LOCAL EMPTY FRUIT BUNCH CONCRETE: AN INVESTIGATION ON FLEXURAL PERFORMANCE

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DECLARATION

I declare that the production of this thesis is written by me, and I declare that this thesis is an original report that been written by me and submitted for the requirement of my degree studies. Excluding the formulas, quotations, and summaries cited by reference, all the work reported in this paper is all mine

21st JULY 2022

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ABSTRACT

The focus of this project is to study the flexural performance of natural fiber concrete, which in this research is the oil palm empty fruit bunch empty fruit bunch EFB fiber. The oil palm EFB fiber has a great potential to be used as reinforcement filler for concrete due to its mechanical and structural properties. Palm oil EFB fiber structure consists of cellulosic structure that can also be found in other plant fiber. The significance of oil palm EFB fiber to be used as reinforcement filler is that they were readily available as a waste material in Oil Palm agricultural sectors. Since Malaysia is one of the largest oil palm producers, the oil palm EFB fiber decomposition has become one of the major problems faced by this agricultural sector. Other than damping the waste to be decomposed naturally, this waste can be turned into valuable products. By using fabrication methods based on recognized engineering standards such as American Society for Testing and Materials ASTM and British Standard BS, the ability of oil palm EFB fiber as reinforcement fillers in concrete can be achieve. Compared to conventional concrete, flexural performance of oil palm EFB fiber concrete should be better than conventional concrete. However, the result obtained does not meet the expected outcome. This is likely due poor adhesion between the oil palm EFB fiber and concrete matrix material used. Comparison between the obtained result with other research was done, and improvement method was discussed. Improvement proposed is including irradiation of cellulose molecule within the oil palm EFB fiber and using hyper-plasticizer for better dispersion of cement particle and better penetration into oil palm EFB fiber cell wall. Gamma radiation may induce the degradation of cellulose structure, which produce free radicals that can form a stronger interphase bonding with cement particles as hydration process take place.

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ABSTRAK

Konkrit Serat Tandan Buah Kosong: Kajian Berkenaan Tahap Kelenturan

Fokus projek ini adalah untuk mengkaji prestasi lenturan konkrit gentian asli, yang mana dalam penyelidikan ini adalah serat tandan buah kosong EFB kelapa sawit. Serat EFB kelapa sawit mempunyai potensi besar untuk digunakan sebagai gentian tetulang untuk konkrit dan strukturnya. Struktur serat EFB kelapa sawit terdiri daripada struktur selulosa yang juga boleh didapati dalam gentian tumbuhan lain. Kelebihan serat EFB kelapa sawit digunakan sebagai gentian tetulang ialah kewujudannya sebagai bahan buangan dari sector pertanian kelapa sawit. Memandangkan Malaysia merupakan antara pengeluar minyak sawit terbesar, penguraian serat EFB kelapa sawit telah menjadi salah satu masalah utama sector pertanian ini. Selain dariada pelupusan secara semula jadi, sisa serat EFB kelapa sawit boleh ditukar menjadi produk yang berharga. Dengan menggunakan cara pembuatan berdasarkan standard kejuruteraan yang diiktiraf seperti American "Society for Testing and Materials ASTM" dan "British Standard BS", kemampuan serat EFB kelapa sawit sebagai gentian tetulang dalam konkrit dapat direalisasikan. Berbanding dengan konkrit konvensional, prestasi konkrit EFB kelapa sawit harus lebih baik daripada konkrit konvensional. Walau bagaimanapun, keputusan yang diperolehi tidak memenuhi hasil yang diharapkan. Hal ini terjadi berkemungkinan disebabkan oleh kekuatan lekatan yang lemah antara serat EFB kelapa sawit dan bahan matriks konkrit yang digunakan. Perbandingan antara hasil yang diperoleh oleh penyelidikan yang sebelumnya telah dilakukan, dan kaedah penambahbaikan telah dibincangkan. Penambahbaikan yang dicadangkan adalah termasuk menggunakan sinaran radiasi pada kandungan molekul selulosa dalam serat EFB kelapa sawit dan menggunakan hyper-plasticizer untuk penyebarkan zarah simen yang lebih baik ke dalam dinding sel serat EFB kelapa sawit. Sinaran gamma boleh menyebabkan degradasi struktur selulosa, yang menghasilkan radikal bebas yang boleh membentuk ikatan antara fasa yang lebih kuat dengan zarah simen semasa proses penghidratan berlaku.

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LIST OF SYMBOLS

C_3S	Tricalcium silicate
C_2S	Dicalcium silicate
C_4AF	Tetra calcium alumino ferrite
psi	Pound per inch
MPa	Megapascal
GPa	Gigapascal
$wt.\%$	Weight percent
w/c	Water cement ratio
$°C$	Degree Celsius
f_m	Mean strength of target
f_c	Characteristic strength required
k	Statistical constant
s	Standard deviation
N/m^2	Newton per meter squared
kg/m^3	Kilogram per meter cubic
r	Rate of loading
S	Rate of rise in maximum stress on the tension face
b	Average width
d	Average depth
L	Span length
P	Maximum loading
m	slope
I	Moment of inertia
mm	Millimetre
μm	Micrometre
in	Inch
N	Newton
kgf	Kilogram-force
lbf	Pound-force

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ABBREVIATION

ACI	American Concrete institute
ASTM	American Society for Testing and Materials
BS	British Standard
EFB	Empty Fruit Bunch
EN	European Norm
FFB	Fresh Fruit Bunch
FRC	Fiber Reinforced Concrete
IS	Indian Standard
M15	Concrete mix of 15 N/mm^2 compressive strength
M20	Concrete mix of 20 N/mm^2 compressive strength
M25	Concrete mix of 25 N/mm^2 compressive strength
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
OPC	Ordinary Portland Cement
UMS	Universiti Malaysia Sabah
USB	Universal Serial Bus
UTM	Universal Testing Machine

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The evolution of concrete is an engineering development, that has significantly improved human civilization, urbanization, and industrialization. According to Richard W. Steiger (1995), the Romans are generally known to have made the first concrete engineering, however archeologists have found 6500 B.C concrete in Syria. During the stone age era, the Syrians made permanent fire pits for heating and cooking using concrete (Richard W. Steiger, 1995). This resulted in crude calcination of the surrounding rock and the unintentional discovery of lime construction material. From the Middle East, the application of concrete technology spread and evolved, particularly in Europe. Joseph Aspudin has been credited as the inventor of the first Portland Cement in the United States in 1824 (Ryan, 1929). These days, Portland Cement has become a common ingredient used worldwide for concrete, mortar, stucco, and non-specialty grout.

Concrete has significantly improved via different processes throughout the years. Fiber-reinforced concrete is one of the improvements to cope with construction material's structural and mechanical properties. The American Concrete Institute ACI committee conducted the first comprehensive report on fiber-reinforced concrete in the 1990s, and since then, FRC has improved to a more significant progress. One of the most important mechanical properties of fiber reinforced concrete FRC, particularly its flexural performance, has been standardized, resulting in EN 14651 and ASTM C1609 standards. Standardization of

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the corresponding properties has led to the safer structural performance of concrete. Natural fiber is one of the reinforcement fillers used in fiber reinforced concrete FRC. The oil palm EFB fiber has a great potential to be used as reinforcement fillers within concrete matrix due to its mechanical properties. However, this mechanical property is determined by the proportion of material used which are oil palm EFB fiber, cement, and water. Thus, the flexural performance of oil palm EFB fiber concrete is being investigated to obtain the optimum proportion of oil palm EFB fiber to be used as filler materials in concrete. Preparation for the materials used and development, as well as flexural test are according to ASTM standard.

1.2 Problem Statement

Empty fruit bunch oil palm EFB fiber is one of the agricultural waste products of oil palm sector. According to Derman *et al*. (2018), oil palm EFB fiber stand as the highest waste product generated from fresh fruit bunch FFB. It was recorded that oil palm EFB fiber produced by oil palm industry in Malaysia are around 15.8 to 17 million tons per year (Derman *et al*., 2018). Large production of oil palm EFB fiber waste may contribute to disposal issue for some mill, since they may need large area only for disposal purposes. The optimum dosage of oil palm EFB fiber as the reinforcement filler materials in concrete for producing the specific flexural performance is not yet being standardized. Thus, applying the suitable standard to produce M15 grade oil palm EFB fiber concrete in this research is one of the steppingstones to the standardization of oil palm EFB fiber concrete mix design and development. As the M15 concrete aged, the compression strength of oil palm EFB fiber concrete will also increase. Thus, the maximum flexural performance with varied aging period needs to be determined to find out the maximum flexural performance of the concrete.

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1.3 Research Objectives

The aim of this research project is to investigate the flexural performance of local empty fruit bunch EFB fiber concrete. This aim can be achieved by the objectives below.

i. To study the effect of varied oil palm EFB fiber (percentage by weight) as filler material to the flexural performance of M15 grade concrete.
ii. To study the flexural performance of oil palm EFB fiber concrete with varied aging period.

1.4 Scope of Works

The scope of works is as follow:

i. Carry out the literature review on the existing and past research related to oil palm EFB fiber concrete structural and mechanical properties from multiple sources including journals, books, and articles.

ii. Design and fabrication of oil palm EFB fiber based on international standards.

iii. Fabrication of oil palm EFB fiber concrete is according to mould size of 215mm x 102.5mm x 65mm.

iv. Laboratory test of oil palm EFB concrete flexural strength, that take place in Makmal Ujian Kayu, Fakulti Perhutanan, Universiti Malaysia Sabah UMS.

v. Carry out documentation of the oil palm EFB fiber concrete research project progress and data.

1.5 Research Methodology

The most important method to achieve the project objectives is to understand previous research associated to the project. Literature review regarding the research on oil palm EFB concrete were done based on journals, articles, and books. Studies from the previous research is important for better understand

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regarding the project, suitable experimental standard, and additional information which may affect the overall performance of fabricated oil palm EFB fiber concrete.

To produce oil palm EFB fiber concrete, materials used is being prepared accordingly, based on the appropriate mix design and development standard. This is important to ensure that the fabrication process done smoothly. Standard referred for the material preparation is as described in ASTM C150 - 07. For fabrication of concrete with the desired quality, the material used need to be treated according to the recommended standard. Other ASTM standard used for methodology part is including ASTM C125 – 07, ASTM C 192 /C 192M – 07, and ASTM C94/C 94M. The British Standard used for concrete mix design is BS EN 601-1: 2001. For experimental test of flexural strength, the American standard used is ASTM C93 – 08.

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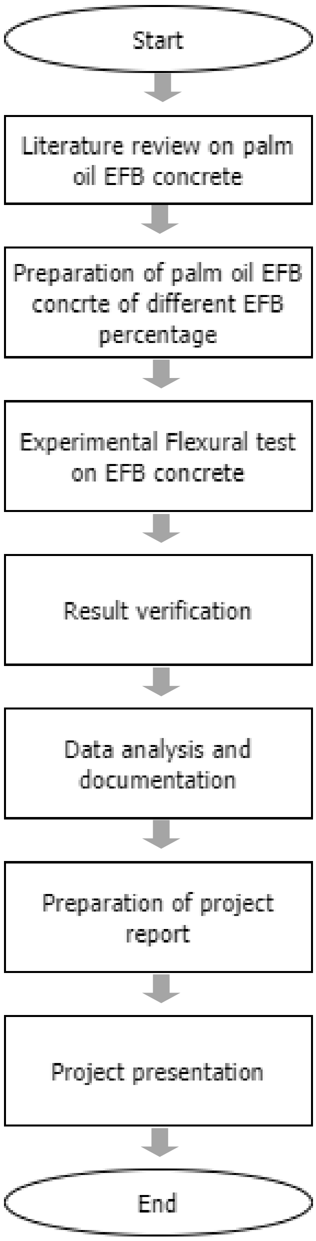

Figure 1.1: Flowchart of the project

1.6 Research Contribution

This research should give significant result for the suitability of oil palm EFB fiber to be used as reinforcement fillers in concrete. The flexural strength information for the corresponding proportion of oil palm EFB fiber used in this research can be used as reference for oil palm EFB fiber concrete fabrication and development in

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the future. Since Malaysia is one of the largest oil palm producers in Asia, oil palm EFB fiber is readily available as waste materials that need to be composed. Thus, this research is important for better utilization of the capability and availability of oil palm EFB fiber waste to be used as an excellent reinforcement filler material of concrete in the future.

1.7 Research Commercialization

The development of fiber reinforced concrete FRC is one of the highlighted studies nowadays. The most used type of fiber for the FRC are made of steel, glass fiber polymer and natural fiber. Steel fiber is widely used due to its excellent mechanical properties. However, the main problem of using steel fiber is rusting issue, and hence its mechanical performance will be reduced significantly as the rusting process take place. Natural fiber is suitable to be used as reinforcement filler material in concrete since they were easy to be obtained, and readily available in the nature, which can also be in the form of waste product from agricultural activities. In addition, the oil palm EFB fiber is readily available with oil content. Oil may act as the curing material that would assist in preserving the structural characteristic of oil palm EFB fiber. Thus, oil palm EFB fiber would not degrade easily, and has a high potential to be used as reinforcement filler material for concrete.

Palm oil EFB fiber concrete that has a better mechanical performance to weight compared to conventional concrete. Thus, by studying the proper curing procedure and suitable proportion of oil palm EFB fiber to be used in the FRC, this waste material has a high potential to become an excellent filler material for concrete reinforcement.

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1.8 Thesis Organization

The chapter in this report is basically classified into five chapters. These chapters were elaborated according to following descriptions:

Chapter 1 discussed about the information regarding to project background, problem statements, objectives, methodology, scope of work and report organization. The significance of using oil palm EFB fiber as reinforcement filler in FRC is also being reviewed.

Chapter 2 is the literature review about the oil palm EFB fiber concrete mechanical and structural properties. Aspects that need to be consider for better fabrication process by the previous research is also being discussed in this chapter. Parameter such as proportion of admixtures used for oil palm EFB fiber concrete is also mentioned. From the literature review, the best possible solution is being applied for this project.

Chapter 3 shows the materials and methodologies used during production and testing of oil palm EFB fiber concrete. The procedure is be based on specification used for concrete engineering purposes which are according to American Standards for Testing and Materials ASTM and British Standards BS.

Chapter 4 discussed about the data presentation and result of flexural performance of oil palm EFB fiber concrete. From the result, the improvement recommendation of oil palm EFB fiber concrete is being discussed.

Chapter 5 summarize the achievement and weakness of using oil palm EFB fiber as reinforcement filler for concrete. Any suggestion and enhancement on the project are being mentioned in this chapter.

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CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Literature review is a study that examines the research that have been done to help comprehend the application of oil palm EFB fiber as an alternative natural fiber to be used as reinforcement filler material in fiber reinforced concrete FRC. The structural and mechanical properties of oil palm EFB fiber is investigated to see the effectiveness of oil palm EFB fiber as reinforcement filler material for concrete.

2.2 Natural Fiber

There are many types of natural fiber that can be used as reinforcement filler material for concrete structure. These natural fibers are readily available in nature such as fibers from coconut husk, sisal, sugarcane, bamboo, jute fiber, oil palm EFB fiber, and vegetables fiber. According to Daniel *et al*. (2001), mature coconut husk, which has tough skin, and contains fibrous structure which can be separate easily by degrading the soft material organically using water. This process is mostly used in the less developed countries (Daniel *et al*.,2001). Thus, for less developed countries, natural fiber can become a useful reinforcement filler material for low-cost concrete construction.

Daniel *et al*., (2001) claimed that the natural fiber has been used by several countries for construction purpose. In Australia, gypsum plaster sheets production is done using sisal fibers. This is due to the toughness of sisal fiber, with ultimate

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tensile strength around 40, 000 to 82, 400 psi compared to other natural fiber (Daniel *et al.*, 2001). The sugar cane bagasse fiber properties are based on its ageing, and effectiveness of the milling plant. For production of desirable quality fibers, solid structure of sugarcane needs to extract form the fiber (Daniel *et al.*, 2001). Sugarcane fiber can withstand ultimate tensile strength from 26, 650 to 42,000 psi (Daniel *et al.*, 2001). Other than that, the bamboo is also being used for scaffoldings and its fiber can be used as reinforcement material for concrete since it good in tensile stress (ultimate tensile stress, around 50,750 to 72,500 psi). Unfortunately, bamboo fibers have large capacity to absorb water, low modulus of elasticity and extraction process require specific tools (Daniel *et al.*, 2001).

Natural fiber has its own properties, which determine if it is suitable to be used as filler material in concrete. Oil palm oil palm EFB fiber has a tensile strength around 50 to 400 MPa, and young's modulus value from 1 to 9 GPa (Jawaid *et al.*, 2013). Thus, the oil palm EFB fiber has a high possibility to be used as reinforcement fiber, since its combination with concrete matrix may lead to better resistance against crack propagation.

2.3 Fiber Reinforced Concrete FRC Mechanical Properties

According to Rai & Joshi (2014), the concrete reinforced with fiber shows higher compression strength compared to conventional concrete. The flexural strength of natural fiber reinforced concrete FRC is based on the combination of tensile, compression and shear load (Rai & Joshi, 2014). For FRC shear structural behaviour, shear value of beams which strengthen with fibers increased up to 80% (Rai & Joshi, 2014). Introduction of inconsistent fiber pattern, which distributed within the FRC structure also increased the shear-fraction strength, the post-crack strength, and maximum strength before the structure collapse (Rai & Joshi, 2014). Flexural strength defined as the capability of FRC to bend when applied subjected to force. Thus, as load applied on top of FRC (in this case, rectangular shape), upper surface will experience compression, and lower section in tension. Whilst, the central portion, in between upper and lower separation undergoes shear. In the natural fibers reinforced concrete, force applied on the structure will initiate sliding

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effect on adjoining layers of fibers over one another (Rai & Joshi, 2014). Therefore, resin is used to spread the stress across the composites. To resist against shear loads, the resin constituent must have high mechanical qualities, and be able to adhere well to the reinforcing fiber. According to Rai & Joshi (2014), the enhancement of natural fiber (coir) reinforced concrete is including improvement in compressive strength (increased about 10%), tensile strength (increased 1.78%), flexural strength (increased about 25% to 30%) and resistance to rupture (increased up to 25% to 30%). Rai & Joshi (2014) also stated that the significance of fiber reinforced concrete relies in its flexural performance, and least impact on the strength properties. Cracks occur in FRC has a higher density; however, size of the crack is reduced.

According to Daniel *et al.* (2001), in the report produced by ACI Committee 544 which discuss about the analysis overall types of FRC, concrete that is not reinforced has a lower tensile strength and strain capability at fracture. In order to cope with this problem, the reinforcing steel is used to enhance the structural performance via placement at a specific structure. Another way to improve the structural performance is to use fibers as reinforcement filler materials. The fibers used as reinforcement are spread though out the concrete matrix (Daniel *et al.*, 2001). Besides, oil palm EFB fiber consist of cellulosic based structure which has a hydrophilic nature (Ayu *et al.*, 2020). This property would produce a good adhesion effect between the fiber and concrete admixture.

High portion of cellulose of oil palm EFB fiber is the component which causing it to be durable and suitable to be used as bio-composite material (Sreekala & Thomas, 2003). The According to Ridzwan Ramli *et al.* (2022), the content of fresh oil palm EFB fiber consists of lignocellulose (30.5%), oil (2.5%) and water (67%). Thus, the suitability of oil palm EFB fiber to be used as reinforcement filler for concrete is also being doubt since the exposure to high alkalinity substances, the lignin content of oil palm EFB fiber reduced from 25.83% to 13.61% (Barlianti *et al.*, 2015).

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2.4 Water Cement Ratio

The flexural strength for concrete would be varied based on the water cement ratio w/c. According to (N. Ajay, 2021) magnitude of flexural strength is inversely proportional with water cement ratio value. The flexural performance on concrete (M1, M2, and M3) with different water-cement ratio of 0.40, 0.52, and 0.60 result in flexural strength values of 3.8 MPa, 3.7 MPa and 3.2 MPa respectively (N. Ajay, 2021). This shows that the flexural strength of concrete decreasing with water-cement ratio. Thus, to ensure that the flexural performance is consistent, water cement ratio need to be set to a fixed value. Water cement ratio does also affect the consistency and workability of concrete. Consistency of concrete defined as the flowability of fresh concrete (ACI Committee 309, 2005). Workability is the wetness measure of fresh concrete can be determined via slump test. Value of workability change directly proportional with water cement ratio used for the concrete construction. In this research the cement water ratio is set to 0.82.

2.5 Concrete Content

According to Dr. RM. Senthamarai (n.d.), the main components of cements consist of Tricalcium silicate (C_3S), Dicalcium silicate (C_2S), Tricalcium aluminate (C_3A) and Tetra calcium alumino ferrite (C_4AF). The hydration of C_3S would occur rapidly after the cement is mixed with water, which also causing rapid development in strength (Dr. RM. Senthamarai, n.d.). However, as the concrete age, hydration rate of C_2S would become slower since the water molecule is reduced (Dr. RM. Senthamarai, n.d.). This may cause delay in achieving the maximum strength of the concrete. The hydration products of cement paste are also affected by the suitable curing process, where a maintained suitable warm and moist environment is important (Safiuddin *et al*., 2007). Controlled environmental aspect of curing process may reduce the porosity of hydrated cement paste and causing the microstructure in concrete to increase (Safiuddin *et al*., 2007). According to Saleh & Eskander (2020), hydration process of Portland cement takes place when C_3S, C_2S, C_3A, and C_4AF react with water to form needle-like crystals of calcium sulfoaluminate hydrate, called ettringite (Saleh & Eskander, 2020). The empty pores of cement

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