dibuat berterusan sebanyak 40mm berdasarkan panjang gentian optimum dari penyiasatan sebelumnya. Ujian eksperimen dalam kerja ini termasuk ujian kemerosotan, ujian kiub, ujian lenturan empat mata dan ujian tegasan pemisahan yang terdiri daripada 60 kiub, 15 rasuk dan 15 silinder. Kubis konkrit diuji pada umur sembuh 3, 7, 14 dan 28 hari, manakala bagi silinder dan rasuk hanya perlu diuji pada 28d. Proses pengawetan air yang berterusan telah dijalankan untuk semua kiub, silinder dan sampel rasuk untuk tempoh yang diperlukan. Dari pelbagai hasil ujian, prestasi konkrit biasa dan sifat konkrit ringan dan mekanikal gentian konkrit bertetulang serat minyak kelapa sawit telah disahkan. Penyelidikan menunjukkan bahawa kekuatan mampatan menurun pada semua peringkat umur dengan peningkatan pecahan pecutan PALF, manakala kekuatan tegangan dan kekuatan lenturan yang berpecah memberikan hasil yang positif dengan sedikit penambahan serat. Kemasukan PALF meningkatkan kekuatan tegangan dan lenturan sehingga 3.28 MPa dan 6.55 MPa masing-masing. Berbanding dengan campuran kawalan 0 %, apabila serat meningkat kepada 1 %, kekuatan lenturan dan kekuatan tegangan meningkat sehingga 36.32 %. Dari hasil yang diperoleh, 1.0 % PALF adalah nisbah volum serat optimum untuk pembangunan kekuatan tegangan dan lentur. Dari segi kebolehmampuan, penambahan PALF dalam campuran konkrit secara drastik menurunkan kebolehkerjaan konkrit yang baru dicampur dengan air serat yang diserap. Oleh itu, dapat disimpulkan bahawa PALF sesuai untuk digunakan dalam konkrit ringan, namun tidak sesuai untuk menghasilkan konkrit ringan yang tinggi.

ABSTRACT

Concrete is formed by coarse aggregate embedded in the cement matrix which fills the spaces and voids among the aggregate's particles and glue them together. In this experiment, lightweight concrete, which is more environmentally sustainable as compared to conventional concrete, which fully using cement was studied. Lightweight concrete is more environmentally sustainable as compared to conventional concrete because lightweight concrete reduces usage of cement as well as quantities of aggregates which results in destruction of hills causing geological and environmental imbalance. Conventional concrete is relatively a brittle material where the structural cracks will be developed even before loadings are applied due to its low tensile strength, limited ductility, and little resistance towards cracking. The external load will lead to further propagation of existing cracks and eventually caused spalling of concrete and the newly formed additional cracks. Hence, inclusion of reinforcement in concrete is necessary**.** Fibres are commonly used in concrete to control the propagation of micro cracks, shrinkage and to improve the strength and performance of concrete. In the past researches, due to consideration of threat to the environment, eco-friendly fibre is introduced to the field of concrete as an alternative source of fibre to be used in concrete for increasing its mechanical properties. The highlight of this research is to focus on the mechanical behaviour of pineapple leaf fibre (PALF) in oil palm shell lightweight concrete in different fibre volume fractions to concrete volume 0.5%, 1.0%, 1.5% and 2.0% of PALF compared to plain concrete. PALF was extracted and then treated with sodium hydroxide with concentration of 10% to enhance fibres durability. In this research, the length of PALF was made constant as 40 mm based on optimum fibre length from previous investigations. The experimental testing in this work include slump test, cube test, four-point bending test and splitting tensile test which comprises of 60 cubes, 15 beams and 15 cylinders. The concrete cubes were tested at the curing age of 3, 7, 14 and 28 days, whereas for cylinder and beam were tested at 28 days. Continuous water curing process was conducted for all cubes, cylinders and beams samples for the required period. From the various test results, the performance of plain concrete and lightweight concrete and mechanical properties of fibre reinforced oil palm shell lightweight concrete were evaluated. The research showed that the compressive strength decreased at all ages with an increase in PALF volume fraction, whereas splitting tensile strength and flexural strength give positive result those with a small amount of fibre addition. The inclusion of PALF increase the tensile and flexural strength up to 3.28 MPa and 6.55 MPa respectively. Compared to the control mix 0%, when the fibre increase to 1.0%, the flexural strength and tensile strength increase up to 36.32%. From the results obtained, 1.0% PALF is the optimum fibre volume ratio for tensile and flexural strength development. In terms of workability, the addition of PALF in concrete mix drastically decreased the workability of freshly mixed concrete as the fibre absorbed water greatly. Hence, it can be concluded that PALF is suitable to be used in lightweight concrete, however not suitable to produce high strength lightweight concrete.

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LIST OF SYMBOLS

%	Percentage
mm	Millimetre
MPa	Mega Pascal
kg	Kilogram
kg/m^3	Kilogram per cubic metre
N	Newton
^oC	Degree Celsius
kN	kilo Newton
kN/s	kilo Newton per second
^oC	Degree Celcius

LIST OF ABBREVIATIONS

PALF	Pineapple leaf fibre
ASTM	American Society for Testing and Materials
FRC	Fibre-reinforced concrete
Vf	Volume fraction
PALF	Pineapple leaf fibre
OPC	Ordinary Portland Cement
OPSLWC	Oil palm shell lightweight concrete
SSD	Saturated surface dry
UTM	Universal Testing Machine
HSLWC	High strength lightweight concrete
NaOH	Sodium Hydroxide

CHAPTER 1

INTRODUCTION

1.1 Research Background

Concrete is formed by coarse aggregate embedded in the cement matrix which fills the spaces and voids among the aggregate's particles and glue them together. In this experiment, lightweight concrete which is more environmentally sustainable as compare to conventional concrete which fully using cement is used. Lightweight concrete is more environmentally sustainable as compare to conventional concrete because lightweight concrete reduces usage of cement as well as quantities of aggregates which results in destruction of hills causing geological and environmental imbalance. In this research, the main purpose of investigate lightweight concrete because lightweight concrete has lower strength as compare to conventional concrete, we want to investigate by addition of fibre composite can enhance lightweight concrete strength until which extent.

Plain concrete is a relatively brittle material where the structural cracks will be developed even before loadings are applied due to its low tensile strength, limited ductility, and little resistance towards cracking. The external load will lead to further propagation of existing cracks and eventually caused spalling of concrete and the newly formed additional cracks. Hence, inclusion of reinforcement in concrete is necessary. A French gardener by name Joseph Monier first invented the reinforced concrete in the year 1849. Fibres are commonly used in concrete to control the propagation of micro cracks, shrinkage and to improve the strength and performance of concrete. Portland cement concrete is weak in tension loading while strong in compression loading whereas reinforced concrete is strong in compression loading as well as tension loading.

Therefore, eco-friendly fibre is introduced to the field of concrete to enhance its tensile capacity.

Egyptians has developed the concept of using fibres in the concrete mix as one of a reinforcing materials before they used to mix the straw and hairs of animals in the concrete as a material of reinforcement. (Mahesh and Kavitha, 2016). Natural fibre based composites are under intensive study due to their eco-friendly nature, peculiar properties, huge and wide range availability, easy and safe handling due to their flexibility, and biodegradable nature. From the socioeconomic prospective, PALF can be a new source of raw material to the industries and can be potential replacement of the expensive and non-renewable synthetic fibre.

In the past researches, due to consideration of threat to environment, researchers have used plant fibres as an alternative source of steel and/or artificial fibres to be used in composites (such as cement paste mortar and/or concrete) for increasing its strength properties. (Kavitha & Dr. T Felix 2017) These plant fibres, herein referred as natural fibres, include coir, sisal, jute, pineapple leaf, kenaf, abaca leaf, bamboo, palm, banana, hemp, flax, cotton and sugarcane.

Pineapple leaf fibre (PALF) is one of the fast-growing plants and abundantly available wastes materials of Malaysia as compared to other natural fibre which are less productive. Hence, PALF has gained stimulants as an alternative to substitute synthetic fibres. Their use can lead to sustainable development. Since they are waste material, make use of them can reduce landfill consumption, environmental containment as well as reduce cost to manage them. Synthetic (chemically produced) fabrics are made by joining monomers into polymers, through a process called polymerization. Examples of synthetic fabrics include polyester, acrylic, nylon and rayon. They were costly and have an impact on environment as it is not biodegradable. Rayon is artificial silk that made from wood pulp. The sustainable supply of PALF can reduce the pressure on forest and agriculture.

1.2 Problem Statement

The major disadvantage is that concrete develops micro cracks during curing. It is the rapid propagation of these micro cracks developed in plain concrete easily under applied stress basically due to drying shrinkage. Plain concrete possesses a very low tensile strength, limited ductility and low resistance towards cracking especially lightweight concrete where its compressive and flexural strengths reduce with its density hence need some reinforcement in it. Concrete in service thus cracks easily and this cracking creates easy access routes for deleterious agents resulting in early saturation, freeze-thaw damage, scaling, discoloration and steel corrosion. To overcome this problem, various types of fibre composites were added into cement matrix to enhance the crack control and also concrete strength. In this research, natural fibre composite is used instead of synthetic fibre as synthetic material which are by-products of petroleum are non-biodegradable, synthetic products take a long time to decompose, creating long-term pollution. Nylon is hard to recycle, making them hard to decompose, accumulate landfills more. Besides, addition of steel fibre in concrete although can reduce micro cracks propagation but steel have high probability to corrode once it exposes to environment causing it to lose bonding capability in concrete.

1.3 Research Objectives

The objectives of the research are as follows:

i. To determine the physical properties (workability) of OPS lightweight concrete

ii. To determine the mechanical properties (compression test, flexural test and split tensile test) of OPS lightweight concrete with 0.5%, 1.0 %, 1.5 %, and 2.0 % of pineapple leaf fibre

iii. To validate the performance of plain concrete and OPS lightweight concrete

1.4 Scope of Research

The highlight of this research is to focus on the mechanical behaviour of PALF in oil palm shell lightweight concrete in different fibre content (fibre volume ratio to concrete volume ratio) as compared to plain concrete. PALF is a product extracted from pineapple leaf which is easily available in the states of Johor, Sarawak, Sabah, Kedah, Selangor, Penang, and Kelantan. These fibres extracted are then treated with sodium hydroxide with the optimum concentration of 10 % to enhance fibre durability. In this research, the length of PALF is made constant based on fibre optimum length to determine the effect of the amount of PALF added towards the mechanical performance of concrete. Tests that will be carried out are slump test, cube test, four-point bending test or also known as flexural strength test and split tensile test. Slump test is carried out to determine the effect of PALF on the fresh properties of concrete mix whereas cube test, four-point bending test and split tensile test was conducted to study the behaviour of PALF reinforced concrete in term of cube compressive strength, beam flexural strength and cylinder tensile strength. The size of the cube was 100 mm x 100 mm x 100 mm, beams were cast in a size of 100 mm x 100 mm x 500 mm whereas cylinder size was 100 mm diameter with 200 mm height. Each of cube, beam and cylinder were designed in concrete grade 30. There was a total of 60 cubes, 15 beams and 15 cylinders need to be cast. Cubes that are cast need to be tested at curing aging of 3, 7, 14 and 28 days referencing the BS 1881: Part 116 (compressive strength), ASTM C78 / C78M – 15a (flexural strength) whereas for cylinders and beams just need to be tested at 28 days. The fibre volume ratio to concrete volume for cube, cylinder and beam that will be tested in this research are 0 % (control specimen), 0.5 % 1.0 %, 1.5 %, and 2.0 %.

1.5 Research Significance

The combination of natural fibre and both fine and coarse aggregates embedded in cement matrix has been investigated for years to find out the best alternative to replace synthetic fibres. Example types of natural fibres that researchers have been evaluate are such as jute, kenaf, pineapple leaves and bamboo fibres on their ability and feasibility as one of the reinforcing materials in concrete as alternatives to synthetic fibres. For instance, K. V. Sabarish, 2017 had investigated the mechanical strength of sisal fibre reinforcement. Result shows that all the specimens showed increased in compressive strength, split tensile strength and flexural strength is about 13%, 15.5% and 12% for sisal fibre concrete. Toughness of concrete also increases by the addition of the fibre. However, concrete may experience reduction in strength due the increase in the fibre percentage and that may lead to porous structure by the agglomeration.

In this research, same as what Linto and Mathew, 2017 had investigated, this research also take the naturally available fibre, PALF as a substitute material to the reinforcement to identify optimum volume ratio of PALF reinforced to lightweight concrete and evaluate the performance of PALF reinforced concrete with normal plain concrete in term of workability, compressive and flexural strength by mixing PALF volume ratio of 0.5%, 1.0%, 1.5%, and 2.0% to lightweight concrete volume with constant fibre length. Inclusion of fibre reinforcement in concrete can enhance many of the mechanical characteristics of the basic materials such as fracture toughness, flexural strength and resistance to fatigue, impact, thermal shock and spalling. In recent years, a great deal of interest has been created worldwide on the potential applications of natural fibre reinforced cement (NFC) based composites. Recycle usage of waste disposal pineapple leaf and transform it into PALF can reduce environmental problem at the same time the usage of renewable and biodegradable of PALF as construction material can help adopt sustainable construction and green building practice. Natural fibres have been widely used in various applications, especially as reinforcement for polymer matrix composites (Bledzki & Gassan 1999; Faruk et al. 2012; Wirawan et al. 2009). This is because of their lower environmental impact, lower carbon footprint and embodied energy, renewability and carbon storage potential (Pervaiz & Sain 2003)

CHAPTER 2

LITERATURE REVIEW

2.1 Background

Fibre-reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. The usefulness of fibre reinforced concrete (FRC) in various civil engineering applications is indisputable. It is gaining attention as an effective way to improve the performance of concrete which is weak in tensile strength. It contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, glass fibres, synthetic fibres and natural fibres.

In the past years, various researches had been done by consolidating fibre material in the cement matrix form composite materials. Participation fibre reinforcement in concrete, mortar and cement adhesive work to improve the engineering properties of many based materials such as fracture resistance, bending strength and resistance to fatigue, impact, thermal shock or chipping. Fibre reinforced concrete has so far been successfully used in slabs on grade, architectural panels, precast products, offshore structures, structures in seismic regions, thin and thick repairs, crash barriers, footings, hydraulic structure, tunnelling, bridge decks, pavements, loading docks, thin unbounded overlays and many other applications.

Nowadays, the concrete industry is now moving towards the phase of sustainable development as synthetic fibre are expensive and not environmentally friendly. The scientists and engineers have been actively exploring to find the materials that have comparable mechanical properties will be used as replacement of synthetic fibre that can provide an innovation to enhance the plain concrete. These natural fibres have wonderful mechanical properties, lower cost, biodegradability, and are abundantly available in nature. Reinforced concrete by fibres that have enhanced capabilities offer a suitable alternative, practical and economical to overcome the lack of features of conventional concrete or mortar.

2.2 Oil Palm Shell Lightweight Concrete

Malaysia is well known as one of the world's largest producers and exporters of palm oil. OPS are one of the huge wastes producing from oil palm extraction process. As a result, the OPS which are light and naturally sized were ideal for substituting aggregates in lightweight concrete construction. Studies by found that oil palm shells were the organic aggregate which is better impact resistance compared to normal weight aggregate. In terms of bond, OPS concrete behaves similar to other structural lightweight aggregate concretes. The experimental bond strength of OPS concrete was much higher than the theoretical bond strength as stipulated by BS 8110. (Mannan et. al 2006).

Besides, OPS contain many pores and the water absorption is high compared to normal weight aggregate. Porosity in nature of OPS have low bulk densities causes its composite will also have lightweight. Before the OPS uses as an aggregate replacement in concrete, the material needs to undergo treatment process to remove dust and oil coating. Manna and Ganapathy, 2014 had introduced six pre-treatments to remove impurities from aggregate. (Manna et. al, 2004) Following are the methods suggested:

i. Partial oxidation of organic aggregate;
ii. Water proofing;
iii. Neutralization with alkali or precipitation of tannates, or sulphate treatment;
iv. Mixing with lime or calcium chloride for better performance of concrete as an accelerator;
v. Microorganism treatment of aggregate by boiled water with ferrous sulphate;
vi. Removing oil coating with detergent and water.

However, there is still some hesitation with regarding to the use of OPSLWC. This may because the mechanical properties of OPS concretes are slightly lower than other types of LWAC. Most of the previous studies had shown that OPS concrete produced cube compressive strength of approximately 25 MPa and using OPS cannot produce concrete with compressive strength above 30 MPa. One of the reasons for such low strength of OPS concrete is the weaker bond between the OPS and the cement matrix. Lower flexural strength of OPS concrete will result in early cracks in OPS concrete beams. (Alengaram, 2008)

2.3 Pineapple Leaf Fibre

Fibre can be natural and synthetic. Primary plants are the natural fibre that the plants grow while for secondary plants are the natural fibres extracted from the waste product of the plants (Nguong, Lee, & Sujan, 2013). Natural fibre can be extracted from animal or plant. Figure 2.1 shows the classification of natural fibre.

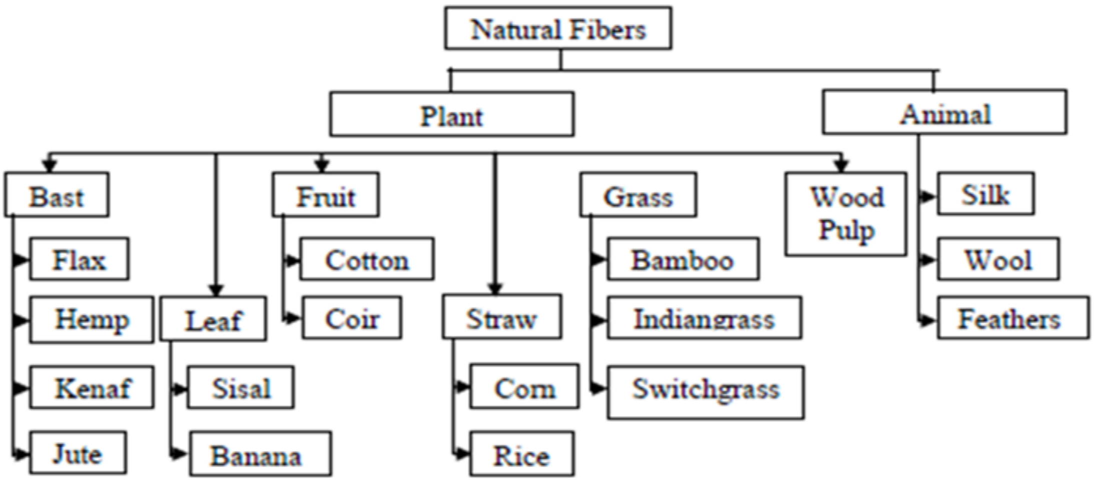


Figure 2.1 Classification of natural fibre

Source: P Zakikhani et al. (2014)

PALF are come from the leaves of the plant Ananas Comosus (Bromeliaceae family) is one of the most essential tropical fruits in the world after banana and citrus. Pineapple ranked 2nd among all the fruits produced in Bangladesh in terms of total cropping area (67842 acres). Total production of pineapple during 2010-2011 was 218.6 thousand metric tons. Pineapple is categorized in a group of major fruit due to its multi-forms in consumption especially the PALF which is extracted from its leaf nowadays has gradually play significant role in sustainable construction development.

Malaysia was one of the big players in the pineapple industry. It was one of the three main pineapple producing countries during the 1960s and 1970s, after Costa Rica and the Philippines. Figure 2.2 shows the trends of production, export, and area of pineapple industry from 1975 to 2015. Within 40 years, due to the innovation and implementation of technology such as high-density planting system and use of better fertilizers, the production trend of Malaysia's pineapples slightly grew upward compared to areas planted. From Figure 2.2, the production of pineapple in Malaysia is increasing since 1975 until 2015 due to higher demand from local consumption. (DOA, 2016)

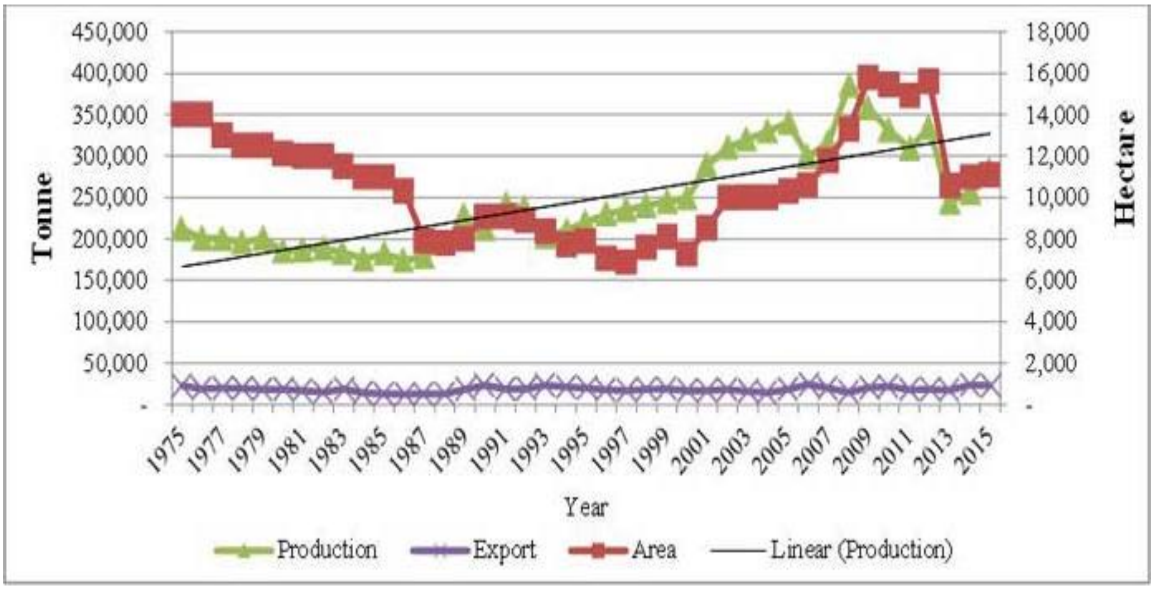


Figure 2.2 Production, export, and area trends of pineapple Industry in Malaysia, 1975–2015

Source: MOA (2016)

The Asian region is a major supplier of pineapples in the world. Figure 2.3 shows the Asian region which contributed almost 50% of the world pineapple production during the 2005-2014, and accounted for around 48%, followed by Americas (36.6%) and Africa (14.4%) (FAO, 2016).

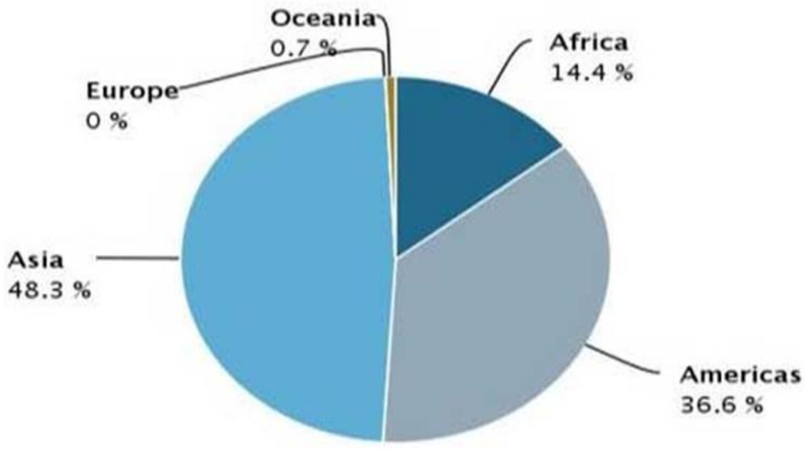


Figure 2.3 Average share pineapple production by region in 2005-2014

Source: Comtrade & FAO (2016)

According to statistic, Malaysian Pineapple Industry Board (MPIB, 2016) reported that in 2015, Malaysia exported about 20,278.9 tons of fresh pineapples to several countries, particularly to its traditional destination Singapore. (Halim and Science, 2018) In agricultural processes, agro-waste such as stem, crown, core and peel are removed during harvesting activities. People choose easy way to handle these wastes by open burning before consecutive replanting process. This had become an environmental issue. Nowadays they trying use make paper using pineapple leaf. In construction, we hope that can contribute to environment by reusing and incorporate this fibre in concrete.

2.3.1 Chemical Properties of Pineapple Leaf Fibre

Among the different natural fibres, PALF contains comparatively higher cellulose content which exhibits superior mechanical properties 70-82% and comparatively low microfibrillar angle. It can be concluded that the PALF consists of cellulose in the range of 67-81%, hemicellulose 9-19%, hollocellulose 80-88% and lignin 4-15%. Table 2.1 shows chemical composition of PALF summarized from previous study.

Table 2.1 Chemical composition of PALF

CHEMICAL COMPOSITION [%]	SOURCE							
	Bhaduri et al. (1983)	*Salha et al. (1990)*	*Mohanty et al. (2000)*	*Reddy and Yang (2005)*	*Abdul Khalil et al. (2006)*	*M.Idicula et al. (2006)*	*K.G. Satyanarama et al. (2007)*	*Siregar et al. (2008)*
Cellulose	69.5	68.5	70-82	70-82	73.4	81	80	67.1-69.3
Hemicellulose	-	18.8	-	18	-	-	-	-
Hollocellulose	-	-	-	-	80.5	-	-	82.3-85.5
Lignin	4.4	6.04	5-12.7	5.0-12.0	10.5	12.7	12	14.5-15.4
Pectin	1.2	1.1	-	-	-	-	-	-
Fat and wax	4.2	3.2	-	-	-	-	-	-
Ash	2.7	0.9	-	0.7-0.9	2	-	0.1-1	1.21

Source: Yahya, S.A. et al. (2016)

The presence of hydroxyl groups in the chemical structure of PALF will absorb moisture from air and make it hydrophilic in nature. Hydrophilic and possess large amount of moisture absorption properties of natural fibres can be seen the drawbacks because they will adversely affect the adhesion between the fibres and cement matrix and eventually this will cause loss of strength in the long run (Herrera-Franco & Valadez-González, 2005). To prevent this, the surface of fibres should be modified to improve the fibre-matrix adhesion. This hydrophilic nature of PALF can also be reduced by different chemical treatments which in turns contribute to the fibre/matrix adhesion of the composite materials. This led to a better composite quality and properties.

2.3.2 Physical/Mechanical Properties of Pineapple Leaf Fibre

Natural fibres are tough, elastic and demonstrate good mechanical strength. The composite from natural fibres is introduced for commercial purpose and becomes a good alternative of synthetic fibre reinforced composites in many uses. A comparison of mechanical and physical properties between natural fibres and synthetic fibre is described in Table 2.3. As we can see from Table 2.3, synthetic glass fibres have high density of 2.55 g/m^3 with significantly high cost, whereas natural fibre exhibits lower density in range of 0.6-1.6 g/cm^3 and low cost. Besides that, synthetic glass fibre also environmental unfriendly as it is non-biodegradable, non-renewable and require high energy consumption. Table 2.2 shows that physical and mechanical strength of PALF.

Table 2.2 Physical and mechanical strength of PALF

MECHANICAL & PHYSICAL PROPERTIES	SOURCE							
	George et al. (1993)	*Luo and Netrawati (1995)*	*Mohanty et al. (2000)*	*Reddy and Yang (2005)*	*Arib et al. (2006)*	*M.Idicul a et al. (2006)*	*K.G. Satyanarama et al. (2007)*	*Mohamed et al. (2009)*
Cell length [mm]	-	-	-	3.0-9.0	-	-	10	-
Diameter [μm]	5.0-30.0	-	20-80	-	-	50±6	1.56/4.5	105-300
Density [kg/m^3]	1.44	1.36	-	-	1.07	1526	1440	-
Elongation at break [%]	1.6	3.37	1.6	0.8-1.6	2.2	3.0-4.0	-	1.41
Micro fibrillar angel [°]	12	-	14	-	-	14	8.0-15.0	-
Moisture content [%]	-	-	11.8	10.0-13.0	-	13.5	-	-
Tensile Strength [MPa]	170	445	413-1627	-	126.6	413±8	-	293.08

Source: Yahya, S.A. et al. (2016)

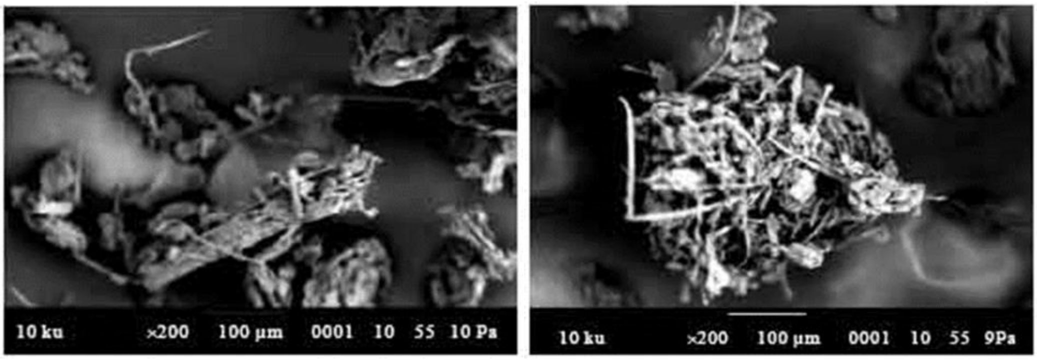
Table 2.3 Comparison of mechanical properties of PALF and other fibre

	Fibre	*Density [gcm^{-3}]*	*Tensile modulus [GPa]*	*Specific tensile modulus [GPa/gcm^{-3}]*	*Tensile strength [MPa]*	*Specific tensile strength [MPa/gcm^{-3}]*
Bast	Flax	1.45-1.55	28-100	19-65	343-1035	237-668
	Hemp	1.45-1.55	32-60	22-39	310-900	214-581
	Jute	1.35-1.45	25-55	19-38	393-773	291-533
Leaf	Sisal	1.40-1.45	9-28	6-19	347-700	248-483
	Pineapple	1.44-1.56	6-42	4-27	170-727	118-466
	Banana	1.30-1.35	8-32	6-24	503-790	387-585
Seed	Cotton	1.50-1.60	5-13	3-8	287-597	191-373
	Coir	1.10-1.20	4-6	3-5	131-175	119-146
	Oil palm	0.70-1.55	3-4	2-4	248	160-354
Other	Bamboo	0.60-1.10	11-30	18-27	140-230	210-233
	Wood pulp [a]	1.30-1.50	40	26-31	1000	667-769
	E-glass	2.55	78.5	31	1956	767

[a] Particulate form of softwood pulp (produced using Kraft separation method)

Source: Shah (2013)

Compared to other natural fibres, PALF exhibits comparatively superior mechanical properties due to its high cellulose content around 70-82% and low microfibrillar angle (14°) (Mohanty et al., 2005). Anatomical structure and morphology of PALF plays an important role in the internal strength of concrete. The anatomical structure and morphology of PALF can be analysed using Scanning Electron Microscopy (SEM). PALF gives high fibre content because of the arrangement of fibre. SEM analysis are shown in Figure 2.4. The SEM analysis shows that many bundles of packed fibre on the surface area of PALF. (Daud et al. 2014)



a) Surface area of PALF b) Packing of PALF

Figure 2.4 Anatomical structure and morphology of PALF

Source: Daud et al. (2014)

Figures 2.4 shows the surface area of the PALF and the agglomeration of fibre structure inside the leaf. The surface of PALF had been filled with many fibre matrixes that were condensely packed together. The arrangement and packing of fibre matrix on the surface of PALF will affect the strength of the fibre itself. Condensed arrangement of fibre could increase the fibre strength. (Reddy & Yang, 2005) The condensed fibre is important in the structure of the paper produced from the pineapple leaf. (Sridach, 2010) The fibre surface contains waxes and other of entrusting substances like lignin, pectin and hemicelluloses. These substances form a thick layer to protect the substances of cellulose inside the matrix layer of fibre. (Rowell et al., 2000)

2.3.3 Structural Behaviours of Pineapple Leaf Fibre in Concrete

Md. Milon Hossaina, 2015 had investigated an experiment about mechanical properties such as tensile strength, tensile modulus, and elongation at break percentage of the PALF content. The results revealed that PALF content improves the composite performance significantly. Higher mechanical properties were reported for 30% PALF content. Tensile strength and tensile modulus increase about 131% and 172% respectively compared to neat polyester. Fibres do not significantly improve the flexural strength. The main benefit of inclusion fibre in concrete is to improve the ductility in post cracking of the concrete by improving its energy absorption capacity and apparent ductility to provide crack resistance and crack control. Also, it helps to maintain structural integrity and cohesiveness in the material. Flexural toughness increases considerably when fibres are used. (Soutsos, Le & Lampropoulos, 2012)

Dispersion of fibre in the concrete cement matrix is a three-dimensional reinforcing network which will help to improve cement-based composite internal and external stresses transmission. (Beddar, M, 2004) Fibre can be described as another form of aggregate other than fine and coarse aggregates with extreme deviation in shape. It helps to interlock the aggregate particles and reduce the workability of concrete. Eventually, fibre promotes the cohesiveness of the mix and reduce the degree of segregation. (Mahadik, Kamane, & Lande, 2014)

Modulus of elasticity of fibre reinforced concrete (FRC) is the tendency of an FRC to deform along an axis when opposing forces are applied along that axis or in other word, the ratio of tensile stress to tensile strain. Research show that an increase in the fibres content FRC modulus of elasticity will also increase. It was found that for each 1% increase in fibre content there is an increase of 3% in the modulus of elasticity. (Wafa, 2009)

In term of flexure strength, contribution of fibres in reinforced concrete increases ductility, tensile strength, moment capacity, and stiffness. The fibres improve crack control and preserve post cracking structural integrity of members. Whereas in term of torsion which is the twisting of an object due to an applied torque, the use of fibres eliminates the sudden failure characteristic of plain concrete beams. It increases stiffness, torsional strength, ductility, rotational capacity, and the number of cracks with less crack width. (Wafa, 2009)

For column, fibre have the potential to provide concrete with significant ductility. It helps to increase of fibre content slightly increases the ductility of axially loaded specimen, help alter the failure mode of cylinders. The use of fibres helps in reducing the explosive type failure for columns. Ductility in structures is important for many reasons, including give warning of incipient collapsed by the development of large deformations prior to collapse, provide concrete structures with alternative load paths and the ability to redistribute internal actions as the collapse load is approached, enable relatively large deformation to be accommodated and energy to be absorbed without collapse during an earthquake; and assist in providing robustness, i.e. the ability to withstand unforeseen local accidents without collapse. (Gilbert and Bernard, 2018)

Fibre reinforced concrete is a material that can exhibit significant post-crack performance and turn brittle conventional concrete to become more ductile. The fibres in cement matrix intercept between micro-cracks that formed and provide tensile capacity across the crack. Figure 2.5 shows the post-cracking performance of FRC and Table 2.4 presents about comparison between conventional reinforced concrete and fibre reinforced concrete

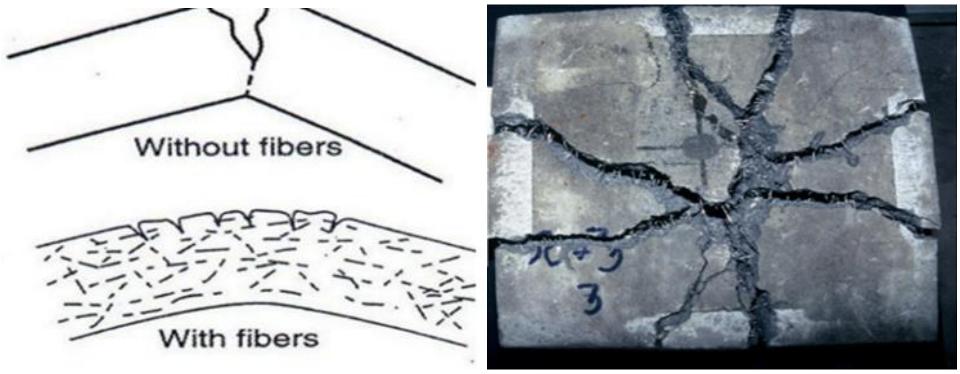
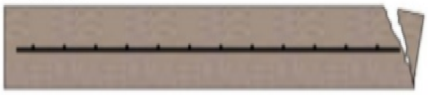
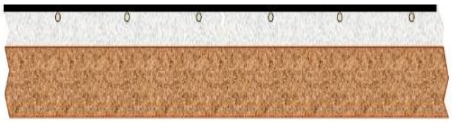
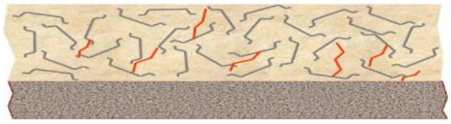
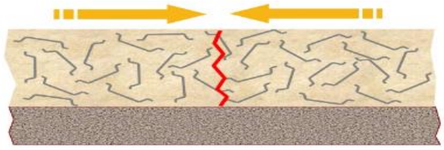
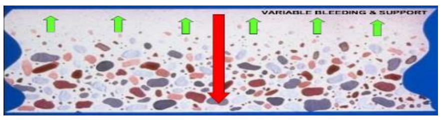
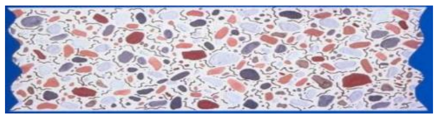


Figure 2.5 Post-cracking performance of FRC

Source: Sukumar (2014)

Table 2.4 Comparison between conventional reinforced concrete and fibre reinforced concrete

Conventional Reinforced Concrete	Fibre Reinforced Concrete
 Local damage to conventionally reinforced concrete	 Fibre reinforced concrete-universal crack control
 Provide single point crack restraint	 Control micro-cracking in hardened concrete  Provide continuous crack restraint from bottom of slab to just below surface
 High probability to occur bleeding and settlement in plain concrete	 Steel fibre reduce bleeding and settlement resulting in a more, homogeneous mix
 Compressive strength is comparatively low in plain concrete which cause severe damage	 Compressive strength is marginally enhanced by inclusion of fibre in cement matrix

Source : Iso (2008)

2.4 Factor Affecting Mechanical Properties of Pineapple Leaf Fibre Reinforced

Physical and mechanical properties of composites like viscoelastic behaviour processing, tensile strength, flexural strength, and impact are dependent on length of fibre, matrix ratio, and fibre arrangement. The properties of natural fibre reinforced concrete are influenced by the characteristics of natural fibre added. There are several factors which will affect the properties of natural fibre reinforced concrete in term of concrete strength enhancement including the type of fibre used, fibre geometry fibre surface and other factors are summarized in Table 2.5.

Table 2.5 Factors affecting properties of natural fibre reinforced concrete

Factors	Variables
Fibre type	Coconut, sisal, sugarcane, bagasse, bamboo, jute, wood and vegetables, canes, skin from trunk
Fibre geometry	Length, diameter, cross section, rings, and hooked ends
Fibre form	Monofilament, strands, crimped, and single-knotted
Fibre surface	Smoothness, presence of coating
Matrix properties	Cement type, aggregate type and grading, additive type
Mixing method	Type of mixer, sequence of adding constituents, method of adding fibres, duration and speed of mixing
Mix design	Water content, workability aids, defoaming agents, fibre content
Placing method	Conventional vibration, vacuum dewatering, sprayed-up concrete number, extrusion and grunting
Curing method	Conventional, special method

Source: Sethunarayanan & Chockalingam (2008)

2.4.1 Mechanical Properties Affected by Fibre Content

Strength of fibre reinforced concrete may affect due to fibre content that added. Figure 2.6 shows that an increasing trend in tensile modulus of the fabricated composite is evident except 35% fibre content. 35% fibre content shows the deviation from the trend (regarding addition of PALF) and shows around 31% decrease in tensile modulus than the highest modulus. Modulus of elasticity of fibre-reinforced concrete increases slightly with an increase in the fibres content. Each 1% increase in fibre content there is an increase of 3% in the modulus of elasticity. (Reddy et. al 2017)

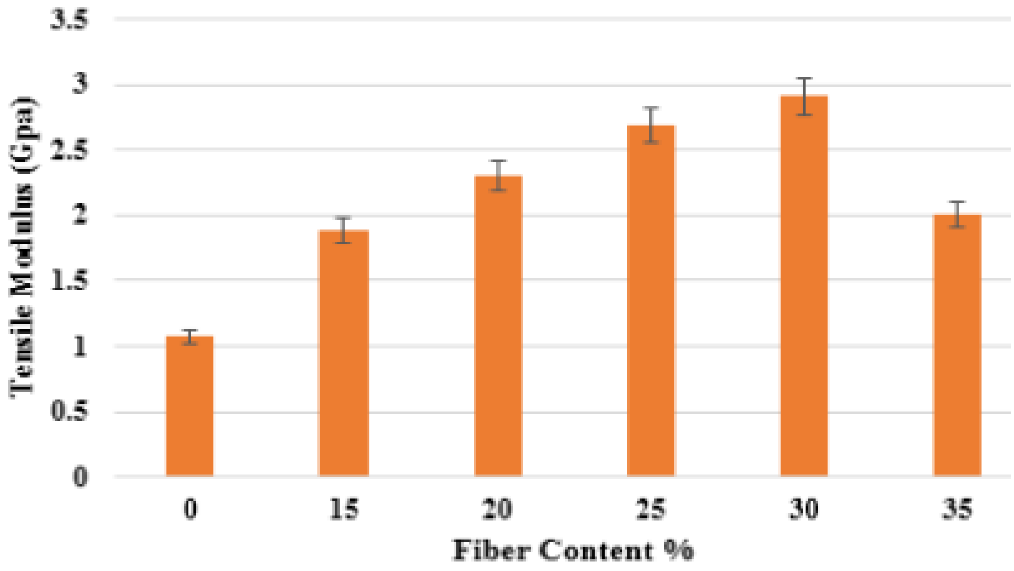


Figure 2.6 Tensile modulus of PALF/Polyester composite

Source: Hossain & Elahi (2014)

2.4.2 Mechanical Properties Affected by Fibre Treatment

Another factor that affect fibre concrete strength is fibre treatment. The ability of fibre to interfacial bond with matrix will affect the fibre concrete strength and fibre elongation of break. Elongation at break, also known as fracture strain, is the ratio between changed length and initial length after breakage of the test specimen. It expresses the capability of natural plant fibre to resist changes of shape without crack formation. The elongation at break percentage is quite low in case of neat matrix. A gradual increasing trend is evident in elongation at break percentage for PALF/Polyester composite samples. Addition of PALF in pure polyester resin decreases the brittleness of polyester and, therefore, the elongation at break increases. The result of the impact of fibre treatment on the elongation at break of PALF/Polyester composite is shown at Table 2.6.

Table 2.6 Impact of fibre treatment on the mechanical properties of PALF/Polyester composite

Treatment	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at Break%
5% NaOH (12 hours)	69.67±3.59	3.11±0.18	6.74±0.93
5 % NaOH (24 hours)	71.23±4.81	3.41±0.72	6.49±0.14

Source: Hossain & Elahi (2014)

2.4.3 Mechanical Properties Affected by Fibre Surface

The mechanical properties of the composite materials are greatly influenced by the interaction between fibre and matrix. The higher the interaction the higher the mechanical properties. An effective bio-composite material with sufficient mechanical properties can be fabricated by reinforcing PALF with polyester matrix. The interfacial bond may be improved by the chemical treatment on the surface of the fibre. Surface treatment of the composite by alkali promoted the fibre-matrix adhesion and thus yielded best mechanical properties. Longer immersion times shows the best mechanical properties compared to shorter immersion times. Alkaline immersion at were more effective in removing different elements such as waxes, greases and impurities from the fibre surface. At longer alkaline immersion for coir fibre it was reported that the fibres were rendered more rugged and porous, without being significantly degraded, leading to better fibre wetting, to a stronger fibre/matrix interface and thus to better mechanical properties.

2.4.4 Mechanical Properties Affected by Mixing and Placing

The mix should have a uniform dispersion of the fibres in order to prevent segregation or balling of the fibres during mixing. Most balling occurs during the fibre addition process. Increase of aspect ratio, volume percentage of fibre, and size and quantity of coarse aggregate will intensify the balling tendencies and decrease the workability. To coat the large surface area of the fibres with paste, experience indicated that a water cement ratio between 0.4 and 0.6, and minimum cement content of 400 kg/m are required. Compared to conventional concrete, fibre reinforced concrete mixes are generally characterized by higher cement factor, higher fine aggregate content and smaller size coarse aggregate. A fibre mix generally requires more vibration to consolidate the mix. External vibration is preferable to prevent fibre segregation.

2.4.5 Challenges for Pineapple Leaf Fibre as Reinforcement

The main drawback of natural fibre is moisture absorption, it does not make good bonding with hydrophobic matrix. Due to the presence of strongly polarized hydroxyl groups in the chemical structure of PALF provide fibre with hydrophilic character, it absorbs moisture from air thus make it hydrophilic in nature. This hydrophilic nature of PALF fibre can be reduced by different chemical treatments which in turns increase the fibre/matrix. Thus, to enhance the adhesion property of fibre, it needs surface modification by using appropriate chemicals treatment like dewaxing, treatment with NaOH and grafting of acrylonitrile monomer onto dewaxed PALF. The impact of fibre treatment on mechanical properties of composite is presented in Table 2.7.

Table 2.7 Tensile properties of untreated and treated PALF

	Tensile strength (MPa)	Young's modulus (GPa)	Strain to failure (%)
Untreated	613.75	1379500.0	6.67
Heat treated	671.64	6725.4	3.16
Alkali treated	763.60	2899.9	3.60
Heat + alkali treated	1088.60	6441.6	3.79

Source: Yusof & Yahya (2015)

From Table 2.7, it is obvious that surface treatments will increase PALF tensile strength. In addition, PALF treated with both heat treatment and alkaline treatment exhibit the highest tensile strength (1088.60 MPa). The surface modification by chemicals like sodium hydroxide (NaOH), 2,4-dinitrochlorobenzene, benzoyl peroxide (BPO), and BPO/acetylation can minimize water absorption and improves the mechanical properties. Alkaline treatment increases the surface roughness of the fibres (Li et al., 2007), it removes lignin, wax and oils of the fibre cell walls and disrupt hydrogen bonding in the network structure. An increment of effective contact area in the fibres creates higher adhesion between the fibre and the polymer matrix, improving the mechanical properties of the composite (George et al., 1997). Bonding agent resorcinol (reso), hexamethylenetetramine (Hexa), and silica can also provide good affinity for PALF and exhibits better adhesion.

Another major problem of natural fibre as a reinforced material may have improper contact between fibre adherent surface and polymer matrix causing a bad interaction load transformation from matrix to fibre. Existence of natural waxy substance on surface of fibre layer provides low surface tension, which does not allow a strong bond with polymer matrix. PALF shows lower degree of compatibility with hydrophobic polymers due to its hygroscopic nature. They also generate moisture absorption problems in composites and promotes strong fibre-to-fibre hydrogen bonding that holds the fibres together. (Hujuri et al., 2008)

Besides that, another challenge is high fibre content problem. When the fibre content is higher, properties decreased due to the increment in fibre-to-fibre interactions, void content, dispersion and fibre alignment problems. Poor dispersion of the fibre and the void content in polymer composites with the hydrophilic character of natural fibres also one of the challenges of fibre concrete. Past researchers had suggested various methods to improve the fibre surface to make it suitable for good interfacial fibre/matrix bonding. Natural fibre reinforced polymers are susceptible to humidity and water absorption that causes a physical degradation of final product. High moisture content in fibre can cause swelling or dimensional defect at the time of composites preparing that affect the physical and mechanical property of the final product. Moisture diffusion into polymer depends on various factors such as molecule structure, polarity, crystallinity and the hardeners used in composite making. (Jawaid et. al 2015) Significant progress has been made in the last 30 years towards understanding the short and long-term performances of fibre reinforced cementitious materials and ways to improve durability of PALF.

2.5 Pineapple Leaf Fibre Extraction method

Appropriate fibre extraction technique is required to produce good quality PALF in a reasonable quantity to make utilization of these excellent lignocellulosic fibres feasible. Extracting PALF from fresh leaves was easy due to low fibre-tissue interfacial strength giving cleaner and intact fibre bundles and technical fibres. Figure 2.7 shows the production process of PALF.

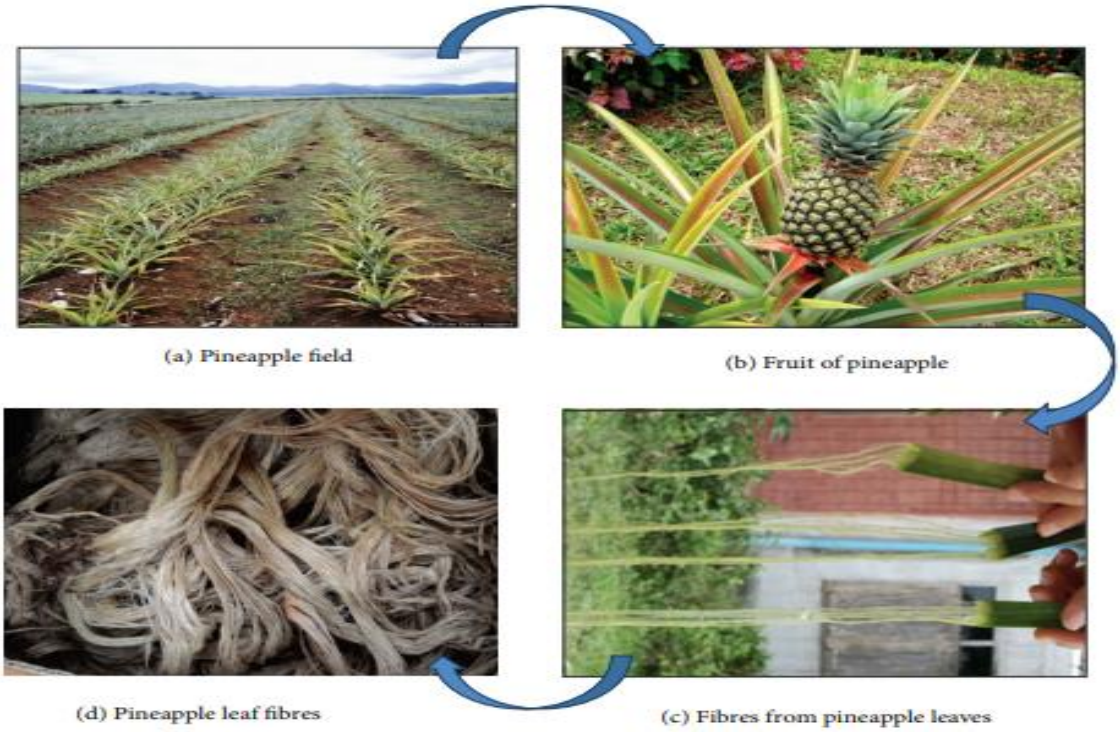


Figure 2.7 Production process of PALF

Source: Asim et al. (2015)

PALF is a high textile grade commercial fibre. It is generally extracted by manual extraction and mechanical extraction by decorticator machine. The process of extracting long vegetable fibres is of great importance since the quality as well as the quantity of extracted fibres is strongly influenced by the method of extraction employed. Manual extraction process of PALF is time consuming and laborious. On the other hand, the automatic decorticator machine is costly and it need skilled operator. So, this paper aims to design and develop a new method in extraction of PALF by which the pineapple farmer can easily extract the PALF and the quality and quantity fibre is ensured.

2.5.1 Manual Extraction Method

By using ceramic plate scratch over the pineapple leaf with pressure and fast movement, can extract the fibre beneath the leaf as shown in Figure 2.8. 500 leaves per day can be extracted by a fast and skilled scraper. The fibres are washed and dried in open air after being scratched. After drying, the fibres are waxed to remove the entanglement and the fibres are knotted. During the knotting process, each fibre is extracted singly from the bunch and knotted end to end to form a long continuous strand. The fibre is then sent for warping and weaving. The drawback of this process is a lot of fibre is lost and it is very laborious and time wasting. Figure 2.8 shows the manual extraction of PALF by using ceramic plate.

Figure 2.8 Manual extraction of PALF

Source: Uddin et al. (2017)

2.5.2 Mechanical Extraction Method

PALF can be obtained by using conventional decorticator machine as shown in Figure 2.9. The machine has three rollers which are feed roller, leaf scratching roller and serrated roller. Firstly, the leaves were fed through the feed roller and then passed through the scratching roller. The upper surface of the leaves is first scratched by scratching roller blades to remove the waxy layer and then passed through the serrated roller creating space for retting microbes. The closely fitted blades of the roller macerates the leaf and produces several breaks on the leaf surface for easy entry of the retting microbes. (Nayak et al., 2016) Figure 2.9 shows the decorticating of PALF by using decorticator machine.

Figure 2.9 Mechanical extraction of PALF

Source: Hoque et al. (2015)

2.6 Pineapple Leaf Fibre Length

From previous discussion in Table 2.5, showed that fibre geometry is one of the factors which will affect the properties of natural reinforced concrete. From previous research carried out by Vinod B. & Dr Sudev L. J, 2014 who investigated about the effect of fibre length on mechanical properties of PALF reinforced bisphenol composite. This research aimed to determine the effect of fibre content as natural reinforcement in concrete which will significantly improve the strength of concrete. Fibre length with 3 mm, 6 mm, 9 mm and 12 mm were subjected to be analysed. The result showed that increase in fibre length will induce higher tensile strength but further increase of length will cause tensile strength decreased. (Vinod B, 2014)

Besides that, another research which had been done by Kishor B.S et al, 2011 also showed that, the higher impact strength of 6.41 J/mm^2 was obtained for fibre of length 15 mm compared to the fibre length of 3 mm, 6 mm and 9 mm. From this experimental study, it was observed that the fibre length greatly influences the impact properties of reinforced composites. Hence, to make a high-performance fibre concrete, it is important to use optimum fibre length. The length of PALF can be decided based on two considerations including fibre aspect ratio and fibre critical fracture length.

2.6.1 Fibre Aspect Ratio

Aspect ratio represents the ratio of length of fibre to the diameter of it. Long, thin fibre often provides superior properties, but are also often more expensive to produce and may be more difficult to be dispersed uniformly in the composite. Whereas short aspect ratio fibre typically provides better compressive properties, but these composites are typically less resistant to damage propagation. Figure 2.10 illustrates about 2 types of fibre aspect ratio. Short fibre A with lower aspect ratio whereas long fibre B with higher aspect ratio.

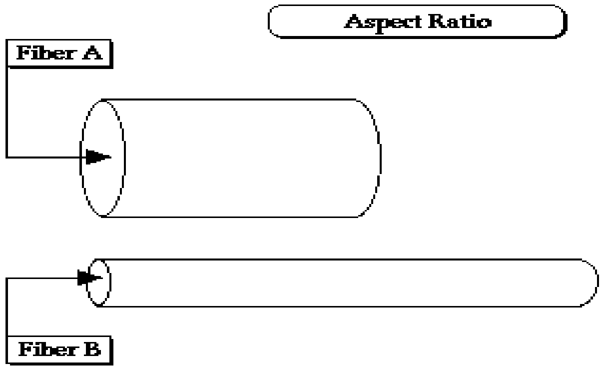


Figure 2.10 Illustration about 2 types of fibre aspect ratio.

Source: Callister (2006)

From the previous research, it is very common to find out that numerous researchers used fibre aspect ratio to determine the length of fibre to be added into cement matrix as reinforcing material. From the previous research carried out to investigate the aspect ratio (l/d) of bamboo fibre as reinforcing material in concrete, it was found that the aspect ratio of 40 had given the maximum result for the fibre reinforced composite strength. Meanwhile, for the aspect ratio of 40, the length of fibre adopted is forty times the diameter of the fibre. The diameter of bamboo fibre was 1.156 mm for the research and for the aspect ratio of 40, 46 mm of fibre length was found as optimum fibre length. (Mahesh & Kavitha, 2016)

2.6.2 Fibre Optimum Length

The mechanical performance of short fibre composite is at its maximum at fibre critical fracture length or also known as optimum length. (Takagi and Ichihara, 2004) Critical fibres length is necessary for effective strengthening and stiffening of the composite material. The mechanical characteristics of a fibre-reinforced composite depend on the degree to which an applied load is transmitted to the fibres by the matrix phase. The magnitude of the interfacial bond between the fibres and matrix phases is an important factor to affect the extent of this load transmittance. Under an applied stress, this fibre–matrix bond ceases at the fibres ends, there is no load transmittance from the matrix at each fibre’s extremity. A matrix deformation pattern is shown schematically in Figure 2.11.

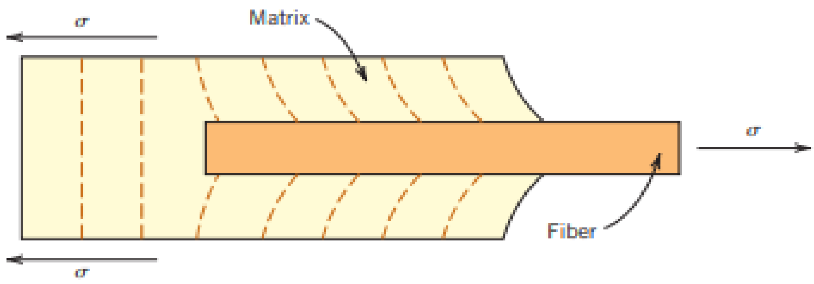


Figure 2.11 The deformation pattern in matrix surrounding a fibre that is subjected to an applied tensile load.

Source: Callister (2006)

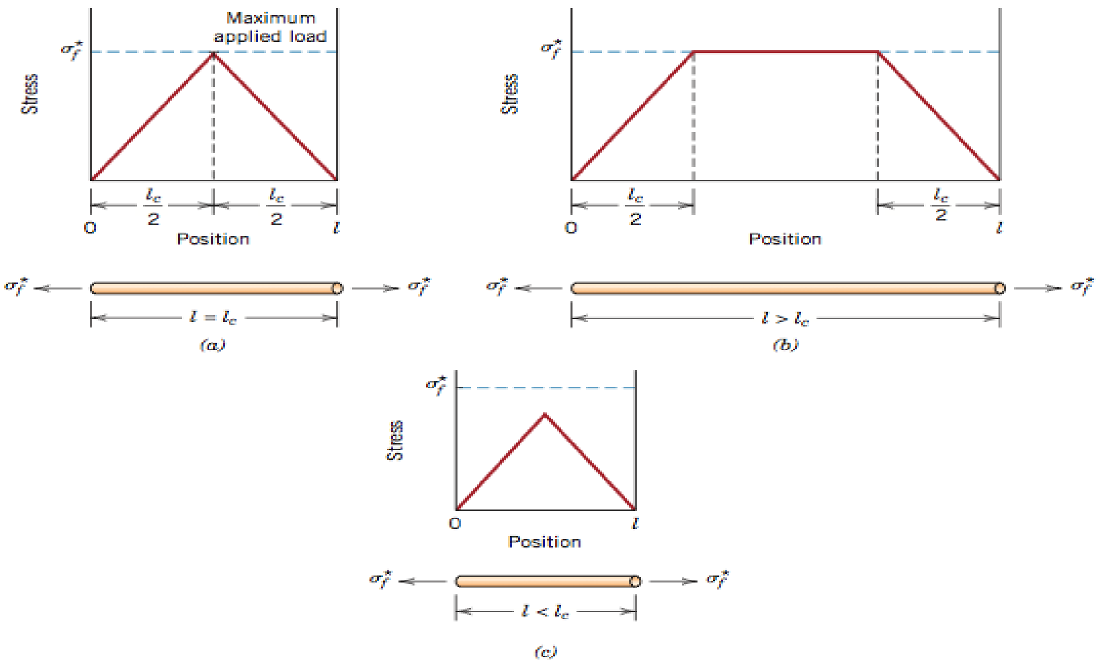


Figure 2.12 Stress profiles when the fibres length: (a) equal to the critical length; (b) greater than the critical length; and (c) less than the critical length for a fibres reinforced composite that is subjected to a tensile stress equal to the tensile strength.

Source: Zhang et al. (2013)

Figure 2.12 shows the stress profiles with variable fibre length conditions. Fibres for which l > lc represents continuous or long fibres whereas for fibres lengths shorter than critical length are indicated as discontinuous or short fibres. In previous research had proved that long fibres perform better and significant improvement in composite strength. Discontinuous fibres which is significantly less than lc discourage the stress transference and will cause matrix to deform easily around the fibres. Hence, the fibres that are used as reinforcement in concrete should be the optimum length which possess enough adhesion with concrete cement matrix and at the same time not exceed fibres critical fracture length which will cause the fibres to fail at breaking mode. Correct usage of fibres length can help in enhance concrete strength significantly. According to research carried out by Zhang, Huang, & Chen, reported that 45 mm of bamboo fibre length performed the best to improve mechanical strength of concrete at 1% of bamboo fibre added into matrix. (Zhang et. al, 2013)

2.7 Fibre Fraction to Concrete Volume Ratio

As discussed earlier, there are various factors which will influence the natural fibre reinforced concrete properties in term of strength. Fibre content is one of the significant variables affect the strength of concrete. This research aimed to determine the effect of PALF volume fraction present in the cement matrix which is ratio to concrete volume. According to a study conducted by previous researchers about the behaviour of different amount of steel fibre as concrete reinforcement, the outcome of the study showed that the compressive strength, splitting tensile strength and flexural strength increased with the addition of steel fibre. The compressive strength was increased from 11 % to 24 %, flexural strength from 12 % to 49 % and 3 % to 41 % for splitting tensile strength. (Shende, Pande and Gulfam Pathan, 2012) Figure 2.13 shows mechanism of failure of concrete cylinder with variable steel fibre fraction.

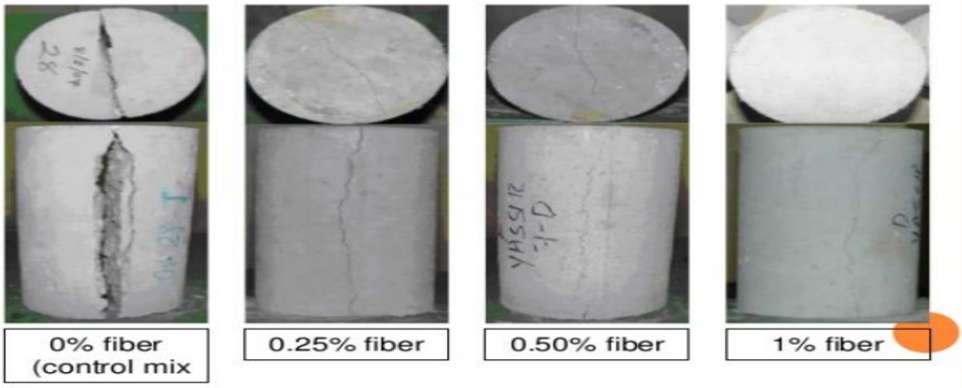


Figure 2.13 Mechanism of failure of concrete cylinder under splitting tensile test

Source: Chand and Jhansi (2014)

Same as the purpose of the research mentioned above, in this research, fibre volume ratio was made variable with 0.5%, 1.0%, 1.5% and 2.0% to concrete volume with constant fibre length to determine optimum volume ratio of PALF. Although fibre brings positive effect to concrete strength, but it has to be added in optimum amount. Based on previous findings about evaluation on mechanical properties of PALF. It showed that addition of 30% fibre content increased the tensile strength around 131% but further addition of 5% fibre decreased the tensile strength by almost 19% due to the high-volume fraction fibres act as flaws and improper alignment of fibres in the matrix result in higher voids content in the composite and lower tensile strength. (Hossain et. al, 2014)

2.8 Physical Properties Test

Fresh properties of concrete can be measured and investigated through workability test. Workability is defined as the amount of effort, mechanical works or energy required to handle fresh concrete with minimum loss of uniformity. There are two aspects in term of workability which are consistency and cohesiveness of concrete (Li, 2011). Consistency is the measurement of how easily the flow of concrete while cohesiveness is the ability of cement paste to bind concrete ingredients uniformly. Even though workability is not the fundamental properties of concrete, it should be designed well to suit different type of construction and method of handling, placing, compacting and finishing of concrete.

2.8.1 Slump Test (fresh properties)

Workability is defined as the ease of fresh concrete can be mixed, transported, placed, compacted and finished to final shape with minimum efforts and without segregation of ingredients. Complementary of fibres in concrete can enhance the mechanical properties of hardened concrete but may cause difficulties for fresh concrete in the process of mixing, handling, placing and consolidation. The fibres act as a barrier to coarse aggregates movement reducing the materials mobility. Concrete should have medium workability not poor nor high, so that its performance is very high. The strength of concrete is significantly affected by the presence of voids in the compacted mass, it is vital to achieve a maximum possible density. Hence, it is important to evaluate for the concrete mobility before casting concrete as if low workability concrete may not be compacted to its desired density resulting in high porosity and less strength. In a study conducted by previous researchers, showed that the slump value decreases upon addition of 0.5% vf polypropylene fibres into the OPSLWC. The reduction in slump value was found to be 60% compared to conventional concrete. (Yap, Alengaram and Jumaat, 2013) The result of slump test is illustrated in Figure 2.14.

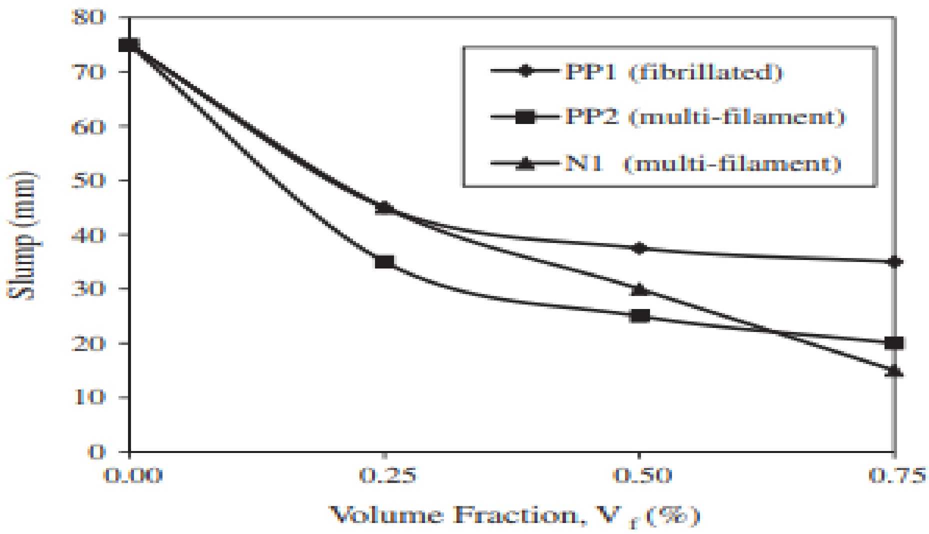


Figure 2.14 Workability of OPSFRC versus volume fraction

Source: Yap, Alengaram and Jumaat, (2013)

Workable concrete can be achieved by using optimum amount of fine aggregate and adding super plasticizer. This can improve the concrete flowability and reduce fibre segregation. And it is evident in many researches. According to a study conducted by Campione, 2001, who investigated on mechanical properties of steel fibre reinforced lightweight concrete with pumice stone or expanded clay aggregates, all mixtures attained good workability by adding 1.5% of super plasticizer. Generally, a low amount of fibres is recommended to achieve good workability for fibre reinforced concrete. (Campione et al., 2001)

Concrete slump test should be carried out from batch to batch to check the uniform quality of concrete on site in a short time. This test is easily and inexpensive to conduct too. The apparatus required for this test are slump cone, base plate, tamping rod and measuring tape. First, fill freshly mixed concrete in slump cone layer by layer. Each layer is tamped with 25 strokes by using tamping rod free by free fall action. The slump cone is then removed vertically from the concrete and the remaining height of the concrete is measured. The four common slumps encountered are true slump, zero slump, collapse slump and shear slump. According to ASTM C143 standard, the permissible slump is true slump. (Sabale and Ghugal, 2014). The types of slump are shown in Figure 2.15.

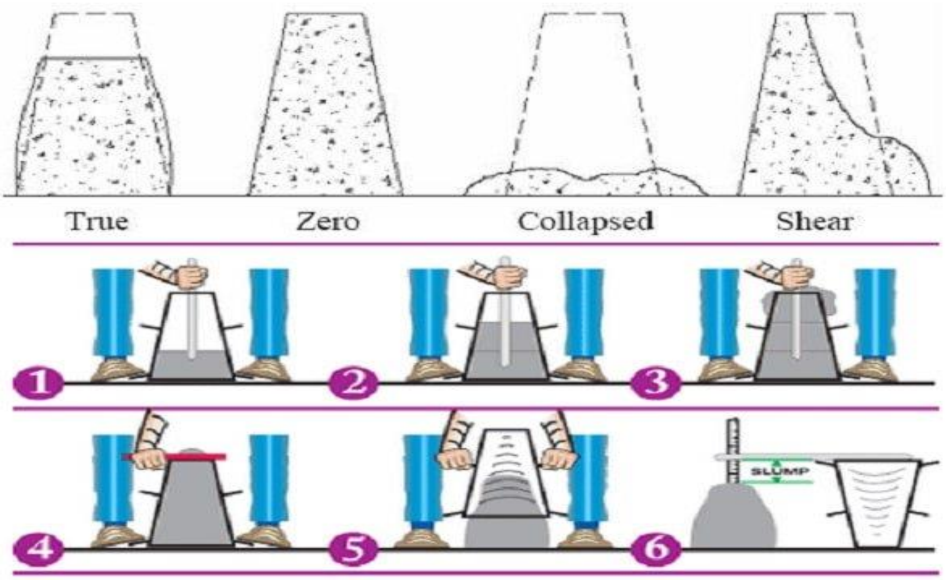


Figure 2.15 Types of concrete slump

Source: Sabale & Ghugal (2014)

2.9 Mechanical Properties Test

Hardened concrete properties normally will have compressive strength 2000-8000 psi (14-56 MPa), tensile strength 200-800 psi (1.4-5.6 MPa) and its compressive strength will be larger than tension since concrete is notch sensitive. A hardened concrete will have the ability to resist stress exerted externally without failure. The failure of hardened concrete can be seen through the appearance of cracks developed due to deformation of concrete caused by the external stress applied. In this research, three destructive tests are carried out to determine the internal strengthening of hardened concrete including cube test, four-point bending test and split tensile test.

2.9.1 Cube Test

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size, while in tension, size elongates. Test for compressive strength is carried out either on cube or cylinder. Various standard codes recommend concrete cylinder or concrete cube as the standard specimen for the test. ASTM C39/C39M provides Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Compressive strength formula for any material is the load applied at the point of failure to the cross-section area of the face on which load was applied.

Compressive Strength = Load / Cross-sectional Area

Based on finding from a study, about the mechanical properties of PALF reinforced concrete. The results showed the superior performance of the PALF towards the compressive strength improvement. The compressive strength is found to be increasing from 0 to 0.1 %. The highest value of compressive strength obtained for 0.1 % PALF addition was found to be 40.53 MPa after 28 days of curing. Figure 2.16 shows the graph of 28 days compressive strength of PALF reinforced concrete. (Mathew, 2017)

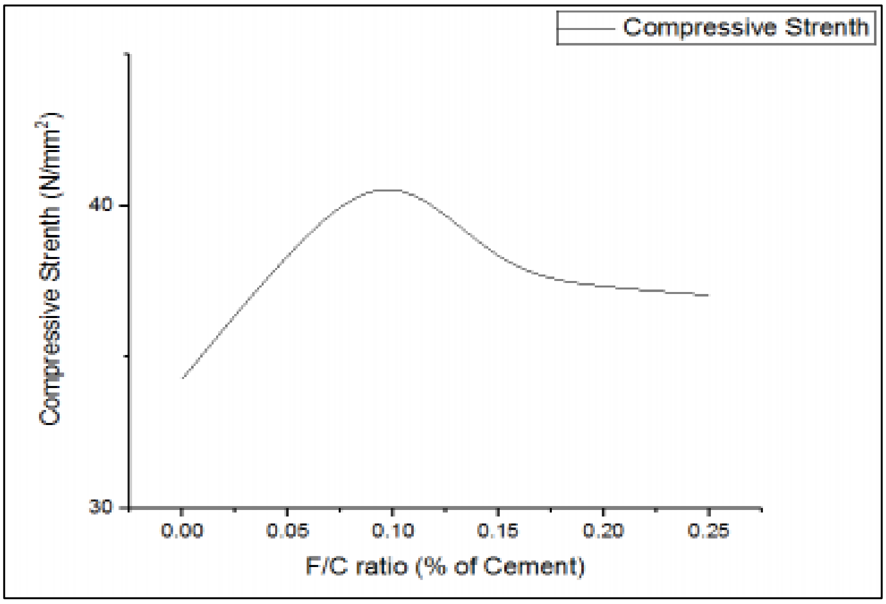


Figure 2.16   28 days compressive strength of PALFLWC versus volume fraction

Source: Mathew (2017)

2.9.2 Four-Point Bending Test

Flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa) and is determined by standard test methods ASTM C78 (third-point loading) or ASTM C293 (centre-point loading). Flexural test can say a more advanced test than compression and tensile test as when a specimen is placed under flexural loading all three fundamental stresses are present: tensile, compressive and shear and so the flexural properties of a specimen are the result of the combined effect of all three stresses. The most common purpose of a flexure test is to measure flexural strength and flexural modulus. Four-point bending test which also known as flexural test is quite similar with 3-point bending test. The different between both tests is three-point bend test consists of the sample placed horizontally upon two points and the force applied to the top of the sample through a single point. In four-point bend tests, the force is applied through two points on the specimen so that the sample experiences contact at four different points and is bent more in the shape of a "U". The four-point flexure test is more suited towards the testing of a large section of the sample, which highlights the defects of the sample better than a 3-point bending test. Figure 2.17 shows four-point bending test model.

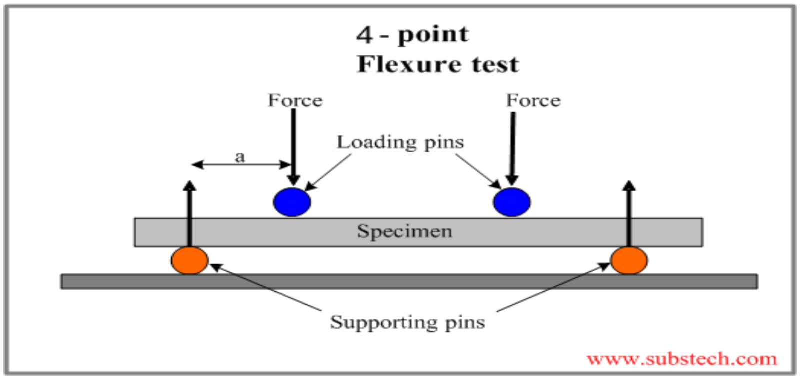


Figure 2.17 Set up of four-point bending test

Source: Bowlby (2014)

From previous research works conducted to measure the strength of the concrete containing PALF at various dosages (0% to 1%) in 0.25% increments. The experimental results showed that the flexural strength of concrete prisms increased with the increase of PALF in concrete up to 0.75%, beyond that there was a decrease in flexural strength. (Roselin, 2018) Table 2.8 shows the result of concrete prisms flexural strength.

Table 2.8 Flexural strength of concrete prisms

Percentage of pineapple fibre	Flexural strength (N/mm^2)	
	After 7 days	After 28 days
0	3.46	4.22
0.25	3.72	4.52
0.50	3.88	4.66
0.75	4.05	4.89
1	3.93	4.72

Source: Roselin (2018)

2.9.3 Splitting Tensile Test

The concrete is weak in tension and cannot withstand strong tension force. The cracks developed in concrete when tensile forces exceed its tensile strength. Therefore, tensile strength of concrete becomes important to ascertain the load at which the concrete cracks. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The procedure is based on the ASTM C496 (Standard Test Method of Cylindrical Concrete Specimen) which similar to other codes like IS 5816 1999. In splitting tension test, a concrete cylinder, similar to the type utilized in compression tests, is arranged with its horizontal axis among the platens of a testing machine. Figure 2.18 demonstrates the splitting tensile strength model.

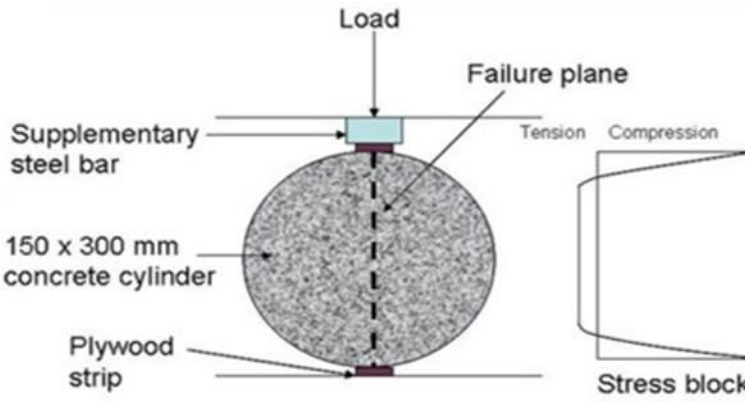


Figure 2.18 Splitting tensile test model

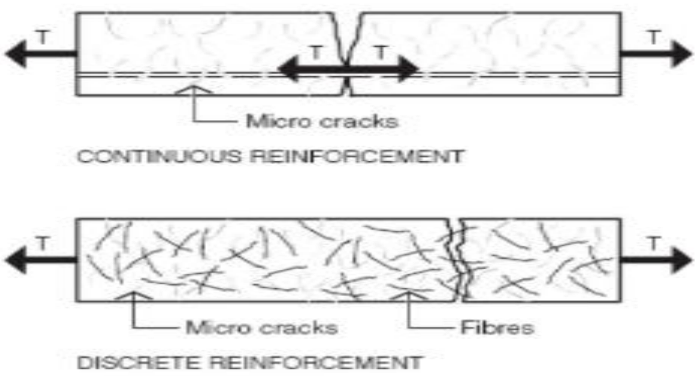


Figure 2.19 Internal strengthening of fibre reinforced concrete

Source: Kasturi Metal, Steel Fibre Manufacturer (2013)

Figure 2.19 illustrates the advantage and internal strengthening of fibre in cement matrix when post cracking occurs. When cracks occur, it creates a pulling force pull the concrete to either side. Inclusion of fibre significantly enhance effect post cracking making concrete tougher, more impact resistance and more load carrying capacity. Many researches have been shown that addition of fibre can enhance tensile strength of concrete. According to a journal investigated about effect of PALF loading on the mechanical properties of PALF– polypropylene composite, it was observed that with the increment of PALF loading by 12.9% at 30wt% PALF loading, the tensile stress of the composite has dropped drastically by 76.4% as compared to conventional concrete when PALF loading increased up to 70%. (Kasim et.al, 2015) Figure 2.20 shows the tensile strength result with variable PALF loading.

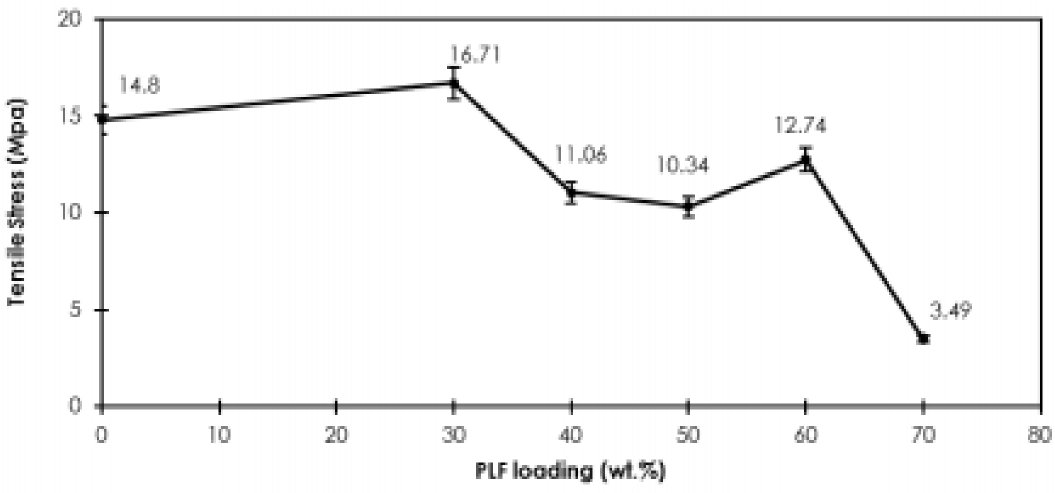


Figure 2.20 28 days tensile strength result versus PALF loading

Source: Kasim et.al (2015)

2.10 Summary

The highlight of this study is investigation on OPSLWC and by addition of pineapple leaf fibre as natural reinforcement can enhance OPSLWC strength until which extent. Low tensile properties, low strain at fracture of plain concrete structures and the increase of environmental awareness, lead to the application of fibre inclusion in concrete. In previous researches, bio-fibres are being explored extensively by researchers in various applications. Based on the literature review, OPS contain many pores and the water absorption is high compared to normal weight aggregate. Porosity in nature of OPS will affect bonding between the OPS and the cement matrix. Pre-treatment such as water proofing, neutralization with alkali, sulphate treatment, mixing with calcium chloride and so on were introduced by previous researcher. During the PALF preparation process, the length of PALF adopted is made constant based on the aspect ratio and optimum length considerations from the past researches. The OPSLWC mix design also determined through past researches. The design mix that significantly increase concrete strength is used for this research. The fibre volume fraction to specimens' volume investigated in this study is within range of 0% to 2.0%. The specimens prepared are tested by cube test, four-point bending test and splitting tensile test to determine their mechanical properties. Finally, the performance of PALF reinforced concrete is discussed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research was conducted to study the effect of different percentage of PALF as strength enhancer for plain concrete. The methodology of this research included compression test (cube test), splitting tensile test and four–points bending test (flexural test). In order to ensure the outcomes of this research meet the objectives, the treatment of fibre was qualitatively controlled. At the same time, the length of the PALF adopted in this research was made constant based on consideration of aspect ratio and optimum fibre length. The highlight of this chapter is to present the complete procedures of laboratory works, materials and techniques that were adopted throughout this research. There are some stages involve in this research including PALF preparation, specimen's preparation, curing and testing of specimens. There are three types of specimens required for this research including cubes, columns and beams. The laboratory works for this research is shown in the research flow chart in Figure 3.1 and Figure 3.2.

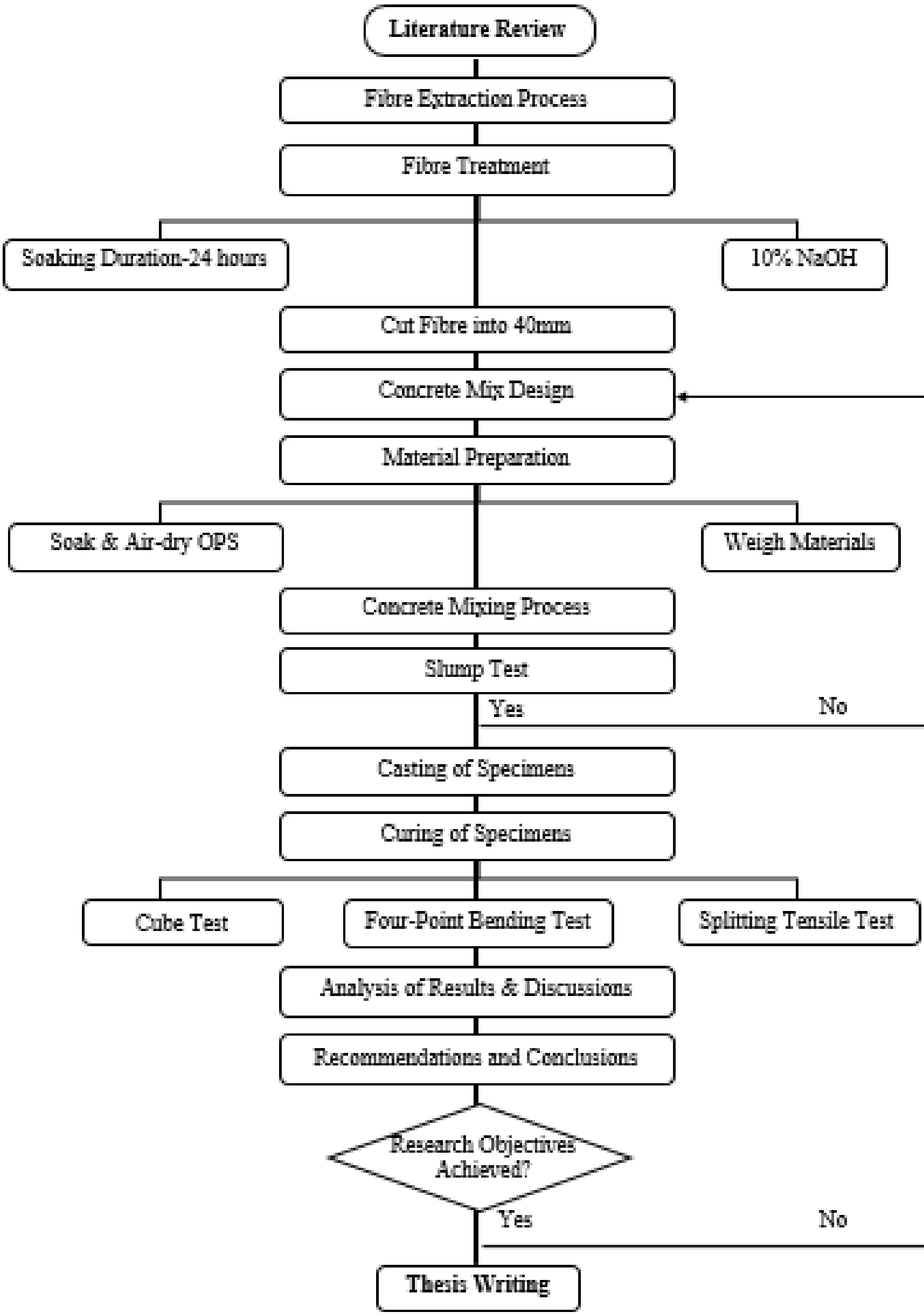


Figure 3.1 Research flow chart

Figure 3.2 Procedure of laboratory work. (a) Alkaline treatment of the extracted fibre. (b) Clean the fibre after soaking to remove NaOH. (c) Air-dry the OPS after soaking in water for 24 hours (d) After all materials are prepared, use the concrete mixer to mix all the materials. (e) Construct the slump test before pouring fresh concrete in mould. (f) Obtain the slump value for true slump. (g) Pour the fresh concrete mix in moulds. (h) After 24 hours, unmould the specimens and cure them in water.

3.2 Pineapple Leaf Fibre Preparation

3.2.1 Treatment of Pineapple Leaf Fibres

PALF were received from local Malaysian company in fibres form. The PALF were extracted from its leaves through conventional decorticator machine. Then PALF had undergone chemical modification. Dry PALF were soaked into NaOH solution at 30°C with a liquor ratio of 1:10. Fibres were kept immersed for 2 hours in the alkali solution and afterwards, they were washed with fresh water several times to remove any traces of NaOH (Maniruzzaman et al., 2012). After washing, the fibres were dried in an oven at 80°C for 24 hours to remove the moisture content and lignin of the fibres. Chemical treatment with NaOH can reduce the moisture content from the fibres, thereby increase the fibres strength. Chemical treatment also enhances the flexural rigidity of the fibres. This treatment able to clear all the impurities on the surface of the fibres and also stabilize fibres molecular orientation. Then, the treated fibres are leaved to be air-dried in laboratory for several days.

3.2.2 Pineapple Leaf Fibre Optimum Aspect Ratio Determination

Aspect ratio is the ratio of fibres length to fibres diameter. It has great influence on concrete mechanical properties. Normally, higher aspect ratio (longer fibre) will induce higher concrete strength. Previous research had proved that long fibres perform better and significant improvement in composite strength. But if the aspect ratio is too high (fibre length exceeds fibres critical fracture length) will cause the fibres to fail at breaking mode. There are many researchers used aspect ratio to determine optimum fibres length. PALF diameter can be as small as 3 μm or larger and their aspect ratio could be up to 2000. (Kengkhetkit et. al, 2018) In this research, the optimum aspect ratio adopted was 800. The optimum aspect ratio was determined based on previous research conducted by Thomas, 2011 about dynamic mechanical properties of PALF polyester composites. (Thomas et. al., 2011)

3.2.3 Pineapple Leaf Fibre Diameter Determination

PALF diameter determination process is one of the important stages of this research in order to find optimum PALF length. The diameter of extracted PALF was determined through electronic digital calliper as shown in Figure 3.3, with sensitivity up to 0.01 mm. Three measuring points were taken at different location along the PALF and average diameter was determined from the three set of readings. The average diameter was found to be 50 µm (0.05 mm). Figure 3.3 shows the instrument that is used for fibres diameter measurement, electronic digital calliper.

Figure 3.3 Electronic digital calliper

3.2.4 Pineapple Leaf Fibre Length Determination

In this research, the PALF length was set constant with optimum length 40 mm. This optimum length was determined based on aspect ratio. From previous discussion, optimum aspect ratio and average diameter of PALF were determined as 800 and 0.05 mm, respectively. The optimum PALF length can be calculated through formula below:

$$\text{Length, } l = \text{Aspect ratio} \times \text{Diameter, } d$$

In a research conducted by Susilowati and Sumardiyanto, 2018, also showed that 40 mm was the optimum PALF length. The highlight of this research was to determine optimum fibres length and optimum fibres fraction in cement matrix. Based on the research, the treated and dried fibres were cut into pieces to 20 mm, 30 mm and 40 mm. The result was tabulated in Table 3.1. It showed that the maximum tensile strength of 22.17 J/mm^2 was obtained for composites with 40 mm fibres length and 30vf. % fibres content.

Table 3.1 Result of tensile strength test of various fraction PLF/Epoxy and various fibres length

No	% vf (PLF/ Epoxy)	Length of fiber (mm)	Tensile Test (MPa)			
			Test 1	Test 2	Test 3	Averages
1	10/90	20	12.8	13.1	12.5	12.80
2		30	13.5	12.8	12.6	12.97
3		40	14.0	14.2	14.1	14.10
4	20/80	20	14.9	14.8	15.3	15.00
5		30	15.2	15.8	16.0	15.67
6		40	16.2	15.8	16.3	16.10
7	30/70	20	17.0	16.5	16.9	16.80
8		30	18.1	17.8	17.9	17.93
9		40	21.8	22.5	22.2	**22.17**

Whereas for flexural strength of the PALF composite, same as tensile strength, the maximum flexural strength of 35.53 N/mm^2 was obtained for composite with 30/70%vf and 40 mm fibres length. The result of flexural strength was tabulated in Table 3.2.

Table 3.2 Result of bending test of various fibres fraction and fibres length

No	% vf (PLF/ Epoxy)	Length of fiber (mm)	Bending Test (N/mm^2)			
			Test 1	Test 2	Test 3	Average
1	10/90	20	10.5	11.1	10.6	10.73
2		30	13.5	14.0	13.3	13.60
3		40	18.7	19.0	18.9	18.87
4	20/80	20	22.1	22.7	23.0	22.60
5		30	25.0	25.3	25.2	25.17
6		40	26.1	25.8	26.0	25.97
7	30/70	20	30.4	30.3	30.7	30.47
8		30	32.0	32.1	31.8	31.97
9		40	35.3	35.5	35.8	**35.53**

Source : Susilowati and Sumardiyanto (2018)

3.2.5 Cutting of Pineapple Leaf Fibre

Fibre should be cut into certain length to ensure enough adhesion between fibre itself and concrete cement matrix. After the optimum aspect ratio and average PALF diameter was obtained, the extracted PALF were ready to be cut into required length. A 0.05 mm average diameter of PALF was measured, the resulting fibres length required was 40 mm based on the aspect ratio of 800. In other word, the required length of PALF to be used as natural reinforcement is 800 times longer than its diameter. A pair of scissors and ruler were used during PALF cutting process. Figure 3.4 shows the cut-in-size PALF.

Figure 3.4 Cut-in-size PALF

3.3 Material Preparation

3.3.1 Oil Palm Shell (OPS)

In view of the escalating environmental problems faced today and considering the rapid depletion of conventional aggregates, the use of aggregates from by-products and/or solid waste materials from different industries are highly desirable. One such alternative is oil palm shell (OPS), which is a form of agricultural solid waste. In this research, lightweight concrete was cast. The ingredients that are used to make lightweight concrete are fine aggregate (sand), oil palm shell (replace coarse aggregate) cement and water. We obtained the oil palm shell from Palm Oil Mill - LKPP Corporation Sdn. Bhd.

OPS aggregates are porous in nature and therefore have low bulk densities. Consequently, the resulting concrete will be lightweight. The 28 days air-dry density of the OPS concrete range was 1960 kg/m^3 and this is within the range for structural lightweight concrete. This gives a saving in weight of about 18% compared to normal weight concrete of 2400 kg/m^3. Although OPS is an organic material, biological decay was not evident as the cubes gained strength even after 6 months. (Teo et al., 2007) Table 3.3 shows the properties of hardened OPS concrete at 28 days.

Table 3.3 Properties of hardened OPS concrete at 28 days

Properties	Value
Air-dry density (kg/m^3)	1960
Compressive strength (MPa)	28.12
Splitting tensile strength (MPa)	2.02
Modulus of rupture (MPa)	4.97
Modulus of elasticity (Gpa)	5.31

Source: Teo et al. (2007)

Although OPS aggregates are porous in nature, the resulting OPS concrete was reasonably impermeable. Since the water/cement ratio of OPS concrete is low at 0.30, the cement paste is of sound quality. Low water/cement ratio increase the strength of concrete, which consequently enhances its resistance to cracking due to internal stresses. In general, the utilization of OPS waste provides a good alternative to the conventional building materials. The use of OPS in concrete can help overcome the over-dependence on depletable resources, especially in areas where OPS are in abundant supply.

In this research, due to high water absorption of OPS, OPS was soaked for 24 hours and then air-dried in the laboratory to attain a saturated surface dry (SSD) condition to increase the total moisture content before casting the concrete. High water absorption of about 25% of OPS will cause high volume of pores in cement matrix weaken the particle strength and stiffness. This can be solved by pre-soaking of OPS before mixing process. Figure 3.5 shows the OPS are leaved for air-dried after soaking for 24 hours.

Figure 3.5 Air-dried of OPS after soaking for 24 hours

3.3.2 Ordinary Portland Cement (OPC)

Cement plays an important role in freshly mixed concrete to lubricate, coat and finally bind all aggregates together cohesively. Cement from different sources exhibit different properties which will influence the concrete mix. In this research, Ordinary Portland Cement manufactured by YTL Orang Kuat as shown in Figure 3.6 which was packed in 50 kg paper bag and suitable for structural concreting were used. This type of cement was produced with quality assurance and was certified to MS EN 197-01:2004, MS ISO 9001, MS ISO 14001, OHSAS 18001 and MS ISO 50001. A cement content of 520 kg/m3 was used for all mixes.

Figure 3.6 YTL ORANG KUAT Ordinary Portland Cement

3.3.3 River Sand

Fine aggregates are the aggregates with size less than 4.75 mm. In concrete, fine aggregates help to fill the remaining voids of coarse aggregates. This will help to reduce segregation of concrete. For the source of fine aggregates used in this research were the locally available river sands passing through 4.75 mm sieve. The river sand was left air dried prior to passing through sieve. The geometry of river sand could be either crushed or rounded and both types could be used in concrete mix. A sand content of 960 kg/m3 was used in all mixes. The river sand is used as fine aggregate in this research.

3.3.4 Water Content

Water plays the utmost important role in the concrete mixing process to transform cement to cement paste and hence to provide binding to individual aggregate and glue them together to form unique composite material called concrete. The water used in this research was originated from tap water. The water used should be clear and free from any impurities. Water was added gradually into mixer to ensure quality of mixing. Water to cement ratio adopted for this research was 0.3.

3.3.5 Mineral Admixture

Silica fume (SF) procured by the company satisfies all the requirements of the International Standards; ASTM C1240 and AS 3582. Silica fume at 5% of the cement weight was added as additional mineral admixture. Incorporation of fine SF greatly improved the interfacial bonding between the aggregate and cement paste and increased the compressive strength

3.3.6 Super plasticizer (SP)

All mixes have been super plasticized. Potable water to binder (w/b) ratio of 0.30 was used for all mixes. The SP used in this study was Polycarboxylic Ether (PCE) complies with the ASTM C494/C494 M specifications. The amount of SP was kept constant at 1.2 % of the cement weight in order to improve workability as fibres and OPS have high water absorption ability.

3.4 Specimens Preparation

3.4.1 Number and Size of Specimens Used

The size of cube was 100 mm x 100 mm x 100 mm, beams were cast in size of 100 mm x 100 mm x 500 mm whereas cylinder size was 100 mm diameter with 200 mm height as shown in Table 3.5. Each of cube, beam and cylinder were designed in concrete grade 30. There were total of 60 cubes, 15 beams and 15 cylinders need to be casted. Cubes that are casted need to be tested at curing ages of 3, 7, 14 and 28 days referencing the BS 1881: Part 116 (compressive strength), ASTM C78 / C78M – 15a (flexural strength) whereas for cylinder and beam just need to be tested at 28 days. The fibre volume ratio to concrete volume needed to be tested for cube, cylinder and beam are 0% (control specimen), 0.5%, 1.0%, 1.5%, and 2.0% in this research. The density of PALF for this study is 1022 kg/m^3. The fibre content and number of specimens needed to be cast for cube, beam and cylinder specimen and dimension of each type specimen are summarised as Tables 3.4.

Table 3.4 Number of cubes, cylinders and beams specimens

Fibre content (%)	Number of specimens				PALF (m^3)	PALF (kg)
	3 day	7 day	14 day	28 day		
Cube V = (100x100x100) mm = 0.001m^3 per cube						
Control	3	3	3	3	0	0
0.50	3	3	3	3	0.00006	0.061
1.00	3	3	3	3	0.00012	0.123
1.50	3	3	3	3	0.00018	0.184
2.00	3	3	3	3	0.00024	0.245
Cylinder V = (π(50)2x200) mm = 0.00157m^3 per cylinder						
Control				3	0	0
0.50				3	0.0000236	0.024
1.00				3	0.0000471	0.048
1.50				3	0.0000708	0.072
2.00				3	0.0000942	0.096
Beam V = (100x100x500) mm = 0.005m^3 per beam						
Control				3	0	0
0.50				3	0.000075	0.077
1.00				3	0.000150	0.153
1.50				3	0.000225	0.230
2.00				3	0.000300	0.307

Table 3.5 Dimension of cube, beam and cylinder specimens

Type of specimen	Width (mm)	Height (mm)	Length (mm)
Cubes	100	100	100
Beams	100	100	500
Cylinder	100	200	

3.4.2 Concrete Mixing Procedure

All the specimens including cubes and beams were casted by using concrete grade 30 MPa. Due to the addition of different percentage of fibre as reinforcing material in cement matrix, the concrete used in the specimens should be cast manually. The water cement ratio used in this concrete mix design was 0.30. The concrete mixing procedure was carried out in several times due to different type of volume to cement ratio of required to mix in the cement matrix. The volume of concrete mixed with specific percentage of fibre was calculated based on the number and volume of each specimen in addition of 20% concrete wastage assumption.

The quantity of ingredients required including cement, sand and OPS were firstly weighed and mixed for two minutes by using concrete drum mixer. After that, the cut-in-size fibres prepared were then spread evenly in the concrete drum mixer and then mix for another two minutes. Finally, specific amount of water was added gradually into the mixer and mixed thoroughly for three more minutes. The mixture was immediately tested for slump before pouring into the moulds. The concrete mix design is listed in Table 3.6.

Table 3.6 Concrete mix design for lightweight concrete

Cement	Course Aggregate (OPS)	Fine Aggregate (Sand)	W/C	SP (% of cement weight)	Silica Fume (% of cement weight)
520 kg/m^3	330 kg/m^3	960 kg/m^3	0.3 (156 kg/m^3)	1.2% (6.24 kg/m^3)	5% (26 kg/m^3)

3.4.3 Curing Process

Curing of concrete specimens is an important process to control the loss of moisture content from the concrete during cement hydration at the same time to maximize the strength of specimens (Akinwumi and Gbadamosi, 2014). Upon 24 hours after the specimens were casted, steel moulds were removed to allow these specimens to be cured in water curing tank until the day of testing. This process helps to prevent shrinkage of concrete as the moisture content of concrete specimens was maintained. Figure 3.7 shows the continuous water curing of specimens.

Figure 3.7 Curing of specimens

3.5 Cube Test

The moist-cured cube specimens were tested immediately upon they were removed from the concrete curing tank. As stated earlier, three hardened cube specimens were prepared for each weight to cement percentage to improve the accuracy of the result obtained. Cube test or also known as compression test was conducted to determine the ultimate strength of concrete and was carried out in accordance to the standard of BS 1881: Part1 16:1983 and ASTM C39-03. The cube specimens were tested for compressive strength at 3, 7, 14 and 28 days after casting. During cube test, compression load was exerted by the compression testing machine on the cube specimen at the specified rate throughout this research. Both upper and lower bearing faces of cube specimen and bearing plate were firstly wiped clean prior to putting the specimen in the testing machine. After the specimen was placed at the centre of the bearing plate, check whether the upper and lower plain surfaces were appropriately placed. The compression load was then applied continuously at a specified rate without exerting shock on the cube specimen until it failed. The concrete cube test and cube test machine are illustrated in Figure 3.8.

(a) (b)

Figure 3.8 a) Cube specimen compression test b) Cube test machine

The maximum compression load achieved by the cube specimen during the test was recorded together with the type of failure. The appearance of specimen after testing was captured. The compressive strength of each specimen was calculated by dividing the ultimate compressive load carried by the specimen during cube test by average cross-sectional area of bearing face.

$$f_c = \frac{P}{A}$$

Where: f_c= compressive strength of concrete specimen (N/mm^2 or MPa)

P= maximum load can be carried by concrete specimen (N)

A= average cross-sectional area of concrete specimen (mm^2)

3.6 Four-Point Bending Test

Four-point bending test was one of the destructive tests conducted on beam specimens to determine the flexural strength of hardened beam specimens at 28 days with 0.5%, 1.0%, 1.5% and 2.0% fibre addition. The four-point bending test in this research was carried out in accordance to standard BS 1881: Part1 18 and ASTM C 78-02 where the load was applied on the beam specimen by the flexural testing machine at constant rate until the failure was encountered at their designed age. Figure 3.9 shows the control beam was tested using four-point bending test machine.

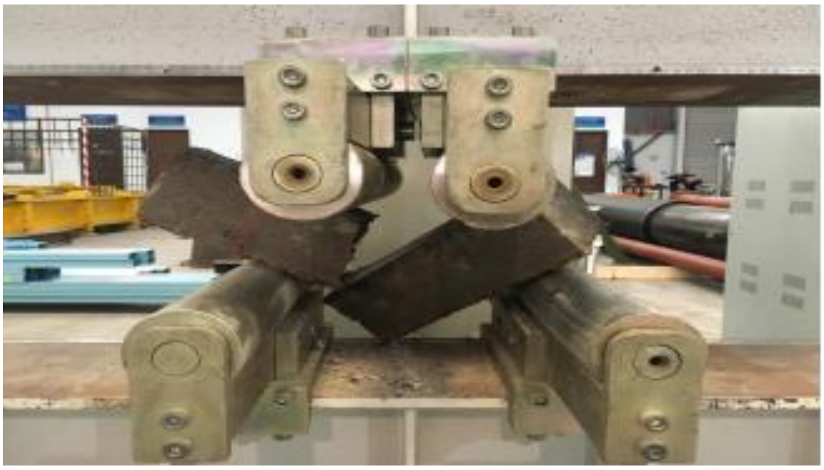


Figure 3.9 Four-point bending machine

As usual, three beam specimens with size of 100 mm x 100 mm x 500 mm in width, height and length respectively were prepared for each type of percentage of PALF volume fraction to concrete volume to ensure the accuracy of the result obtained. Upon the failure was encountered, the ultimate load carried by beam specimen during testing was recorded. The flexural strength or also known as modulus of rapture were calculated by applying elastic beam theory. There were basically two formulas could be applied in calculating the flexural strength of beam specimens. For the case where the fracture initiated in the middle third of the span at the tension surface, the calculation of flexural strength is as follow:

$$R=\frac{PL}{bd^2}$$

Where: R= flexural strength of beam specimen (N/mm^2 or MPa)

P= maximum load can be carried by beam specimen (N)

L= span length (mm)

b= average width of specimen at the fracture (mm)

d= average depth of specimen at the fracture (mm)

For the case where the fracture is initiated outside of the middle third of the beam span by not more than 5%. The flexural strength is as follow:

$$R=\frac{3Pa}{bd^2}$$

Where: R= flexural strength of beam specimen (N/mm^2 or MPa)

P= maximum load can be carried by beam specimen (N)

a= average distance between fracture and the nearest support (mm)

b= average width of specimen at the fracture (mm)

d= average depth of specimen at the fracture (mm)

3.7 Splitting Tensile Test

The spitting tensile test was carried out according to Test Method C 39/C 39M. Load was applied continuously and at a constant rate within the range 0.7 to 1.4 MPa/min (1.2-2.4 MPa/min based on IS 5816 1999) splitting tensile stress until the specimen fails. Steel cylinder specimen moulds are used. There are five batches of concrete mixes with variable fibre content needed to be cast for splitting tensile test. Each batch will have to cast three cylinders. The cylinder moulds were coated with a thin film of oil before use, in order to prevent adhesion of concrete. All cylinders needed to be cured for 28 days. After 28 days of curing process, the wet specimens are taken out for splitting tensile testing. Before testing, water on the surface of specimens were wiped out. Next, put the specimen horizontally in the compression testing machine. Load was applied continuously without shock at a rate within the range 0.7 to 1.4 MPa/min (1.2 to 2.4 MPa/min based on IS 5816 1999). Finally, the cylinder will rupture when the applied load exceeds its tensile strength. Figure 3.10 shows that cylinder splitting tensile test and machine that is used to test for splitting tensile strength which is same as cube test machine.

(a) (b)

Figure 3.10 a) Cylinder splitting tensile test b) Cylinder test machine

The splitting tensile strength of the specimen can be calculated as follows. Figure 3.11 shows dimension of cylinder specimen and imposed loads location.

T= 2P/ pi LD

Where: T = splitting tensile strength, MPa

P = maximum applied load indicated by the testing machine, N

D = diameter of the specimen, mm

L = length of the specimen, mm

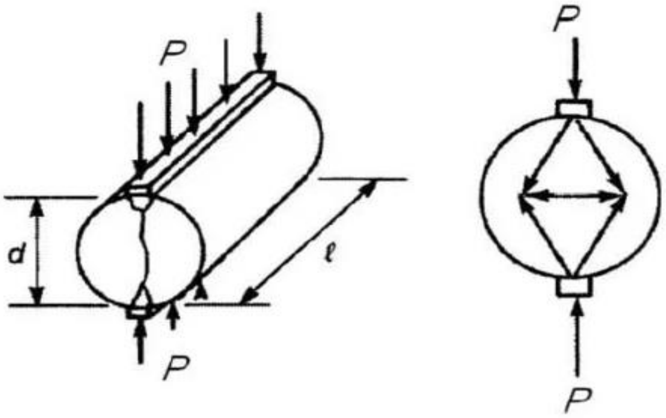


Figure 3.11 Dimension of cylinder specimen and imposed loads

Source: The Constructor Civil Engineering, 2009

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, all the results obtained from experimental works are presented and discussed. The results obtained are categorized as two parts which are the physical and mechanical testing. In term of physical testing, it includes the fresh properties, slump of freshly mixed concrete for both control mix and PALF reinforced concrete mix and hardened density of concrete are discussed in this chapter. Whereas for the mechanical testing that are discussed are compressive strength, splitting tensile strength and flexural strength of concrete. Validation are made by comparing the performance of fibre reinforced concrete with the plain concrete in term of compressive, splitting tensile and flexural strength.

4.2 Slump Test

Slump tests are carried out to determine the consistency or rigidity of uncured concrete. It can also be used as an indicator of an improperly mixed batch. It is important to know whether the mix is in proper mix. If the mix contain too less water, it will restrain movement of mix during concrete placing and if mix contain too much water will affect concrete strength. The use of fibres is well known to influence flow ability of plain concrete intrinsically. This is one of the disadvantages of using fibre in concrete, but this can be solved by addition of super plasticizer increase the mix’s flow without segregation, disperse the cement more evenly and reduce the amount of water in mix by a certain percentage. In this study, the quantity of water and SP is kept constant for all mixes in order to evaluate the effects of different PALF volume fraction on the workability of OPS concrete. The slump result showed that inclusion of PALF to from 0 to 2.0% decreased the workability by 43.55%, 67.74%, 83.87% and 100% as compared to control mix. Control mix has the highest slump value which is 62 mm whereas the 2.0% fibre fraction addition has the lowest slump value due to the increase of effective surface area of fibre for the development of a fibre–matrix bond compared increases the viscosity of the mixture. Figure 4.1 shows that there is a linear relationship between the PALF volume fraction and slump for OPS concrete. The slump result is presented in Table 4.1.

Table 4.1 Slump test result

No	Description	Slump (mm)
1	Control	62
2	1.00 % fibre	35
3	1.25 % fibre	20
4	1.50 % fibre	10
5	2.00 % fibre	0

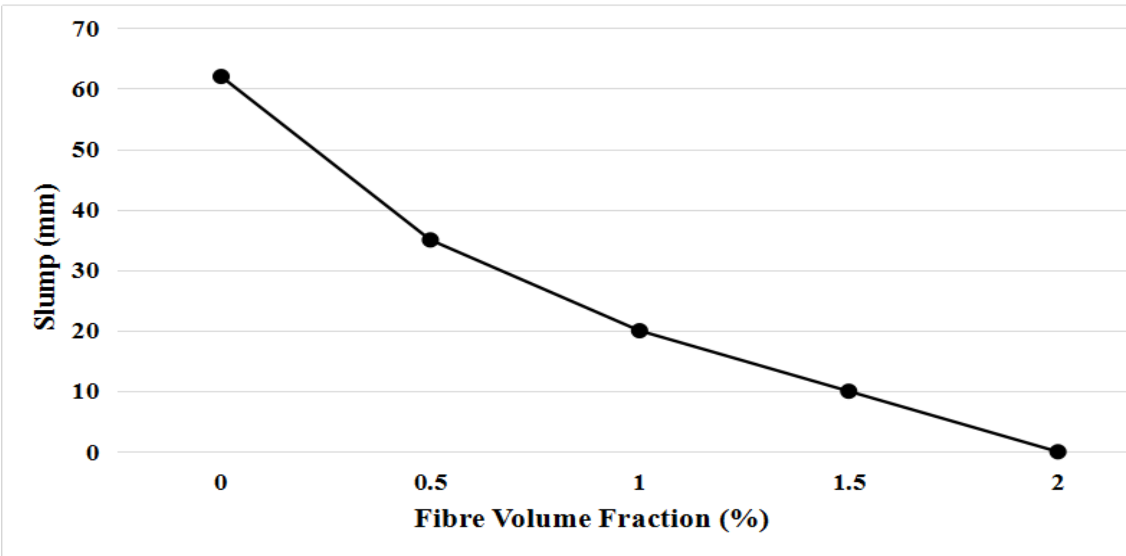


Figure 4.1 Effect of PALF volume fraction on concrete slump

(a) (b)

Figure 4.2 Slump test for (a) PALF reinforced mix (b) control mix

4.3 Hardened Density

Oil palm shell (OPS) is a waste lightweight aggregate originating from the palm oil industry, which is approximately 50% lighter than conventional aggregate. (Shafigh et al. 2012) Two types of density demoulded density and oven-dry density were measured for all mixes. The addition of fibres cause remarkable changes in the density reduction of concrete cannot be ignored, which reduces construction cost in foundation design, erection and installation. Normally inclusion of fibre will decrease the density of concrete, but some fibres increase density like steel fibre. Based on a study about the effect of aspect ratio and volume fraction on mechanical properties of steel fibre-reinforced oil palm shell concrete, showed that the fresh concrete density increased by about 5 to 190 kg/m^3 (0.3 to 10%) with the addition of steel fibres. In this study, due to the PALF low specific gravity, it can be observed that increasing fibre volume fraction cause the slightly density reduction of OPSLWC. As compare to control mix, inclusion of fibre has decrease the oven-dry density and demoulded density up to 11.84% and 3.56% respectively. Normal weight concrete will have a density in the range of 140 to 150 lb/ ft^3 (2240 to 2400 kg/m^3). The oven-dry density and demoulded density for all lightweight mixes are approximately 29% and 21% lower than normal weight concrete taken as 2300 kg/m^3 and are shown in Table 4.2. Hence, there is substantial cost savings by providing less dead load for LWC in this study. Figure 4.3 shows the relationship between density and PALF volume fraction.

Table 4.2 Oven-dry and demoulded density of OPS concrete.

No	Description	Hardened Density	
		Oven-Dry Density (kg/m^3)	Demoulded Density (kg/m^3)
1	Control	1731	1853
2	0.50 % fibre	1686	1833
3	1.00 % fibre	1624	1827
4	1.50 % fibre	1570	1804
5	2.00 % fibre	1526	1787

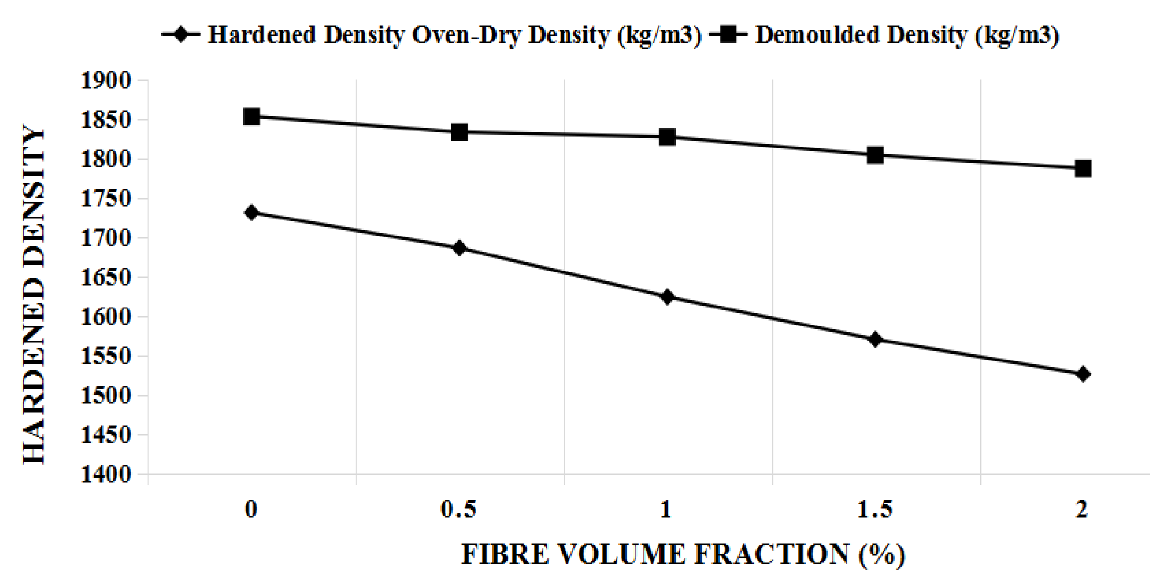


Figure 4.3 Effect of PALF volume fraction on concrete hardened density

The procedures to determine the equilibrium densities of LWC was based on ASTM C 567 Test Method for Determining Density of Structural Lightweight Concrete. According to ASTM C 567, LWC has an air-dry density not exceeding 2,000 kg/m^3 (125 lb/ft^3). In this study, the oven-dry density and demoulded density of all OPS concrete mixes are fall within range 1526-1731 kg/m^3 and 1787-1853 kg/m^3 respectively. Hence, the concrete mixes are all structural lightweight concrete. Generally compressive strength depends on factors such as density, w/b, a/c and s/c ratios. Higher density concrete produces higher strengths. And this is proven in this research, where the compressive strength of concrete obtained in this research also decrease for all ages corresponding to the reduction of density.

4.4 Compression Test

The results of the compressive strength at 3 days, 7 days, 14 days and 28 days are presented in Table 4.3. From the results shown, the compressive strength of OPSLWC decreased at all ages with an increase in PALF fibres volume fraction. The mixes from 0.5% fibre to 2.0% fibre decrease the compressive strength by 19.48%, 7.35% and 7.18% at 3 days, 9.78%, 8.45% and 9.88% at 7 days, 10.53%, 6.07% and 9.92% at 14 days, 10.58 %, 6.22% and 6.39% at 28 days, respectively. All the mixtures attained about 86–92% of their 28 days compressive strength at the age of 14 days. Whereas the ratio of 3 days and 7 days strength to 28 days was 59 to 71% and 72 to 81%, respectively. Holm et al., 2009 reported that the 7 days strength to 28 days strength ratio for high strength lightweight concrete normally is between 86% and 92%. In this research, addition of PALF fail to make it become high strength concrete.

Structural lightweight concretes are defined by the ACI as concretes with a 28 days compressive strength more than 2500 psi (17 MPa) and air-dry unit weight of 115 lb/ft^3 (1850 kg/m^3) or less. (Shale, 2007) Whereas for high strength lightweight concretes strengths is range from 6000 to 9000 psi (41-62 MPa). It has been reported that, not all types of lightweight aggregate are suitable for production of HSLWC. According to the test results showed in a journal, OPS concrete were tested with a compressive strength in the range of 34–53 MPa. (Shafigh et al., 2012) In this study, OPS concrete 28 days compressive strength was in the range of 26–41 MPa, it was not in range of HSLWC. The compressive strength result is tabulated in Table 4.3. The relationship between PALF volume fraction, curing duration and concrete compressive strength is presented in Figure 4.4.

Table 4.3 Development of compressive strength of cube specimens with variable PALF volume fraction.

No	Description	Compressive Strength (MPa)			
		3rd day	7th day	14th day	28th day
1	Control	29.600 (71.0%)	33.80 (81.1%)	38.500 (92.3%)	41.700
2	0.50 % fibre	22.950 (67.8%)	25.97 (76.7%)	30.490 (90.1%)	33.840
3	1.00 % fibre	18.479 (61.1%)	23.43 (77.4%)	27.280 (90.2%)	30.260
4	1.50 % fibre	17.120 (60.3%)	21.45 (75.6%)	25.623 (90.3%)	28.379
5	2.00 % fibre	15.890 (59.8%)	19.33 (72.8%)	23.080 (86.9%)	26.565

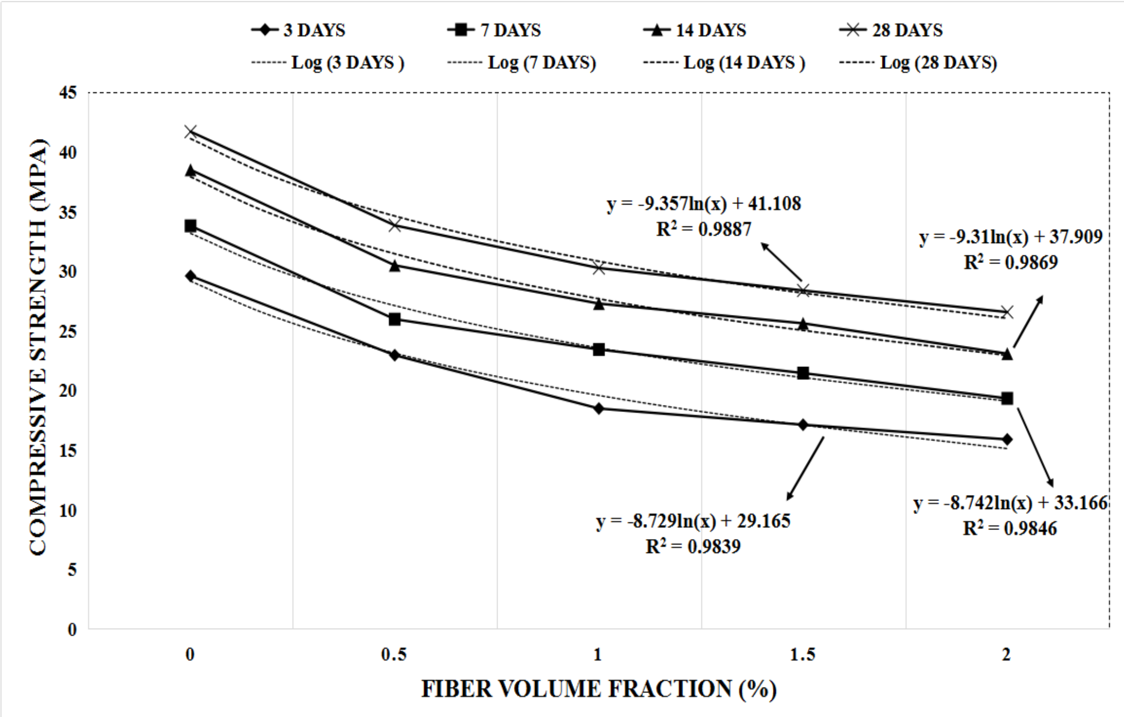


Figure 4.4 Effect of PALF volume fraction and curing duration on concrete compressive strength

Although the result of compressive strength keeps decreasing, the early compressive strength of both plain concrete and fibres reinforced concrete was considered fairly good as at 14 days, the strength almost reach strength at 28 days which is within range 86-92% of 28 days compressive strength. It can be attributed to the incorporation of silica fume (SF) as silica fume will react with calcium hydroxide (CaOH) which is product from hydration of the cement to produce calcium silicate hydrates (C–S–H). It acts as glue to bind aggregate with cement paste and result in reduction of the micro-cracks formed. Besides that, the high-water absorption of OPS and PALF absorb water as well as rugged surface of OPS may cause voids percentage increase in cement paste. The infilling of the voids in the shells by very fine SF particles may have increased the interfacial bonding between OPS and cement matrix thus increased the compressive strength of OPS concrete. Thus, silica fume plays major role in early strength development, allowing aggregates better to participate in stress transfer.

According to Standard Specification for Lightweight Aggregates for Structural Concrete (ASTM C330) Test Method C 39/C 39M, minimum compressive strength for lightweight concrete are as shown in Table 4.4:

Table 4.4 Minimum compressive strength required by Standard Specification for Lightweight Aggregates for Structural Concrete (ASTM C330) Test Method C 39/C 39M

Calculated Equilibrium Density max, kg/m^3 (lb/ft^3)	Average 28-day Splitting Tensile Strength, min, MPa (psi)	Average 28-day Compressive Strength, min, MPa (psi)
	All Lightweight Aggregate	
1760 (110)	2.2 (320)	28 (4000)
1680 (105)	2.1 (300)	21 (3000)
1600 (100)	2.0 (290)	17 (2500)
	Sand/Lightweight Aggregate	
1840 (115)	2.3 (330)	28 (4000)
1760 (110)	2.1 (310)	21 (3000)
1680 (105)	2.1 (300)	17 (2500)

By using interpolation based on the ASTM C330) Test Method C 39/C 39M, calculated the standard minimum compressive strength of the corresponding density obtained from experiment. Table 4.5 demonstrates the comparison between standard minimum compressive strength and compressive strength that obtained from experiment of this study.

Table 4.5 Comparison between standard minimum compressive strength and compressive strength that obtained from experiment.

No	Fibre	28 days		
		Density (kg)	Std. Compressive Strength, min (MPa)	Exp. Compressive Strength, (MPa)
1	Control	1.624	18.20	41.70
2	0.50 %	1.731	25.46	33.84
3	1.00 %	1.686	21.53	30.26
4	1.50 %	1.570	15.50	28.38
5	2.00 %	1.526	13.30	26.57

Generally compressive strength depends on factors such as density, higher density concrete produces higher strengths. In this study, all mixes compressive strength at 28 days are higher than the standard minimum compressive strength of lightweight concrete. Hence, it can be concluded that PALF are material suitable to be used in lightweight concrete but does not suitable to make high strength lightweight concrete.

Although in many researches mentioned that, incorporating fibre in concrete as reinforcement can improve compressive strength of concrete and proved that the use of agriculture waste OPS as aggregate for production of HSLWC is possible. However, in this research, incorporation of PALF gave negative result and PALF reinforced concrete compressive strength was lower than plain OPSLWC. However, it does not mean that PALF does not suitable to be used as construction material, perhaps the concrete strength will increase with fibre after 56 days of curing. In 2011, there was one research investigated about the effect of steel fibre on the mechanical properties of OPSLWC. The result showed that percentage of compressive strength decreased at 3 days and 7 days curing time and at 56 days, it increased as the steel fibre ratio increased. (Shafigh, Mahmud & Jumaat, 2011) There was other author reported that adding fibre to LWC does not affect the compressive strength or, that it even had a negative effect. For instance, a research that was conducted by Chen B et al., 2004, reported that lightweight expanded polystyrene concrete that were reinforced with steel fibre had lower compressive strength compared to the concrete without steel fibre. Besides, according to another journal, also proved that the addition of polypropylene and nylon insignificantly increased the mechanical properties of OPS concrete, particularly for the tensile strength. (Yew et al., 2015) Another study also presented that fibre-reinforced LWC may have two different observations which are no effect and significantly enhance the compressive strength of LWC. (Yap S.P. et.al, 2017) In a study conducted to investigate about lightweight aggregate concrete with fibre reinforcement had mentioned that the addition of steel fibre insignificantly increased the LWAC compressive strength and the polypropylene fibre had no effect on the compressive strength of LWAC. (Hassanpour, Shafigh & Bin, 2012)

4.4.1 Factors that affect reduction in concrete compressive strength

4.4.1.1 Fibre Loading

In this research, fibre inclusion gave a negative result of concrete compressive strength. As mentioned above, addition of fibre may only slightly enhance or no effect on compressive strength. This may due to weak components of LWC include the porous, weak lightweight aggregates and the weak adhesion between aggregates and cement paste. When fibre loading increase, the adhesive nature balling effect of fibres induced high fibre to fibre interactions, this uneven distribution of PALF in cement matrix causing weak bonding between PALF and matrix which the cement matrix was not perfectly firm with PALF. Threepopnatkul et al., 2009 stated that, good adhesion between the fibres and matrix makes it feasible for stress transfer to take place from the matrix to the fibres, thereby improving the strength of the composite. The reinforcement within matrix, well distribution of fibre and their interfacial bonding are directly proportional to properties of composites, where the load acting on the matrix has to be transferred through the interface to the reinforcement. (Kasim et.al, 2015)

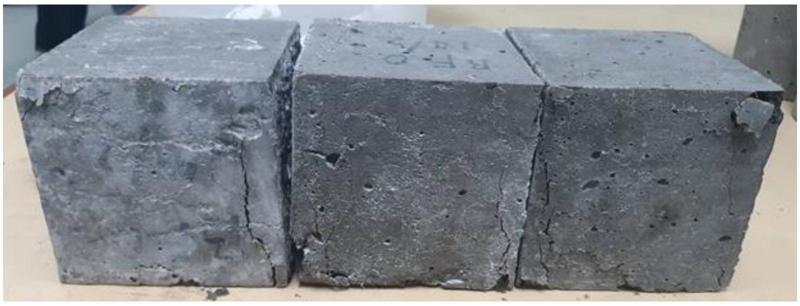
4.4.1.2 Water Content

Water content will affect development of concrete strength as cement need to react with water then only can produce gel that can bind aggregate and cement paste to make it compact. Besides that, high fibre content increases the probability of fibre agglomeration, the uneven distribution of fibre in cement paste will affect concrete strength significantly. High water absorption of OPS and fibres, this will affect the strength develop during curing phase. With an increase of fibres volume fraction, the fibres content also increase, and there is more water being absorbed. The OPS concrete under air drying and full-water curing has water absorption of 11.23% and 10.64% respectively. It is noticeable that most good concretes have absorption below 10% by mass. But this can be resolved by implementing some pre-treatment to OPS. In 2006, a study had been conducted about quality improvement of OPS. The pre-treated OPS aggregates were exposed to severe alkaline, acidic and strong sulphate solutions. The experiment revealed that quality improvement of OPS has reduced water absorption of OPS from 23.3% to 7.2% and there was better adhesion between the pre-treated OPS and the cement paste, which resulted higher compressive strength. Highest 28 days compressive strength of 32.8 MPa are reported in their study. (Mannan et al., 2006)

Based on the study that investigated by Kasim et. al, 2015, at 60wt.% up to 70wt.% PALF loading, it clearly shows the high void percentage appeared in polypropylene composite through the microstructure analysis. This is due to the fibre has high water absorb ability, it absorbs water in cement paste, and when concrete hardened and dried out, formed voids in cement matrix. The voids formed may due to incompletely wettability or bonding between polypropylene and PALF during the fabrication process lead to poor adhesion and affected their mechanical properties. And this can be solved by treatment to fibre before mixing process. (Kasim et. al, 2015) Similar topic also presented in another research about palm kernel shell. High water absorption of about 25% of palm kernel shell caused high volume of pores in cement matrix weaken the particle strength and stiffness. (Alengaram, 2008) That is why in this study, OPS had to be soaked for 24 hours and then air dried in the laboratory to attain a saturated surface dry (SSD) condition before mixing to increase the total moisture content. And fibre is treated with 10% NaOH to remove hydrophilic and polar groups, hydroxyl groups (OH) in their structure. Besides, that rugged surface of OPS also indirectly caused voids appeared in cement paste, although the voids appeared can reduce weight of concrete make it become lightweight concrete but too much of it will affect concrete strength indeed.

4.4.2 Cube Failure Mode

Figure 4.5 shows the failure pattern of plain concrete cube and 2.0% PALF reinforced concrete cubes after compressive strength test. When external load added exceed the load that the specimens can sustain, cracks appear at the peak stage of testing. Cracks were found at surface of both plain and PALF reinforced concrete. Normally, for fibre reinforced concrete, its crack is less than plain concrete as fibre has potential to postpone and reduce crack propagation. However, in this study, the plain concrete cubes cracks are less than fibre reinforced concrete. This is because plain concrete has compressive strength higher and stronger than fibre reinforced concrete.



(a) Plain concrete cube

(a) 2.0% PALF reinforced concrete cube

Figure 4.5 Cube failure pattern

4.5 Splitting Tensile Test

PALF is one of the fibre with the highest a-cellulose content and thus has superior tensile properties over plain concrete. (Morfologi and Serat, 2019) By increasing the tensile strength of LWAC with fibre reinforcement, this improvement has significant effect to avoid drying shrinkage. From the Table 4.6, it is evident that when the fibre content increased till 1.0%, the 28 days splitting tensile strength start decrease. The splitting tensile strength increased from 3.12 MPa to 3.28 MPa then decrease from 3.28 MPa to 2.65 MPa. The rate of increase for 0%, 0.5% and 1.0% mixes are 2.24% and 2.82%, respectively whereas the rate of decrease for 1.0%, 1.5% and 2.0% are 14.63% and 5.36% respectively. The optimum ratio is 1.0% fibre volume fraction. The result of split tensile test is optimistically as a very low fibre volume already can improve the tensile strength of OPS concrete. According to ASTM C330, structural lightweight aggregate concretes need to have a minimum splitting tensile strength of 2.0 MPa. In this study, it exceed the minimum requirement specified by ASTM C330. (Hassanpour, Shafigh and Bin, 2012) Figure 4.6 shows the relationship between the splitting tensile strength and fibre volume. It can be clearly seen that the splitting tensile strength increase with the addition of PALF fibre as shown in Table 4.6. A parabolic correlation of $Ft = -0.0721\ vf^2 + 0.2999\ vf + 2.902$ with R^2 of 0.858 is demonstrated in Figure 4.6; where Ft and vf are the splitting tensile strength (MPa) and fibre volume, respectively.

Table 4.6 Development of splitting tensile strength of cylinder specimens with variable PALF volume fraction.

No	Description	Splitting Tensile Strength (MPa)
		28^{th} day
1	Control	3.12
2	0.50 % fibre	3.19
3	1.00 % fibre	3.28
4	1.50 % fibre	2.80
5	2.00 % fibre	2.65

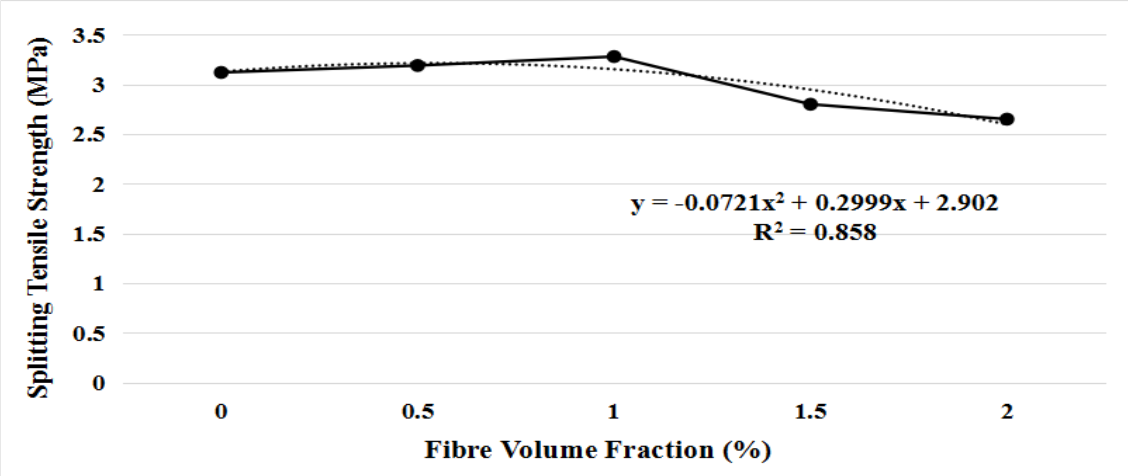


Figure 4.6 Effect of PALF volume fraction on splitting tensile strength.

In this study, the test results showed that OPSLWC has a splitting tensile strength range of 2.6 MPa to 3.3 MPa. In many previous studies, showed that the 28 days splitting tensile strength of OPS concrete in moist curing is in the range of 1.10 MPa to 2.41 MPa. (Shafigh et al. 2012) For example, an experimental carried out to investigate the influence of sand content and silica fume on mechanical properties of palm kernel shell concrete showed result of splitting tensile strength within range of 1.9 MPa to 2.35 MPa. (Alengaram et.al, 2008) The splitting tensile strength measured in this study is significantly higher than previous studies. According to research article, it was reported that the 28 days splitting tensile strength of OPS concrete in moist curing is about 6–10% of the corresponding cube compressive strength. (Yew et al., 2015) In this study, the splitting tensile strength for OPS concrete and PALF fibre OPS concrete was within the range of 2.65 MPa to 3.28 MPa and about 7.4% to 10.84% of the compressive strength. This shows that the PALF obviously enhanced the tensile to compressive strength ratio. Generally, the splitting tensile strength of normal weight concrete is 8% to 14% of the compressive strength. (Shafigh, Mahmud and Jumaat, 2011) The tensile strength of OPS concrete and PALF reinforced OPSLWC in this study is completely in the range of normal weight concrete. Figure 4.7 shows a parabolic correlation with a strong correlation (R^2 = 0.8937) between PALF volume fraction and the splitting tensile strength to compressive strength ratio. The relationship between splitting tensile strength to compressive strength ratio and PALF volume fraction is shown in Table 4.7.

Table 4.7 Relationship between splitting tensile strength to compressive strength ratio and PALF volume fraction

No	Description	Splitting Tensile Strength / Compressive Strength (Ft/Fc)
		28th day
1	Control	0.0748
2	0.50 % fibre	0.0943
3	1.00 % fibre	0.1084
4	1.50 % fibre	0.0987
5	2.00 % fibre	0.0998

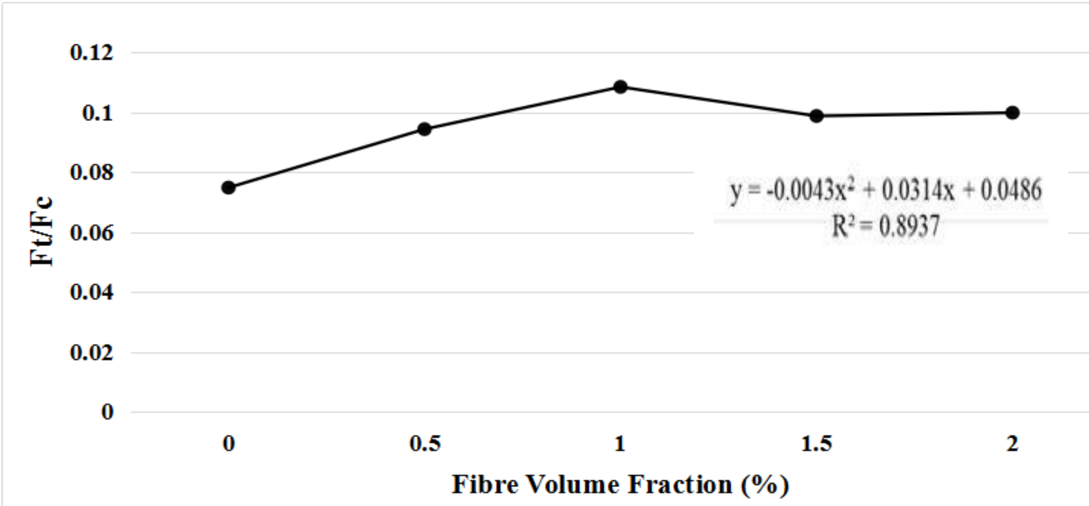


Figure 4.7 Relationship between splitting tensile strength to compressive strength ratio and PALF volume fraction

Although in this study, shows a sign of increasing in the tensile strength but there is still study reported that the tensile strength keeps decreasing with increase of fibre content. According to study conducted about mechanical properties of PALF reinforced tapioca based bioplastic resin composite, the tensile strength result presented show decrease trend as the fibre content increase and the highest average tensile strength were 6.308 MPa at 0% PALF content, this is caused by the increase of fibre in the composites causes fibre agglomeration or fibre overlapping which causes weak bond between tapioca based bio plastic and PALF. Besides that, the composite becomes more brittle as the fibre loading increased due to the change in characteristic of the composite in term of ductility cause the column easier to break. (Mathivanan, 2016)

4.5.1 Column Failure Mode

Figure 4.8 shows the failure pattern of plain concrete column and 2.0% PALF reinforced concrete column after splitting tensile strength test. Cracks were found at surface of both plain and PALF reinforced concrete columns when external load added exceed the load that the specimens can sustain, cracks appeared at the peak stage of testing. For 0% to 1.0% PALF reinforced concrete column, the cracks appeared lesser compared to PALF reinforced concrete column for 1.5% and 2.0% as the column tensile strength decrease beyond 1.0% PALF loading. This can be seen from Figure 4.8, extensive cracks appeared at surface of 1.5% PALF reinforced concrete column as compared to plain concrete column.

(a) 1.5% PALF reinforced concrete column

(b) Plain concrete column

Figure 4.8 Column failure pattern

4.6 Flexural Test

Flexural strength is one measure of the tensile strength of unreinforced concrete beam or slab to resist failure in bending. Fibre has larger endurance on tensile deformation. It creates a pulling effect on the concrete when the matrix is rupturing. The effect of fibre bridging within cement paste, the micro crack will be pulled and tensioned when it develops. The fibre bears the tensile stress transferred from the fracture section and carry the load that the concrete sustained after matrix cracking thus weaken the stress concentration in the fracture area. This pulling effect postpones the developing of cracking damage, improves the tension ductility of concrete, prevent the cracks generating, decrease the crack size, and reduce the number of micro cracks. In this study, same as splitting tensile strength, the increasing of fibre content from 0% to 1.0%, the 28 days flexural strength increase from 4.805 MPa to 6.55 MPa. And when the fibre loading further increase 2.0%, the flexural strength decreases from 6.55 MPa to 5.317 MPa. The rate of increase of flexural strength for 0% to 1.0% mixes is 13.6% and 19.96% whereas for the rate of decrease from 1.0% to 2.0% mixes is 13.74% and 5.89%. Compared to control mix, when fibre increase to 1.0%, the flexural strength can increase up to 36.32%. These results also show that 1.0% is optimum fibre volume fraction. With a small amount of PALF, it can increase flexural strength significantly. In this study can prove that PALF play an important role to improve the ductility and flexural modulus of concrete. A higher flexural modulus material is 'stiffer' than a lower flexural modulus material and can resist deformation under bending moment. Table 4.8 shows the result of flexural strength. A parabolic correlation of $Ft = -0.2833\ vf^2 + 1.8211\ vf + 3.2092$ with R^2 of 0.781 is demonstrated in Figure 4.9.

Table 4.8 Development of flexural strength of beam specimens with variable PALF volume fraction

No	Description	Flexural Strength (MPa)
		28th day
1	Control	4.805
2	0.50 % fibre	5.460
3	1.00 % fibre	6.550
4	1.50 % fibre	5.650
5	2.00 % fibre	5.317

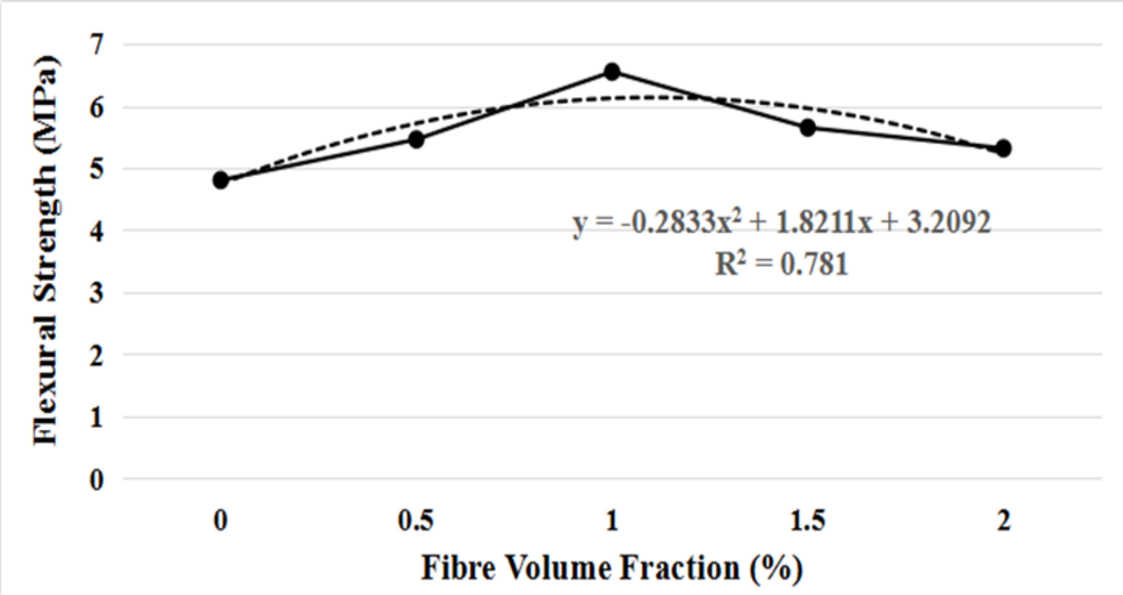


Figure 4.9 Effect of PALF volume fraction on flexural strength.

In other researches, also show the same effect where addition of fibre greatly improves flexural toughness of concrete. For instance, in a study investigate about effect of polypropylene fibre on flexural properties of concrete. From the study, show that when the fibre fraction of polypropylene fibre increased from 0% to 0.12%, the flexural strength increased 26.3% from 7.54 MPa to 9.52 MPa. (Zhang, 2014)

4.6.1 Beam Failure Mode

Beam specimens were tested for flexural strength using Universal Testing Machine (UTM) whereby the load was applied at constant rate of 0.8 kN/s for the whole research. Both control and PALF reinforced concrete experienced same failure mode when it reached its ultimate load capacity. And, the cracks were formed around the mid of the beam span. For plain concrete beam, the specimen failed suddenly at the peak stress. This can be clearly seen from failure pattern of beam, where the plain concrete beam broke suddenly into two parts. Figure 4.10 shows the failure mode of plain concrete beam.

Figure 4.10 Failure mode of plain concrete beam

While for fibre reinforced concrete, the non-uniformly dispersion of PALF in the concrete cement matrix had provided another form of bonding inside the matrix which contribute in transfer or absorb load and restrained the propagation of cracks. The cracks width of fibre reinforced crack was smaller than plain concrete beam. Regardless of the amount of PALF inclusion, the number of cracks found was lesser than that of control beam. The flexural strength of the beam increases with the amount of bamboo fibre added. The improvement of flexural strength in fibre reinforced beam was due to the pull-out capacity of fibre bridging over the crack formed at the tension zone of the beam when the load was constantly applied before reaching its ultimate capacity. The fibres bridged over the cracks formed were transferring the tensile stress over the beam before beam failure. In other word, the addition of PALF in the concrete cement matrix greatly improve the ductility behaviour and reduce tensile deformation of concrete. Figure 4.11 shows the failure mode of PALF reinforced concrete beam whereas Figure 4.12 shows the PALF bridging inside the concrete.

Figure 4.11 Failure mode of 2.0% PALF reinforced concrete beam

Figure 4.12 PALF bridging inside the concrete

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In this research, all the three objectives have been accomplished. This research was carried out to determine the performance of pineapple leaf fibre as natural reinforcement in concrete in term of workability, compressive strength, splitting tensile strength and flexural strength. Recommendations are included in this chapter as references for future work.

5.2 Conclusion

Based on the results obtained, there are few conclusions can be drawn:

i. The workability decreases by increasing the PALF volume fraction because fibre and OPS absorbs water. And the hardened density obtained are all in range of lightweight concrete.

ii. The decrease in compressive strength between OPS lightweight concrete and PALF reinforced OPSLWC at 28 days was found about 18.85% due to fibre agglomeration and high-water absorption of OPS and PALF reduce the cement paste homogeneity and stiffness.

iii. The highest 28 days compressive strength of 41.7 MPa was obtained for PALF reinforced OPSLWC. This proved that, OPS that acted as coarse aggregate replacement, is possible to create high strength lightweight concrete. For PALF reinforced OPSLWC, the highest 28 days compressive strength can reach up to

33.84 MPa. This proved that, the production of grade 30 for fibre reinforced OPSLWC is possible.

iv. The addition of 1.0 % vf of PALF induced great improvement in 28 days splitting tensile strength and flexural strength of PALF reinforced OPSLWC by 5.13 % and 36.32 % respectively. The effect of incorporating PALF at low volume fractions in improving the flexural strength of OPS concrete is more pronounced compared to its effect on splitting tensile strength.

5.3 Recommendations

i. Conduct further advance pre-treatment to PALF besides alkaline treatment. For example, soaking PALF in H_2O_2 (bleaching) for 5 hours to reduce amount of lignin in the sample after alkaline treatment.

ii. Adopt heat treatment method on crushed OPS aggregate to resolve the brittle texture of OPSLWAC besides pre-soaking of aggregates for about 1 hour to attain a saturated surface dry (SSD) condition before concrete mixing.

iii. Increasing the amount of fine aggregate like sand or adding silica fume and reduce OPS composition.

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APPENDIX A

RESULT OF COMPRESSIVE STRENGTH TEST

	COMPRESSIVE STRENGTH, MPa				
	0% PALF	0.5% PALF	1.0% PALF	1.5% PALF	2.0% PALF
3 days	30.100	23.197	17.900	18.479	16.701
	29.100	22.891	18.674	16.152	15.730
	29.800	22.762	18.863	16.729	15.239
Avg.	**29.600**	**22.950**	**18.479**	**17.120**	**15.890**
7 days	33.900	26.591	23.891	22.420	20.901
	33.000	26.183	23.450	20.781	19.565
	34.400	25.137	22.949	21.149	17.524
Avg.	**33.800**	**25.970**	**23.430**	**21.450**	**19.330**
14 days	39.300	30.650	27.690	24.798	23.056
	38.600	31.130	26.889	25.340	22.740
	37.500	29.690	27.261	26.732	23.444
Avg.	**38.500**	**30.490**	**27.280**	**25.623**	**23.080**
28 days	41.300	34.567	30.946	29.404	26.980
	41.900	33.185	28.890	28.880	26.028
	41.900	33.768	30.944	29.853	26.687
Avg.	**41.700**	**33.840**	**30.260**	**28.379**	**26.565**

APPENDIX B

RESULT OF SPLITTING TENSILE STRENGTH TEST

	SPLITTING TENSILE STRENGTH, MPa				
	0% PALF	0.5% PALF	1.0% PALF	1.5% PALF	2.0% PALF
28 days	3.100	3.160	3.554	2.785	2.704
	3.140	3.090	2.980	2.098	2.643
	3.100	3.320	3.306	3.517	2.603
Avg.	**3.120**	**3.190**	**3.280**	**2.800**	**2.650**

APPENDIX C

RESULT OF FLEXURAL STRENGTH TEST

	FLEXURAL STRENGTH, MPa				
	0% PALF	0.5% PALF	1.0% PALF	1.5% PALF	2.0% PALF
28 days	4.725	5.430	6.350	5.890	5.461
	4.630	5.673	6.595	4.905	5.370
	5.060	5.277	6.705	6.155	5.120
Avg.	**4.805**	**5.460**	**6.550**	**5.650**	**5.317**

APPENDIX D

RESULT OF HARDENED DENSITY

	OVEN-DRY DENSITY (kg/m^3)				
	0% PALF	0.5% PALF	1.0% PALF	1.5% PALF	2.0% PALF
28 days	1755	1735	1654	1554	1530
	1740	1640	1631	1586	1547
	1698	1683	1587	1570	1501
Avg.	**1731**	**1686**	**1624**	**1570**	**1526**

	DEMOULDED DENSITY (kg/m^3)				
	0% PALF	0.5% PALF	1.0% PALF	1.5% PALF	2.0% PALF
28 days	1809	1806	1874	1816	1847
	1844	1876	1853	1793	1731
	1906	1817	1754	1803	1783
Avg.	**1853**	**1833**	**1827**	**1804**	**1787**