COMPATIBILITY ASSESSMENT FOR PHYSICAL AND MECHANICAL PROPERTIES OF EMPTY FRUIT BUNCH CEMENT-BONDED FIBREBOARD

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To my beloved parents.

Hjh. Munirah & Hj. Dullah

For their Love, support and strength.

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With the name of Allah,

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ABSTRACT

Agricultural by-products such as EFB fibre may be used as an alternative for producing CBFB. Compatibility assessment for physical and mechanical properties of Cement-Bonded Fibreboard (CBFB) made of Empty Fruit Bunch (EFB) is important to identify the suitability of incorporating EFB into CBFB. However, there are known compatibility issues between EFB fibre with cement mixtures as the fibres contain residual oil and sugar that inhibit cement setting and hydration. Besides that, the geometry of fibre has been said to be a factor that affects the physical and mechanical properties of CBFB. Hence, this study was conducted to carry out the compatibility assessments to improve the properties of Empty Fruit Bunch Cement Board (EFB-CB) besides to identify the role of fibre length in the mechanical and physical properties. Two compatibility assessments which include alkaline treatment by using sodium Hydroxide (NaOH) and cement accelerators which is Calcium Chloride ($CaCl_2$) and Magnesium Chloride ($MgCl_2$) were carried out on EFB-CB fabrications. The fabrication of EFB-CB specimens was done by incorporating EFB fibres with different lengths classified as R7M, R14M and R80M to establish findings on the effect of fibre length on EFB-CB. The research finding shows that the combination of EFB fibre size with distributions of 35%, 45% and 20% for R7M, R14M and R80M respectively is the optimum fibre length that can be used for further research. Whereas the finding on the compatibility assessment shows the requirements for the physical and mechanical properties were met after subjecting EFB-CB to 1% NaOH treatment for EFB fibre along with the addition of 0.3% $CaCl_2$ or 0.4% $MgCl_2$ as cement accelerators. Similar requirements were fulfilled for EFB fibres treated with 4% NaOH with or without cement accelerators. The results indicated that EFB fibre can be regarded as a potential replacement material used in the manufacturing of CFB for non-load bearing applications after it had gone through compatibility improvement methods.

ABSTRAK

Penilaian keserasian bagi sifat fizikal dan mekanikal bagi papan gentian simen (CBFB) dari tandan kelapa sawit (EFB) penting untuk mengenal pasti kesesuaian penggunaan EFB dalam pembuatan CBFB. Serat daripada sisa agrikultur seperti EFB boleh digunakan sebagai alternatif untuk menghasilkan CBFB. Walaubagaimanapun, terdapat isu keserasian antara gentian EFB dan campuran simen kerana gentian EFB mengandungi sisa minyak dan gula yang melambatkan proses penghidratan simen. Selain itu, geometri serat juga dikatakan sebagai faktor yang mempengaruhi sifat mekanikal dan fizikal CFB. Oleh itu, kaedah untuk meningkatkan kekuatan papan gentian tandan kelapa sawit (EFB-CB) telah dijalankan selain mengenal pasti peranan panjang serat EFB terhadap sifat mekanikal dan fizikal EFB-CB. Dua kaedah bagi meningkatkan keserasian simen dan EFB serat termasuk rawatan alkali menggunakan Natrium Hidroksida (NaOH) dan bahan mempercepat pengerasan simen iaitu Kalsium Klorida ($CaCl_2$) dan Magnesium Klorida ($MgCl_2$). Fabrikasi EFB-CB dilakukan dengan menggunakan gentian EFB dengan panjang yang berbeza mengikut klasifikasi saiz gentian iaitu R7M, R14M dan R80M untuk mengkaji kesan terhadap EFB-CB. Daripada hasil kajian, sifat mekanikal dan fizikal yang tertinggi didapati pada specimen yang mempunyai gabungan saiz serat daripada 35% (R7M), 45% R14M, dan 20% (R80M). Daripada hasil kajian penilaian keserasian, piawaian BS mampu dicapai dengan menggunakan kepekatan 1% NaOH bagi merawat serat EFB dan tambahan 0.3% $CaCl_2$ atau 0.4% $MgCl_2$ sebagai bahan mempercepat pengerasan simen. Keperluan yang sama juga dicapai dengan kepekatan NaOH rawatan serat 4% tanpa bahan mempercepat pengerasan simen. Hasil daripada keseluruhan kajian mendapati bahawa serat EFB boleh dianggap berpotensi sebagai bahan pengganti yang boleh digunakan dalam pembuatan CFB selepas melalui kaedah peningkatan keserasian.

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LIST OF SYMBOLS AND ABBREVIATIONS

CBFB	-	Cement-bonded fibreboard
CBBs	-	Cement-bonded boards
EFB	-	Empty fruit bunch
FFB	-	Fresh Fruit Bunch
EFB-CB	-	Empty Fruit Bunch Cement Board
CWBB	-	Cement-bonded wood wool
CBPB	-	Cement-bonded particleboards
OPEFB	-	Oil palm empty fruit bunch fibre
R7M	-	Retain 7 mesh
R14M	-	Retain 14 mesh
R80M	-	Retain 80 mesh
UT	-	Untreated fibre
NaOH	-	Sodium hydroxide
$CaCl_2$	-	Calcium chloride
$MgCl_2$	-	Magnesium chloride
CB-C	-	Cement-bonded composites
SEM	-	Surface morphology examination
BS	-	British Standard
MDF	-	Medium density fibreboard
MOE	-	Modulus of elasticity
MOR	-	Modulus of rupture
IB	-	Internal bonding
TS	-	Thickness swelling
OPC	-	Ordinary Portland cement

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Fibre reinforcement of cementitious materials still remains an exciting and innovative technology because of the basic engineering properties of crack resistance, ductility and energy absorption that enhance infrastructure construction (Swamy, 2000). Composite materials such as cement-bonded wood wool boards (CBWW), cement-bonded particleboards (CBPB), and fibre-reinforced cement boards have been introduced in the recent decades. Cement-bonded composites are made of strands, particles or fibres of wood mixed with Portland cement and additives manufactured into building components used in the construction industry. Wood particles/fibre are the aggregate and the reinforcing agent respectively, cement is the binder, water is the reactant, and the additives are the catalysts (Ashori, Tabarsa, & Sepahvand, 2012).

The potential of using natural fibre as a composite material is highly accepted because it is cheap, sustainable and biodegradable. Besides that, it can also reduce the carbon dioxide, CO_2 released (Brandt, 2008). Wood has been introduced as a natural fibre reinforcement in cement and its use has increased rapidly over the past decade (Kochova, Schollbach, & Brouwers, 2015). However, the usage of wood as fibre reinforcement will lead to the increasing demand for forest sources. Evidently, the use of wood fibre will cause deforestation (Sotannde *et al*., 2012). This is not sustainable for the mass production of wood fibre cement boards in the future (Karade, 2010). Hence, other natural fibres should be considered to replace the utilisation of wood fibre in cement boards.

Nowadays, natural fibre cement boards are mostly made from wood. Due to rapid decrease of wood resources along with economic development and massive deforestation, the utilisation of wood resources needs to be minimised (Singh *et al*., 2013). Natural fibre cement board products need to replace wood fibres with other lignocellulosic fibres. Oil palm empty fruit bunch fibre (OPEFB) is the most interesting fibre that is readily available within Malaysia. Some researchers have reported that the addition of natural fibres reduces the thermal conductivity of composite samples (Wang *et al*., 2016).

However, the main thing that needs to be concerned for producing OPEFB-cement products is the incompatibility between cement and OPEFB fibre. Based on a research study by Yi *et al*. (2002), there are compatibility issues between cement and fibre due to the existence of hemicellulose, lignin and sugar which appear to inhibit the setting of cement hydration significantly. Therefore, the effectiveness and capabilities of the natural fibre cement board need to be justified and tested in order to produce them in large quantities in future.

The most effective method that has been introduced by previous researchers is natural fibre pre-treatment using sodium hydroxide (NaOH) to modify the surface of fibre and a cement-curing accelerator to accelerate the curing of cement which can be applied to increase the compatibility of natural fibres with cement (Bin *et al*., 2014; Karade, 2010). As reported by Asasutjarit *et al*. (2009), chemical composition modification and surface modification could increase the mechanical properties of composites such as modulus of rupture and internal bonding. Apart from that, Hermawan, Subiyanto, & Kawai (2001) stated that the hydration of cement was delayed when natural fibre was added. However, the addition of magnesium chloride ($MgCl_2$) as an accelerator enhanced the cement hydration and ultimate board strength properties.

On the other hand, the fabrication of Empty Fruit Bunch Cement Board (EFB-CB) samples needs to take into consideration the main material length which is EFB fibre. Frybort *et al*. (2008)) has classified particles as strands, flakes, chips and fibre in varying sizes. The cement-bonded boards produced from different particle size and geometry will have different physical and mechanical properties. The research finding by Semple & Evans (2004) indicated that the manufactured cement-bonded boards need larger particle sizes compared to resin bonded panels. In addition, they also clarified that particles with high slenderness ratio (longer and thinner) will produce stronger, stiffer and more dimensionally stable boards.

Therefore, this research is focused on identifying the appropriate fibre size that contributes to the optimum performance of cement boards. This research will also investigate the potential of EFB in cement composites and its performance when different percentages of NaOH pre-treatment and chemical additives are used to enhance its physical and mechanical properties.

1.2 Problem statement

The palm oil industry is one of the most important industries in Malaysia that has contributed to the economics of agriculture. Malaysia has become the largest producer and exporter of palm oil products. However, increasing palm oil production has a negative impact on the environmental. Empty Fruit Bunches (EFB) are a resulting major waste product of palm oil mills (Sumathi, Chai, & Mohamed, 2008). For each tonne of Fresh Fruit Bunches (FFB) processed in the mill, 20-25% are EFBs which are the residues left behind after palm oil fruit harvest and oil extraction (Abu-bakar *et al.*, 2011). Therefore, the use of OPEFB in cement board production is seen as a greener and more beneficial solution for humankind and the environment.

OPEFB is one of fibres belonging to the lignocellulosic family. It consists of three main components namely, hemicellulose (19%-25%), cellulose (40% - 65%) and lignin (19%-21%) (Mat Soom *et al.*, 2006; Sreekala & Thomas, 2003). Sudin & Swamy (2006) stated that EFB fibres contain a wide range of carbohydrates which are known to inhibit normal settings and strength development of cement matrix. These aspects will affect the compatibility of cement mixed with EFB fibre hence reducing the bonding between cement and fibre. The use of OPEFB in cement board production may be cost-efficient, but the main obstacle for producing OPEFB-cement is the incompatibility between cement and OPEFB fibre (Bin *et al.*, 2014). Therefore, the fibre needs to undergo certain compatibility method to overcome this problem.

Previous studies have compared the use of different treatment methods on the performance of EFB fibre. It has been proven that EFB fibre treated with chemicals such as sodium hydroxide (NaOH) was effective in removing residual oil (Hassan & Badri, 2016). However, research findings about relationship between OPEFB fibre pre-treatment and cement hydration remain vague. Since the compatibility of OPEFB with cement needs to be evaluated before fabricating cement-bonded fibreboards, reducing the inhibitory substance in OPEFB is necessary in order to improve the compatibility level of OPEFB and cement. In addition, chemical additives can also improve the performance of cement-bonded fibreboards (Yi *et al*., 2002). two types of chemical accelerators were considered for this study namely, calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$).

Nevertheless, the size distribution of fibre plays an important role as reinforcement in cement-bonded fibreboard in terms of bending strength (Frybort *et al*, 2008). Sotannde *et al*. (2012) found that the incorporation of heterogeneous particle size can enhance the bending strength of cement-bonded composites (CB-C) compared to single particles of larger size. Therefore, the particle size of fibre/wood to be incorporated in cement board production needs to be identified in order to achieve the desired physical and mechanical properties. Apart from research attempts in the manufacturing of Empty Fruit Bunch Cement Boards (EFB-CB), published research regarding the effects of particle dimension on EFB-CB properties are very limited. Therefore, it is essential to explore and identify appropriate fibre sizes that contribute to the optimum properties of cement boards.

1.3 Objective of study

The aim of this research is to study the potential use of Empty Fruit Bunch (EFB) fibres in cement-bonded fibreboards. The research tasks can therefore be outlined as follows;

i. To determine the optimum size of EFB fibre in mixture of cement-bonded fibreboards.
ii. To investigate the correlation between fibre treatment and cement accelerator on EFB-cement hydration rate, surface morphology examination (SEM), tensile properties and EFB chemical composition.
iii. To evaluate the physical and mechanical properties of EFB-CB using different percentages of NaOH treatment and cement accelerators.

1.4 Scope of study

This research primarily focused on laboratory investigation and ways to incorporate EFB fibre into cement-bonded boards to produce acceptable physical and mechanical properties. The scope of work for this study is as follows;

i. The scope of research includes two main materials which are cement and oil palm Empty Fruit Bunch (EFB) fibre.
ii. Empty fruit bunch (EFB) fibre was treated using Sodium Hydroxide (NaOH) in different concentrations (0.2%, 0.4%, 06%.1%, 2%, 3% and 4%).
iii. Incorporating Untreated (UT) fibre and treated fibre to EFB-CB fabrication with concentration 0.4%, 1% and 4% for further detail study.
iv. The EFB-CB mixture was added with 0.1%, 0.2%, 0.3% and 0.4% of chemical accelerators, namely Calcium Chloride ($CaCl_2$) and Magnesium Chloride ($MgCl_2$).
v. The fibre-cement ratio used was 1:3 with an initial water content of 40% of the system and a target density of 1300 kg/m^3.
vi. To produce cement-bonded fibreboards (CBFB) for building materials based on British Standard specifications.
vii. The EFB-CB samples were prepared at Makmal Fabrikasi Perkayuan FKAAS, UTHM. The mechanical testing was done at Makmal Bahan FKAAS whereas the sieve analysis was conducted at Malaysian Palm Oil Board (MPOB), Bangi.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Cement-bonded fibreboards were introduced to overcome concrete brittleness as dispersed fibres play an important role in the concrete reinforcement (Karade, 2007). The first cement-bonded fibreboard using asbestos was invented by an Austrian engineer, Ludwig Hatschek (Alleman & Mossman, 1997). Asbestos is commonly used in the fibreboard industry due to its resistance, high tensile strength and lower cost. However, the usage of asbestos can lead to health risks among human beings (Mossman *et al*., 1990).

To replace asbestos, another inorganic fibre source that can be used to make fibreboard is glass fibre. Glass fibre is considered better than asbestos in terms of fibre bonding and the long-term durability of cement boards (Pye, 1979). In order to achieve cost-effectiveness and sustainability, the usage of glass fibre is not considered convenient as it is an inorganic material (Suradi *et al*., 2009). This makes the biodegradation of this material very difficult.

The application of natural fibres for the production of cement-bonded fibreboards is better than asbestos and glass fibres since natural fibres are non-hazardous, renewable and readily available at a relatively low cost due to established technology for fibre extraction (Kaliwon, Ahmad, & Aziz, 2010). Oil palm fibre extracted from the EFB is proven as an acceptable natural fibre for composite materials since Malaysia is one of the world's largest producer of palm oil and plentiful EFB waste is available at all plantation mills (Abdullah & Sulaiman, 2013a). Figure 2.1 shows the fresh oil palm empty fruit bunch.

This chapter discusses on fibre length effect for cement composite, the methods for compatibility enhancement, i.e. (i) pretreatment of EFB fibre, (ii) modification of cement matrix, and (iii) the combination of the two to the cement board and its performance in terms of physical and mechanical properties. The results obtained were later compared with the findings of previous studies.

Figure 2.1: Oil palm empty fruit bunch

2.2 Potential of natural fibre waste as replacement material

Recently, natural fibres have become one of the most widely explored waste material worldwide due to increasing environmental awareness (Sanjay *et al*., 2016). It is important for researchers to study this material due to several features such as its high performance in terms of mechanical properties, cost effectiveness, lightweight, availability, renewability, environmental friendliness and degradability (Al-Oqla & Omari, 2017). Natural waste is one of the potential sources of renewable energy and reinforcement material in composites. Evidently, natural waste fibre has sparked many research studies to investigate the use of these fibres to replace man-made fibres (Dungani *et al*., 2016). The potential of using natural fibre as a composite material is highly accepted because it is cheap, sustainable, biodegradable, and its ability to reduce the emission of carbon dioxide, CO_2 (Brandt, 2008).

According to Ali (2012), the utilisation of natural fibre as composites such as cement paste, mortar and concrete is economical for increasing the specific performance of physical and mechanical properties. Cement is normally brittle so the addition of fibre to cement board can improve its properties to reduce the brittleness of the cement itself (Masi *et al*., 2015). Ashori, Tabarsa, & Valizadeh (2011) stated that the advantages of natural fibre in cement include low energy consumption, non-abrasive nature and low cost. It is also capable of replacing asbestos-based cement products and is widely available throughout the world.

One of the major characteristics of the forestry and agricultural sector is the production of large quantities of processing wastes that have no economic value other than energy generation. Their presence in recent years has created a major disposal problem since open burning is being discouraged by the Department of Environment in Malaysia (Abdullah & Sulaiman, 2013a). According to Goh *et al*. (2010), oil palm is the main crop in Malaysia with a total plantation area of 4,304,914 hectares. It produces huge amounts of waste such as dead fronds, Empty Fruit Bunches (EFB), shells and chopped trunks. Other sources of agricultural waste are indicated in Table 2.1.

Table 2.1: Agricultural waste produced in Malaysia in 2007 (Goh *et al*., 2010; Mekhilef *et al*., 2011)

Source	**Agricultural waste**	**Waste quantity (ktons)**
Oil palm FFB	Oil palm fronds	46,837
	EFB	18,022
	Oil palm fibres	11,059
	Oil palm shells	4506
	Oil palm trunks	10,827
Replanting paddy	Paddy straw	880
	Rice husk	484
Banana	Banana residues	530
Sugarcane	Sugarcane bagasse	234
Coconut	Coconut husk	171
Pineapple for factories	Pineapple waste	48

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