PROPERTIES OF LIGHTWEIGHT FOAM CONCRETE WITH THE INCLUSION OF FIBRES

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PROPERTIES OF LIGHTWEIGHT FOAM CONCRETE WITH THE INCLUSION OF FIBRES

By

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LIST OF ABBREVIATIONS

LFC	Lightweight Foamed Concrete
OPC	Ordinary Portland Cement
w/c	Water to Cement Ratio
NaOH	Sodium Hydroxide
LWC	Lightweight Concrete
HSC	High Strength Concrete
NSC	Normal Strength Concrete
NSF	Normal Strength Steel Fibre
HSF	High Strength Steel Fibre
SCC	Self Compacting Concrete
AR	Alkaline Resistance
LOI	Loss on Ignition
ASR	Alkali-Silica-Reaction
SEM	Scanning Electron Microscopy
NF	Normal Foam Concrete

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SF Steel Fibre Concrete

SFA Steel Fibre Concrete with Fly Ash Inclusion

GF Glass Fibre Concrete

GFA Glass Fibre Concrete with Fly Ash Inclusion

PF Polypropylene Fibre Concrete

PFA Polypropylene Fibre Concrete with Fly Ash Inclusion

KF Kenaf Fibre Concrete

KFA Kenaf Fibre Concrete with Fly Ash Inclusion

OPF Oil Palm Fibre Concrete

OPFA Oil Palm Fibre Concrete with Fly Ash Inclusion

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SIFAT-SIFAT KONKRIT RINGAN BERBUSA DENGAN PENAMBAHAN GENTIAN

ABSTRAK

Konkrit ringan berbusa (LFC) adalah konkrit ringan yang terdiri daripada buburan mortar di mana gelembung udara terperangkap di dalam sturukturnya melalui penambahan ejen buih. Ketumpatan LFC yang mempunyai perbezaan besar dari 500kg/m^3 hingga 1800kg/m^3 menawarkan pelbagai kelebihan seperti ringan, penebat haba yang baik, penebat bunyi yang bagus dan konkrit yang berupaya mengalir bebas. Walaubagaimanapun, kadar simen yang tinggi dan kekurangan agregat dalam LFC menyebabkan ia mempunyai kadar pengecutan yang tinggi, lemah dalam tegangan dan rapuh. Penambahan gentian telah dikenalpasti berkesan terhadap menambah kekuatan dan masalah kecutan konkrit pada konkrit biasa. Namun, penggunaan gentian didalam LFC masih belum digunakan secara meluas. Kajian ini meliputi siasatan sifat-sifat LFC menggunakan ketumpatan 1000kg/m^3 dengan penambahan lima gentian berbeza (besi, polipropilena, gelas tahan alkali, kenaf dan kelapa sawit) dan abu terbang sebagai sebahagian pengganti simen. Dua peratusan serat digunakan iaitu pada 0.25% dan 0.4%. Sebanyak 30% daripada jumlah simen digantikan dengan abu terbang. Sifat-sifat LFC yang dikaji meliputi ujian kekuatan mampatan, kekuatan lenturan, kekuatan tegangan putus, daya penyerapan air, kecutan pengeringan dan ketahanan haba. Gentian besi menyumbang hampir 40% kenaikan dari segi kekuatan lenturan dan lebih kurang 20% kenaikan dicatatkan untuk kekuatan tegangan putus. Gentian gelas tahan alkali adalah

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penyumbang terbesar kepada sifat kecutan pengeringan dengan 79.3% peratusan prestasi lebih baik. Gentian gelas tahan alkali berjaya menghasilkan keputusan yang memberansangkan secara kiraan purata. Di samping itu, sifat-sifat LFC dengan penambahan gentian boleh dioptimumkan dengan penambahan abu terbang pada jangka masa panjang.

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PROPERTIES OF LIGHTWEIGHT FOAM CONCRETE WITH THE INCLUSION OF FIBRES

ABSTRACT

Lightweight Foamed Concrete (LFC) is a concrete consists of slurry mortar in which the air-voids is entrapped in the structure by the addition of foaming agent. The wide density variation of LFC from 500kg/m^3 to 1800kg/m^3 offers numerous advantages such as lightweight, good thermal and sound insulation, and high flow ability concrete product. Unfortunately, relatively high cement content and lack of aggregate in LFC results in high shrinkage and weak in tension. The inclusion of fibres was known to be effective in enhancing the strength and reducing shrinkage in normal concrete. However, the use of fibre in LFC is not widely practiced. This research investigate the properties of LFC using 1000kg/m^3 density with the inclusion of five different fibres (steel, polypropylene, alkaline-resistance glass (AR-glass), kenaf and oil palm fibre) and fly ash as partial cement replacement. Two different percentages of fibre were used at 0.25% and 0.4%. Thirty percent of cement was replaced by fly ash. Steel fibre contributed almost 40% and 20% of increment towards flexural and tensile splitting strength respectively. The inclusion of AR-glass fibre and fly ash yield the best result in drying shrinkage whereby it recorded 79.3% better performance. AR-glass fibre LFC specimens exhibit the best result in terms of properties enhancement on average. Moreover, the properties of LFC with fibre addition could be optimized with the inclusion of fly ash at the later age.

CHAPTER 1

INTRODUCTION

1.1 Research Overview

The needs of new technology are essential as it enhance the construction industry system and technology for future generation towards greener and sustainable hi-tech system. The new construction system that is cost saving, environmental friendly and more efficient end product has gain a higher market demand from time to time as the world is inventing new systems and technologies. The new construction industry offers new technology that involves relatively new dynamic material and system such as the usage of lightweight concrete, new structural panels and various types of wall blocks.

Apart of working on green and environmental friendly technologies, many production of concrete product had been designed and parts of it are made of lightweight aggregate and aerated concrete. Lightweight Foamed Concrete (LFC) is made normally from mixing slurry mortars to stable foam. This action enclosed small air bubbles within the mortar that reacts as the aggregates thereby making it lighter and possessing special properties such as highly fire resistance and low thermal conductivity. During the plastic stage, gas-form chemicals are mixed into cement mortar, resulting in an increase in volume and decrease in mix density and when the gas escapes, it leaves a porous structure that forms the aggregate (Narayanan and Ramamurthy, 2000). Foamed concrete may have densities ranging from as low as 500kg/m^3 to as high as 1800kg/m^3.

There have been a tremendous amount of researches done on LFC. (Awang *et. al*, 2012, Jones & McCarthy, 2005, Nambiar & Ramamurthy, 2007, Meyer & Mier, 2007). It is known that LFC offers numerous advantages includes lightweight, free flowing substance, excellent fire resistance, great thermal insulation and excellent sound insulation. The ability of LFC to flow freely makes it able to fill voids without the needs of vibration. Therefore, it has widened the range of applications such as material for floor & roof screeds, trench reinstatement, wall blocks or panels, road foundations and also void filling. This has saved a great amount of workmanship and enables consumers to work faster, thus makes it highly cost effective compared to other type of concrete.

The use of LFC comes with a great advantages as well as disadvantages. As quoted by Ramamurthy *et. al*, (2009), the drying shrinkage of concrete is a serious problem as expected in a large paste phase volume. But the drying shrinkage could be reduced by adopting certain ways of method such as autoclave method of curing, usage of lightweight material for the aggregate or partial substitution of Portland cement with certain amount of fine fly ash which is able to reduce the heat of hydration. They also stated that the compressive strength of foam concrete using fly ash as filler has a higher strength than equivalent sand based foam concrete mixes. In addition, the strength increase as the age increases. In terms of contribution towards compressive strength, fly ash can be beneficially used for a medium strength concrete (Bai *et. al*, 2010).

Nowadays, abundant of researches have been conducted to enhance the effectiveness of lightweight concrete for building material. For example, inclusion of fibre in lightweight concrete is one of the approaches that have been increasing in recent years. The knowledge of fibre used in cement composite, mechanisms of durability and mechanical behavior plus its insulating behavior has increased. Many research papers had proven different kind of advantages of fibre incorporating in cement composites. Raju *et. al*, (1977) found that the cube compressive strength of concrete increased linearly with the addition of steel fibres. Normal concrete reinforced with less than 2% of volume content of steel fibres provides better properties compared to normal concrete, especially the improvement of toughness (Chen & Liu, 2005). It was also reported by Sanjuan & Moragues (1997) that shrinkage and differential settlement can be inhibited or prevented effectively by using fibre reinforcement. Similarly applied to foamed concrete it is hoped that the fibre would contribute to the load carrying capacity of the material by shear deformation at the fibre - matrix interface thereby contributing to increased strength.

1.2 Problem Statement

The characteristics of foam concrete which consists of entrained cement paste and high amount of void contents has a critical shrinkage problem. Lack of aggregates and relatively high cement content resulted in high shrinkage and the crack propagation. Shrinkage of concrete initialize the cracking problem and might even have problems related to the geometric imperfection that relates to sizing and quality control of the product. Not only the strength that will be affected but also the way the material fails. However, the use of various types of fibres has been proven to reduce the shrinkage problem. Unfortunately, too few researches on fibres with a true good quality had been done. The effect on properties of LFC using natural and synthetic fibres with specific detailing and result is not yet been proven. Therefore, this study will be focusing on the shrinkage behavior with fibres as additives affecting the properties of LFC.

1.3 Research Objective

The main objective of the research is to investigate the effects of fibres (synthetic and natural) on the mechanical and durability of LFC. Different type and amount of fibre affecting the shrinkage behavior will be investigated as well. Fly ash will be added into account to enhance certain properties of LFC. To be specific, present study was done with the following objectives:

1. To investigate and characterize the effect of different type of fibres on the physical and mechanical properties of fibre foamed concrete.
2. To investigate the contribution of different type of fibres as additive in lightweight concrete towards durability.
3. To study the thermal properties of LFC with fibres inclusion.

1.4 Significance of the Study

There have been massive findings and researches that has been done on the LFC. However, there were too few that covers the shrinkage part of LFC which is one of its critical problems that needs to be emphasized. The present study will expose the advantages and disadvantages of including several fibres in LFC involving two types of fibres from synthetic and natural resources. Mainly, it focuses on the shrinkage of the concrete. It is essential to come out with the LFC that contributes to higher strength of a product. The study in thermal and microstructural analysis will be used to justify LFC behavior towards its mechanical and durability properties. The result from the research findings on the utilization of fibre will address the knowledge gap in the subject of LFC. This will provide researchers a better view of foam concrete with different type of fibre inclusions in the future.

1.5 Research Limitations

There are limitations of findings and experimental work set for this research. This study covers up the investigation of LFC using five different fibres which are steel, polypropylene, alkaline resistance-glass (AR-glass) , kenaf and oil palm fibre. There are six sets of test prepared for the mechanical, durability and thermal properties. The tests were covering the compressive strength, flexural strength, tensile splitting strength, water absorption, drying shrinkage and thermal insulation.

1.6 Thesis Organization

Chapter One is an introductory chapter of the thesis writing. This chapter explains on the general aim of this research. The overview of the study will be explained in detail as well as the problem statement, research objective, research scope, significance of the study and research limitations.

Chapter Two is the chapter where the literature review of the study is explained in detail. Study on various types of possible materials and ways to overcome current issues on durability and mechanical properties of LFC is included in this chapter. Previous studies regarding LFC are taken into account to enhance and produce better findings for this research.

Chapter Three covers methodology of the research. It includes objective of the experiment done, work program, table of the mix design, specifications of material used and type of machinery used in experimental stage.

Chapter Four discuss the overall properties of the LFC with fibres inclusion. There are six main tests covered in this chapter which are the compressive strength, flexural strength, tensile splitting strength, drying shrinkage, water absorption and thermal insulation. The analysis of result and discussions are explained in detail in this chapter.

Chapter Five is the conclusion chapter of the thesis. All of the results, discussions and contents by chapter are summarized in this chapter. Suggestions and future plans are presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review of this study will be covered in detail in chapter 2. Different kind of material and previous studies related to LFC and fibres are thoroughly stated and discussed within this chapter. Proposed research findings from previous studies are considered and combined with related literature review to produce an original thesis for this research.

2.2 Lightweight Foam Concrete (LFC)

LFC is a concrete product that consists of entrapped air bubble that the formation of pores acts as the aggregate. The LFC consists of slurry mortar with the addition of foam by dosage as a point-measure of controlling the density of the LFC product. The slurry mortar is a cement based product consists of ordinary Portland cement (OPC), sand and water with specific determined ratio. There are several factors that affect the properties of LFC in general such as the water, cement and sand ratio, filler effect (sand or cement alternative product), foaming agent, density and curing method. Ramamurthy *et. al*, (2009) had quoted several previous researcher's findings on the proportion mix ratio, density and its compressive strength as presented in Table 2.1.

Table 2.1 Review of the proportion mix, density and compressive strength of LFC

Author(s) and year	**Proportion of cement (kg/m^3) or composition**	**Ratios**			**Density range (kg/m^3)**	**Comp. strength (28 days)**
		S/C	W/C	F/C		
McCormick (1967)	335-446	0.79-2.8	1.58-1.73		800-1800	1.8-17.6
Tam *et. al,*(1987)	390	1.58-1.73	0.6-0.8		1300-1900	1.81-16.72
Regan&Arasteh (1990)		0.6(LAC/C)	0.45-0.6		800-1200	4-16
Van Deijik (1991)	Cement-sand/fly ash				280-1200	0.6-10 (91 days)
ACI 523. 1R-(1992)	Neat cement paste Cement-sand mix				240-640 (DD) 400-560 (DD)	0.48-3.1 0.9-1.72
Hunaiti (1997)		3			1667	12.11
Kearsley & Booyens (1998)	Cement-fly ash replacement 193-577				1000-1500	2.8-19.9
Durack & Weiqing (1998)	270-398 137-380	1.23-2.5	0.61-0.82 0.48-0.70	 1.48-2.5	982-1185 (DD) 541-1003 (DD)	1-6 3-15 (77 days)
Aldridge (2000)	Cement-sand mix				400-1600	0.5-10
Kearsley & Wainwright (2001)	Cement-fly ash replacement 193-577		0.6-1.17			
Tikalsky *et. al* (2004)	Neat cement 149-420 Cement-sand/fly ash 57-149		0.4-0.45 0.5-0.57		 1320-1500	 0.23-1.1
Jones & McCarthy (2005)	300	1.83-3.17	0.5 1.11-1.56	 1.22-2.11	1000-1400 1000-1400	1-2 3.9-7.3
Jones & McCarthy (2005)	500 500	1.5-2.3	0.3 0.65-0.83	 1.15-1.77	1400-1800 1400-1800	10-26 20-43
Nambiar & Ramamurthy (2006)	Cement-sand mix (coarse) Cement-sand mix (fine) Cement-sand-fly ash mix	With filler-cement ratio varied from 1 to 3 and fly ash replacement for sand varied from 0% to 100%			800-1350 (DD) 800-1350 (DD) 650-1200 (DD)	1-7 2-11 4-19

Source : Ramamurthy *et. al,* (2009)

By referring to Table 2.1, it can be concluded that the compressive strength of LFC is closely related to its density. The higher the density, the stronger the compressive strength becomes. But generally, the water to cement (*w/*c) ratio plays the most important role in determining the properties of LFC. The lower the *w/*c ratio, the greater the strength of concrete (Abrams, 1918). The *w/*c ratio rate for LFC is however might differ due to the additional of water as foam included. The necessary *w/*c ratio used for LFC is suggested to be kept at lower rate to avoid unnecessary shrinkage, water excessive and poor workability of LFC. The range of *w/*c ratio is however depends on the use of admixtures and composition which varies from 0.4-0.6 for the densities of 1000-1400kg/m^3 (Jones & McCarthy, 2005, Regan & Arasteh, 1990). Another factor affecting the properties of LFC is the curing method. There are many ways of curing such as water curing, autoclaving, plastic sheets wrapping and steam curing. The way of curing will depends on the usage and environmental condition.

The density of the mortar used in LFC mixing is usually varies between 2150 kg/m^3 to 2250kg/m^3. But as the foam is added, the density of LFC will drop to the rate of desired density. There are two types of foaming agent known to be used which are the synthetic and protein based foaming agent. A portable foaming generator is used to produce fairly stable foam. The chemical agent is diluted in water which will then be forced at high pressure through the foaming lance to produce the foam. The weight of the foam used varies from 60 to 80gram/liter. But it has been stated in earlier publication by McGovern (2000), that foams formed out of protein based surfactant has smaller bubble and the bonding structure of the bubbles are stronger and more stable compared to the synthetic based surfactant. The formation of these bubbles makes it lighter than the normal concrete aggregate in which the usage could varies in so many ways possible.

The LFC is called lightweight due to its lighter weight compared to the normal concrete with a density in the region of 300kg/m^3 to 2000kg/m^3. With the lightness as its main specialty, it has been a tremendous approach for a new trend of building material product. There are so many advantages offered in using LFC. The lightness offers reduction in direct loading of structures thus, results in cost saving in many ways applicable. Unlike normal concrete, the smoothness and free-flowing ability helps in void filling. There will be no compaction and vibration needed in casting stage. Figure 2.1 shows the various usage of LFC in construction industry in the production of lightweight block and a free flowing material.

a) Lightweight block (www.brickmakingmachinetm.com, 2013)

b) Free flowing ability (www.construction-int.com, 2010)

Figure 2.1 Various usage of LFC as construction material

Table 2.2 present the typical properties of LFC published by The British Cement Association. It can be concluded that lower density of LFC compared to normal concrete has many advantages such as lower in thermal conductivity, high in fire resistivity and it offers good sound insulation. Nevertheless, lower density of LFC exhibits higher shrinkage which can lead to the crack propagation.

Table 2.2 Typical properties of LFC

Dry Density (kg/m^3)	**Compressive Strength (MPa)**	**Thermal Conductivity (W/mK)**	**Modulus of Elasticity (kN/mm^2)**	**Drying Shrinkage (%)**
400	0.5-1.0	0.10	0.8-1.0	0.30-0.35
600	1.0-1.5	0.11	1.0-1.5	0.22-0.25
800	1.5-2.0	0.17-0.23	2.0-2.5	0.20-0.22
1000	2.5-3.0	0.23-0.30	2.5-3.0	0.18-0.15
1200	4.5-5.5	0.38-0.42	3.5-4.0	0.11-0.09
1400	6.0-8.0	0.50-0.55	5.0-6.0	0.09-0.07
1600	7.5-10.0	0.62-0.66	10.0-12.0	0.07-0.06

Source: Kearsley, (1999)

The absence of solid aggregate and relatively high cement content in LFC had made the LFC brittle in nature and suffers from serious shrinkage problems. Even normal concrete tend to be weak in tension and suffers from shrinkage but the problem is not really as serious as in LFC. Several researches had been done previously to encounter shrinkage problem by introducing certain amount of additives and fillers such as fibres inclusion. The inclusion of fibre is known to be effective towards reducing the shrinkage in concrete. There are two types of fibre that have been known to be used in the building material technology which are from synthetic and natural resourced fibre.

The usage of fibre in concrete technology has grown popular especially for the synthetic type of fibre such as polypropylene, steel and glass fibre. As for the natural resourced fibre, the research is growing rapidly as it leads to green technology and cheaper in cost.

2.3 Synthetic and Natural Resourced Fibres

Both synthetic and natural resource fibres have its advantages in the matrix proportioning of cement composites. Synthetic fibres are man-made fibres from researches and developments of textile industries. It was first reported to be a component of construction materials in 1965. The types of fibres that have been tried in Portland cement concrete based are acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene. Thus, the use of synthetic fibre reinforced concrete is currently exists worldwide due to its promising feature of optimizing durability and mechanical properties of the concrete. Moreover, it has been proven that synthetic fibres helped to improve the post peak ductility performance, pre-crack tensile strength, impact strength and eliminate temperature and shrinkage cracks.

In comparison of synthetic fibres, natural fibres are believed to be more environmental friendly. Therefore, they are currently getting a lot of attention for replacing synthetic fibres (Thielemants & Wool, 2004). Most of the researches on the use of natural fibres have been conducted to come up with a lower cost of fibres compared to synthetic. Wood fibres derived from bamboo and sugar cane have been used for the production of low cost cementitious composites. Other natural fibres examples are jute, sisal and coconut fibres. It has been stated that natural fibres have many advantages such as they have low density, recyclable and biodegradable compared to the synthetic fibres (Hatta *et. al*, 2008). Even if compressive and tensile strength of natural fibres concretes are slightly lower than the control concrete mix, their deformation behavior shows improvement in ductility and reduced shrinkage (Ramaswamy *et. al*, 1983).

Besides that, natural fibre exhibit many advantages properties and offer significant reduction on the cost and benefit associated with processing compared to synthetic fibre (Toledo *et. al*., 2003, Asasutjarit *et. al*., 2007). Ramli & Dawood (2010) investigated the effect of oil palm fibre on the mechanical properties of lightweight concrete (LWC) crushed brick. The authors had come out with more than 16% of flexural strength enhancement with 0.8% inclusion of palm fibre by volumetric fraction. Portland Cement Association, (1991) have carried out an investigation on the properties of concrete using natural fibres from coconut coir, sugar cane, bamboo, jute, elephant grass, akwata and sisal. Each fibre used will have different results of properties as shown in the Table 2.3.

Table 2.3 Comparison of fibre types and properties. (Portland Cement Association)

Fibre Type	Diameter, 0.001 in.	Specific Gravity	E, ksi x 1000	Tensile Strength, ksi	Strain at Failure, %
Steel					
High Tensile	4-40	7.8	29	50-250	3.5
Stainless	0.4-13	7.8	23.2	300	3
Glass	0.4-.5	2.5-2.7	10.44-11.6	360-500	3.6-4.8
Polymeric					
Polypropylene	20-160	0.9	0.5	80-110	8
Polyethylene	1-40	0.96	0.725-25	29-435	3-80
Polyester	0.4-3	1.38	1.45-2.5	80-170	10-50
Amarid	0.4-.47	1.44	9-17	525	2.5-3.6
Asbestos	0.0008-1.2	2.6-3.4	23.8-28.4	29-500	2-3
Carbon	0.3-.35	1.9	33.4-55.1	260-300	0.5-1.5
Natural					
Wood cellulose	0.8-4.7	1.5	1.45-5.8	44-131	-
Sisal	<8	-	1.89-3.77	41-82	3-5
Coir (Coconut)	4-16	1.12-1.15	2.76-3.77	17-29	10-25
Bamboo	2-16	1.5	4.79-5.8	51-73	-
Jute	4-8	1.02-1.04	3.7-4.64	36-51	1.5-1.9
Akwata	40-160	0.96	0.076-.464	-	-
Elephant Grass	17	-	0.716	26	3.6

Sivaraja *et. al*, (2010) have conducted an investigation on the durability properties of natural fibre concrete composites using coconut coir and sugarcane bagasse. They found that both natural fibres used enhanced all the three mechanical strength properties; compressive, splitting tensile, modulus of rupture and flexural strength. However, the natural fibres concrete enhanced the strength properties only at early ages but the rate of increment had been stated to be lower at later curing age.

The only problem that could have caused the deterioration of fibres in concrete is they suffer degradation through high alkaline environment of cement paste also known as Portland cement especially for natural resourced fibre. High alkaline environment dissolves lignin and hemicelluloses phase thus weakening the natural fibre structure (Silva & Rodrigues, 2007). Figure 2.2 illustrates the morphological layer of natural fibre in general. These lignin and hemi-celluloses is believed to be fragile in alkaline environment as it dissolves the lignin and hemi-celluloses (Silva & Rodrigues, 2007, Ramakrishna & Sundararajan, 2005, Filho *et. al*, 2000, Kriker *et. al*, 2008). For extra information, alkaline solution such as Sodium Hydroxide, (NaOH) is frequently be used in composite industries upon removal of lignin and hemi-celluloses to achieve desired product. The effect towards natural resourced fibres are more serious in this case compared to synthetic fibres as the sulfate and chloride attack due to active chemical erosion in matrix could penetrate easily into the inner part after the desolation of lignin and hemi-celluloses.

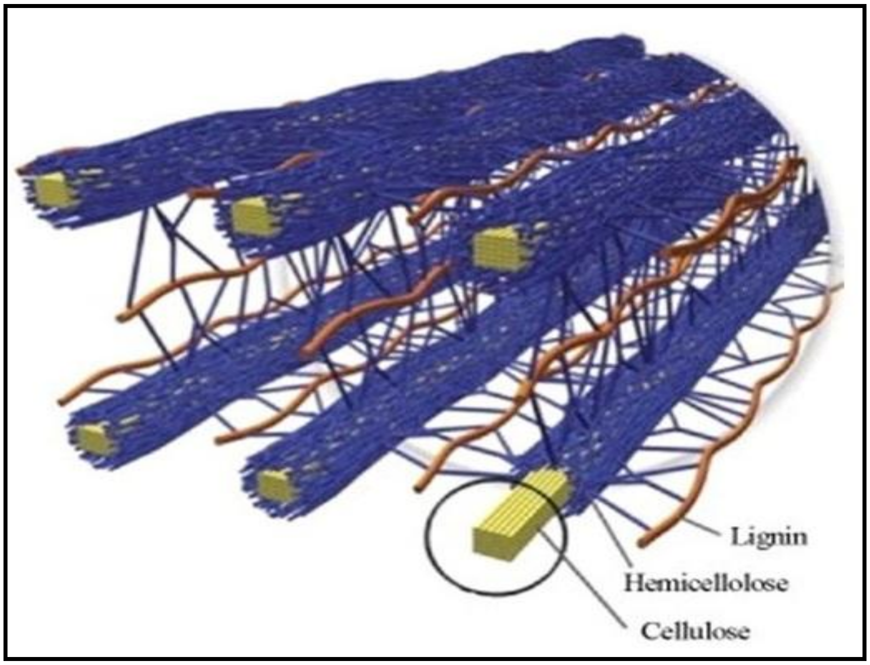

Figure 2.2 Layers of morphological constituent in natural fibre (Doherty *et. al*, 2011).

In addition, one of the most important factor in incorporating fibre in concrete is the rate of fibre distribution as it affects both fresh state and hardened-state properties of the concrete (Boulekbache *et. al*, 2010). They confirmed that the rheology of concrete is directly influencing the orientation of the fibres. Poor distribution of the fibres has led to less homogeneity and more defects in the matrix.

Study on the effect of compressive strength of normal concrete with natural fibres has been done by Ramaswamy *et. al*, (1983). They stated that vegetable fibre concretes exhibited substantially lower shrinkage compared to plain concrete mixes, while in the view of compressive strength, vegetable fibres had been proven to have no effect to increase the value. Figure 2.3 shows the cube compressive strength of three fibres which are Jute, Coir and Bamboo with plain concrete mix as the reference increasing by age in weeks. The compressive strength mostly remains the same or slightly decrease compared to normal concrete mix. Coir fibre has almost the same compressive strength with the control mix compared to Bamboo and Jute fibres which the compressive strength are slightly lower than the control mix.

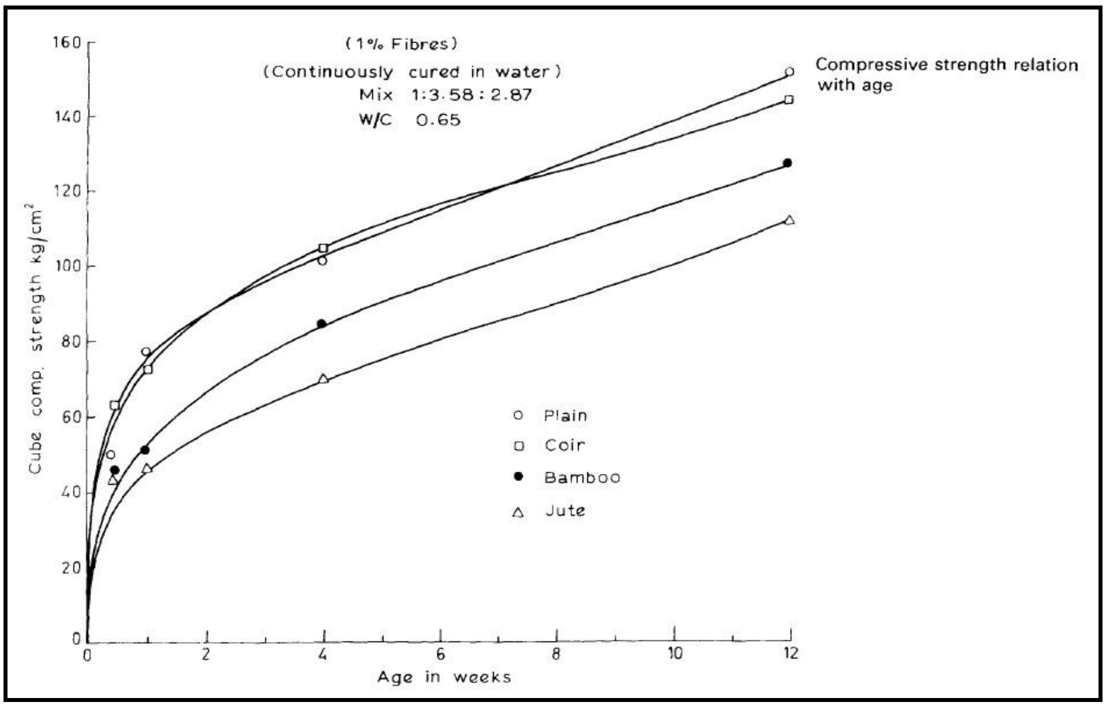

Figure 2.3 Cube compressive strength by age in weeks. (Ramaswamy *et. al,* 1983)

Apart of all justifications made and findings reviewed, it can be concluded that the fibre incorporation in concrete is not really worth it to be included for the purpose of compressive strength enhancement in concrete especially in lightweight forms (Akinkurolere, 2010, Kim *et. al*, 2010, Daneti *et. al*, 2011). The effect can even be classified as deteriorating for certain fibres. The introduction of filler effect such as fly ash is necessary at this stage to help increase the compressive strength of fibrous concrete specimens.

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2.4 Effect of Fibre on Compressive Strength

Compressive strength is an important measure in producing a good quality of concrete. In most cases, fibre seems to have a positive and encouraging result in enhancing the compressive strength of concrete. It was reported that the compressive strength of normal concrete increases with the inclusions of polypropylene fibre (Prashant *et. al*, 2011). Vikrant *et. al*, (2012) also stated that the compressive strength of normal concrete is increased by the inclusion of 0.5% steel fibre out of total volume fraction. More than 17% of total average increment of compressive strength was recorded by the author using 3 different sizes of fibre. In contrary, Rohit *et. al*, (2012) found that only marginal increase of compressive strength was recorded in their investigation using 12mm polyester fibre towards normal concrete. Akinkurolere (2010) also found that there was no remarkable increase in compressive strength of normal concrete but the increment was stated to be higher in tensile splitting strength.

However, those kinds of contributions are reported to have its effect optimized towards NC but not on lightweight concrete (LWC). The result of compressive strength for lightweight aerated concrete has been reported to be weakly dependant on the amount of fibre included in the specimens (Kim *et. al*, 2010). The author found that with the inclusion of 1% polypropylene fibre, the compressive strength gradually decreases. Daneti *et. al*, (2011) also found that the inclusions of fibres in LWC showed no contribution towards the compressive strength but more on flexural and shrinkage test result. This kind of attributes has strongly changed author's opinion towards fibre affecting compressive strength of LWC.

The presence of fibre in LWC certainly gives big impact of change in terms of cohesion between fibre and admixture. Compressive strength is strongly related to water to cement ratio, bond between mortar and aggregate and sizes of the aggregates (Elices & Rocco, 2008, Rocco & Elices, 2009). With the inclusion of fibre, the water absorption rate is higher which rapids up the loss of water during setting time. This has made the compressive strength of LWC decreases gradually. LWC properties are also known to be highly affected by the porous structure that acts as the aggregate. The inclusion of fibres might have destroyed the porous formation which also leads to lower compressive strength result.

Fukang (2013) investigated the effect of polypropylene fibre on mechanical properties of LFC. He found out that the compressive strength of both specimens with and without fibre indicated almost an equal strength which he concluded that the influence of fibre is limited for compressive strength. Nevertheless, the fibre has improved the post-peak load carrying capacity. The same pattern has been found by Meyer & Mier, (2007) in using poly venyl alcohol fibres in LFC. They stated that the fibre did not significantly increase compressive strength but only the post-peak load carrying capacity was improved. Ahmed *et. al*, (2013) also found that the compressive strength of LFC was marginally decreased with the inclusion of crimped plastic fibre. The decrement was recorded at 0.5%, 0.75% and 1% percentage of fibre inclusion with 4.4%, 13.7% and 18.3% decrement recorded respectively.

2.5 Effect of Fibre on Flexural Strength

Fibre seems to have a very good contribution towards flexural strength of concrete regardless of the type of concrete used. A lot of researchers have reported that flexural strength of concrete is increased with the inclusion of fibres in either normal or lightweight type of concrete. Sounthararajan & Sivakumar (2013) stated that 20.55% of increment was achieved at 7 days and 25% at 28 days of test in their investigation with the inclusion of 0.3% by volume fraction of glass fibre using normal concrete. Rohit *et. al*, (2012) achieved more than 18% of flexural strength increment at early age of test using 12mm polyester fibre. He also found that more than 40% of flexural strength increment could be achieved with the introduction of fly ash up to 60% of inclusion.

Most researchers agree with the statement that fibre inclusion is able to boosts up flexural strength of concrete. Bagherzadeh *et. al* (2012) also found that almost 30% average of increment of flexural strength of concrete had been recorded in his research on polypropylene fibre. Chanh (2005) reported the same pattern of increment in which the steel fibre was included in his research.

Moreover, Ramli & Hoe (2010) have found that the inclusion of coconut, barchip and glass fibre successfully enhanced the flexural strength of high strength concrete (HSC) in their research. It was reported that the inclusion of 1.8% coconut, 2.4% glass and 2.4% barchip fibres achieved the optimal result with the result of 18.1%, 19.2% and 24.7% higher than the control specimen respectively. The coconut fibre has been said to have deleterious effect towards flexural strength of concrete at early ages. But, the strength developed well after 28 days of test with adequate curing. However, barchip and glass fibre both resulted in a more consistent way. This has strengthened author's opinion that natural fibres needs more custody compared to those synthetic fibres as synthetic fibres had been well treated from factory to be more durable.

Furthermore, Mydin & Soleimanzadeh, (2012) investigated the inclusion of polypropylene fibre in LFC at elevated temperatures. The results indicated an improvement of flexural strength at 0.4% fibres inclusion but the inclusion of more than 0.4% resulted in reducing the flexural strength. Moreover, Byun *et. al*, (1998) did also justified and improvement of flexural strength with the inclusion of vynylon fibre with 2.04 times of improvement was recorded.

2.6 Effect of Fibre on Tensile Strength

The incorporation of fibre in concrete is known to be helpful in terms of enhancing the tensile splitting strength of concrete. The enhancement of tensile properties of concrete is attributed to the ability of fibre to carry the load through shear stress at the interfacial zone. This kind of attribution is much helpful especially for LWC which is known to have none load bearing element that can be subjected to absence of coarse aggregates.

Aydin (2013) had conducted investigations on the use of normal strength steel fibre (NSF) and high strength steel fibre (HSF) towards properties of normal (NSC) and HSC. It has been found that the splitting tensile strength of concrete increases parallel to the fibre dosage and strength regardless of the type of fibre used. But the strength enhancement was stated to be more efficient towards HSC compared to NSC. 16% and 19% of tensile splitting strength enhancement was respectively recorded for NSF and HSF on NSC, whereby 20% and 36% was respectively recorded for NSF and HSF on HSC.

Furthermore, Parveen & Sharma (2013) found that the hybridization of polypropylene and steel fibre has significantly increases the tensile splitting strength of concrete. With the inclusion of 0% up to 0.4% of polypropylene fibre and 0.8% constant percentage of steel fibre, 0.3% + 0.8% resulted in 47% of increment in tensile split which is the optimum result in the author's findings. The inclusion of more than 0.3% of polypropylene fibre has been stated to marginally reduce the tensile splitting strength of concrete. Significant increment of tensile splitting strength of concrete had been stated by Shende & Pande (2011) with the use of hook stain steel fibre at 0%, 1%, 2% and 3% by volumetric fraction. The tensile splitting strength increases up to 29% of increment with the utilization of 3% steel fibres.

On the other hand, fibre seems to have an outrageous impact towards enhancing lightweight type of concrete. Mohammed (2007) stated that 54.98% and 77.12% increment of tensile splitting strength of LWC with broken bricks for 0.5% and 1% fibre inclusions correspondingly. In addition, Yap *et. al*, (2013) stated more than 80% of tensile strength increment with the inclusions of multi-filament polypropylene fibre in oil palm shell concrete outperforming the other two fibres; fibrillated polypropylene and nylon fibre. Mo *et. al*, (2014) also found that tensile strength can be increased directly up to 41% with the addition of 1.0% steel fibre in OPSC.

Dawood & Hamad, (2013) justified an improvement of splitting tensile strength with the inclusion of glass fibres in LFC. The highest strength recorded was up to 46% of increment compared to the control specimen by using 0.6% fibre while 15.7% and 31.5% increment was recorded using 0.2% and 0.4% fibres respectively. Ahmed *et. al*, (2013) also found that the inclusion of crimped plastic fibre increased the splitting tensile strength with the increment trend was noted at higher percentage of fibre inclusion. The increment was recorded with 21.6%, 35.2% and 55.7% at 0.5%, 0.75% and 1% of fibre inclusion respectively.

2.7 Effect of Fibre on Porosity

Porosity is an important measure in determining the properties of LFC. Apart of being good as free-flowing and has lighter material, LFC is also chosen as an alternative material because of its advantage in better durability such as sound insulation, thermal