Compatibility improvement method of empty fruit bunch fibre as a replacement material in cement bonded boards: A review

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Abstract. The utilization of oil palm empty fruit bunch (OPEFB) fibre on bio-composite product has been introduced to replace current material mainly wood fibre. OPEFB is widely available as palm oil is one of the major agricultural crops in Malaysia. EFB fibre are lignocellulosic materials that could replace other natural fibre product especially cement bonded board. However, the contains of residual oil and sugar in EFB fibre has been detected to be the reason for incompatibility issue between EFB fibre and cement mixtures. Regarding on the issue, a study has been conducted widely on finding the suitable pre-treatment method for EFB fibre to remove carbohydrate contained in the said fibre that are known to inhibit cement hydration. Aside from that, cement accelerator was introduced to enhance the hydration of cement when it was mixed with natural fibre. Hence, this paper will summaries the previous findings and in-depth study on the use of EFB fibre as a replacement material in cement bonded fibre boards.

1. Introduction

The potential use of natural fibre as bio-composites has been accepted globally, because it is cheap, sustainable, biodegradable and reduces the carbon dioxide (CO₂) emissions [1]. The use of wood fibre has been increased rapidly as a natural composite in cement based products i.e. cement bonded board [2]. However, the utilization of wood fibre will lead to the increase demand of forest sources. Ultimately, the use of wood fibre as a bio-composites material will increase the rate of deforestation [3]. The growth in the use of palm oil production caused the environmental issue and created solid waste in terms of abundance quantity of empty fruit bunch (EFB) from oil palm mills [4]. Oil palm empty fruit bunch fibre (OPEFB) is the most important fibre that is readily available within Malaysia. subsequently, the attention is required on the production of OPEFB-cement products and study on the incompatibility of cement and OPEFB fibre. The issue of compatibility between natural fibre and cement has been highlighted in many previous studies on application of bio-composites. Based on research by Yi, et al. [5], there is compatibility issue between cement and fibre due to the existing of hemi-cellulose, starch, sugar, tannins and lignin which appear to inhibit significantly the setting of cement hydration.

To resolve this issue, previous research suggested the most effective method is pre-treatment of the natural fibre using Sodium hydroxide (NaOH) and cement-curing accelerator to accelerate the curing time of cement which could improve the compatibility of natural fibre with the cement [6, 7]. This article summarises the methods of OPEFB pre-treatment and cement accelerator for cement bonded...
fibre board (CBFB) used by previous researchers. It is expected that this information will provide an idea to utilize OPEFB as a main material for cement bonded composites.

2. Previous research work

This paper summarises the previous findings on the factors that affect compatibility, improving compatibility, pre-treatment and the use of chemical additive as cement accelerator by utilizing EFB fibre.

2.1. Factors affecting compatibility

The compatibility affecting of EFB fibre on cement is consisted by a number of factors. One of the factors is of EFB fibre's wide range of carbohydrates such as hemi-cellulose, starch, sugar, tannins and lignin that are known to inhibit normal setting and delayed the setting time of the cement matrix [8]. The natural fibre cannot be used directly on cement matrix due to the existence of residual oil that interrupts the penetration of binding agent and thus affecting the properties of the final EFB-products [9, 10].

2.2. Method of compatibility improvement

Many researchers carried a series of tests to improve the compatibility of fibre and cement by using some modification of fibre method mainly physical, chemical and thermal pre-treatments (extraction or soaking of wood particles in some solutions such as hot water and sodium hydroxide before its mixing with cement) [11, 12]. Natural fibre needs to be modified before being utilized on cement bonded board, thus reducing carbohydrate contained in EFB fibre is essential to improve the bonding between EFB fibre and cement.

On the other hand, some studies carried out a series of tests designed to improve the natural fibre-cement mixtures by addition of some chemicals such as magnesium chloride and calcium chloride [14, 15]. Chemical additive is one of the modification method commonly found to accelerate the setting time of cement matrix which is suitable for application of natural fibre cement composite products. It is reported by Nazerian and Sadeghiapanah [15] that fibre-cement compatibility and rapid hydration of cement paste could be improved by addition of an accelerator. There were different methods tried by researchers to treat the EFB fibre in order to enhance its compatibility with many types of product. Table 1 shows the previous research focusing on methods of OPEFB treatment. It is clearly shown that the most common fibre pre-treatment has been used by other researcher is chemical treatment by using sodium hydroxide (NaOH).
Table 1: Previous study on EFB pre-treatment method.

| Ref. | Research | Fibre treatment | Method | Finding |
|------|----------|-----------------|--------|---------|
| [9]  | Oil Content Effect | 0.2, 0.4, 0.6 & 0.8% of; -NaOH -Acetic acid | Soaked 24 hours | Treated fibre using NaOH successfully removed more residual oil from the EFB surface compared to treatments using acetic acid. |
| [10] | Thermal Behavior | 10% NaOH | Soaked 48 hours | NaOH has removed a significant percentage of hemicellulose thus increasing the cellulose content compared to H$_2$O$_2$ treated fibre. |
| [12] | Effect of OPEFB Pre-treatments | Physical Chemical (NaOH) Thermal | Soaked 4 hours | Fibre treated by chemical followed by thermal treatment has produced the best reducing sugars as compared to the physical pre-treatment. |
| [16] | Medium Density Fibre Board | 2% NaOH | Soaked 30 minutes | Fibre treated with NaOH is more effective than water to remove the residual oil. |
| [17] | Biocomposite | 20g in 500ml Erlenmeyer flask of distilled water | Soaked 3 hours at temperature 75ºC | Tensile and flexural modulus of treated EFB fibre is higher than untreated EFB fibre. |
| [18] | Medium Density Fibre Board | 2% NaOH | Soaked 30 minutes | Fibre treated with NaOH shows the highest MOR (31.4 MPa) and increased the mechanical and physical properties of fibreboards. |
| [19] | Biocomposite | 5% NaOH | Soaked 2 hours | Treated fibre biocomposite shows increasing values of mechanical properties compared to untreated fibre. |
| [20] | Corrugating Medium & Fibreboard | 0, 1, & 2% NaOH | 121 ºC for 1, 2 & 3 hours | Optimum conditions for chemical treatment was 2 hr with 2% NaOH. |
| [21] | Medium Density Fibre Board | 0.2, 0.4, 0.6 & 0.8% of; -NaOH -Acetic acid | Soaked 24 hours | Fibre treated with 0.4% of NaOH produced the lowest TS compared with other treatment concentrations. |
| [22] | Reinforced Epoxy Composite | 2% NaOH | Soaked 30 minutes | Fibre treatment improved the tensile strength of the OPEFB fibre reinforced epoxy composites. |

Sodium hydroxide (NaOH) is reportedly could modify the surface of EFB fibre and disrupts the crystalline region in the cellulose, thus undergo complete de-crystallization and weaken the energy bonding of cellulose [13, 14]. Furthermore, oil and impurities of EFB fibre could be removed by using chemical pre-treatment method. It was noted by Ndazi et al. [24] that the sodium hydroxide (NaOH) have good ability to break hydrogen bonding in network structure of fibre cellulose which can increase fibre surface roughness. From Table 1, Sodium hydroxide (NaOH) is the reagent that is widely used for EFB fibre pre-treatments, which can be conducted over a wide range of operating condition such as different concentration of NaOH and soak period of EFB fibre. Apart from pre-treatment, the previous studies indicated that the chemical accelerator could affect the hydration setting and compressive strength of cement-bonded fibre board [24, 25] i.e. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE). The percentage and type of chemical additives on
compatibility of fibre-cement water mixtures are summarized in Table 2. Normally the percentage of chemical additive that have been used in range between 0.5 – 5% depending on the type of chemical. Based on the table, the favourable type of chemical used as cement accelerator is calcium chloride (CaCl$_2$) followed by magnesium chloride (MgCl$_2$).

Table 2: Previous study of chemical additive used as cement accelerator.

| Ref. | Material | Chemical additive (%) | Remarks |
|------|----------|-----------------------|---------|
| [3]  | Wood (Afzelia Africana) | MgCl$_2$ 2 A1Cl$_3$ 2 CaCl$_2$ 2 Al$_2$(SO$_4$)$_3$ 2 Other 2 | CaCl$_2$ was the best accelerator follow by MgCl$_2$ and A1Cl$_3$. MgCl$_2$ is most effective additive among other chemicals. |
| [5]  | Wood (Sugi) | MgCl$_2$ 4 A1Cl$_3$ 4 CaCl$_2$ 4 Al$_2$(SO$_4$)$_3$ 4 | 4% CaO, Na$_2$SiO$_3$ 2% CaCl$_2$ was selected for the best compatibility. Admixture with a chloride basis had an excellent behaviour. |
| [14] | Waste Wood | MgCl$_2$ 0.5, 1 2.5 A1Cl$_3$ 0.5, 1 2.5 CaCl$_2$ 0.5, 1 2.5 Al$_2$(SO$_4$)$_3$ 0.5, 1 2.5 FeCl$_3$ 4 | Three chemical additives were suitable as an accelerator. |
| [25] | Pinus Wood Dust | MgCl$_2$ 4 A1Cl$_3$ 4 Na$_2$SiO$_3$ Al$_2$SO$_4$ 4 | MOR & MOE increased when added 5-7% of MgCl$_2$. |
| [26] | Wood (Tree Pruning Waste) | MgCl$_2$ 3 A1Cl$_3$ 3 CaCl$_2$ 3 Al$_2$(SO$_4$)$_3$ 3 | Three chemical additives were suitable as an accelerator. |
| [27] | Oil palm Frond | MgCl$_2$ 0, 2.5 5 A1Cl$_3$ 0, 2.5 5 CaCl$_2$ 0, 2.5 5 | The accelerator was compatible with cement. |
| [28] | Bagasse, Cotton stalk, Sunt sawdust | MgCl$_2$ - A1Cl$_3$ - CaCl$_2$ - Al$_2$(SO$_4$)$_3$ - | Aluminium sulphate meets the requirements of MS 934. |
| [29] | Bamboo | MgCl$_2$ 2 A1Cl$_3$ 2 CaCl$_2$ 2 Al$_2$(SO$_4$)$_3$ + Na$_2$SiO$_3$ 2 | 1.5% of CaCl$_2$ was similar to 3.5% of MgCl$_2$. |
| [30] | 6 forest species | MgCl$_2$ 1.5, 2.5, 3.5 A1Cl$_3$ 1.5, 2.5, 3.5 CaCl$_2$ 1.5, 2.5, 3.5 Al$_2$(SO$_4$)$_3$ + Na$_2$SiO$_3$ 1.5, 2.5, 3.5 | Optimum condition obtained when CaCl$_2$ is 5%. |
| [31] | Newsprint paper | MgCl$_2$ - A1Cl$_3$ - CaCl$_2$ - Al$_2$(SO$_4$)$_3$ - | CaCl$_2$ and CaO were found to be effective accelerator. |
| [32] | Kenaf Fibre | MgCl$_2$ - A1Cl$_3$ - CaCl$_2$ - Al$_2$(SO$_4$)$_3$ - | Improved physical and mechanical properties of wood-cement composite. |
| [33] | Wood | MgCl$_2$ 3 A1Cl$_3$ 3 CaCl$_2$ 3 Al$_2$(SO$_4$)$_3$ 3 | Additional chemical accelerator affects the properties of CBFB. |
| [34] | Musa Paradisiaca | MgCl$_2$ - A1Cl$_3$ - CaCl$_2$ - Al$_2$(SO$_4$)$_3$ - | 5% dose of CaCl$_2$ enhanced the MOE & MOR properties. |
| [35] | Eucalypt and Poplar | MgCl$_2$ - A1Cl$_3$ - CaCl$_2$ - Al$_2$(SO$_4$)$_3$ - | 5 |
It was observed that additional chemical additive can modify the setting time of cement hydration for utilization of natural fibre into cement bonded fibre board products. Early study on utilization of oil palm fibre was conducted by Hermawan et al. [27] to cement bonded fibre board product which was reported to enhance the mechanical performance with addition of 5-7 % of MgCl₂. However, the additional of other accelerator need to be emphasized based on previous studies that applied several types of chemical accelerator on different type of natural fibre which have same structural composition with EFB fibre. Therefore, other types of chemical additive should also need to be considered to accelerate the setting time of EFB fibre-cement mixture.

3. Conclusion
Based on the extensive literature review as suggested by the several researchers, the following conclusions have been drawn;

(a) EFB fibre can be utilized as replacement of other natural fibre i.e. wood fibre by improvement method of chemical treatment with sodium hydroxide (NaOH) which could remove the part of hemicellulose and lignin contains present in EFB fibre.
(b) Amount of silica body removed in EFB fibre is depend to the concentration of Sodium Hydroxide (NaOH) and soaking period.
(c) It was perceived from the previous studies that the cement accelerator could affect the hydration setting and compressive strength of cement-bonded fibre boards.
(d) Chemical additive by using CaCl₂ and MgCl₂ seems to be a good potential as they increased the setting time of cement matrix.

As per conclusions above, it is recommended to modify the structure of EFB fibre by using Sodium Hydroxide (NaOH) as a pre-treatment agent and additional of cement-curing accelerator i.e. calcium chloride (CaCl₂) and magnesium chloride (MgCl₂) to improve the compatibility between EFB fibre and cement for the cement bonded board product. However, it is essential to study on the different concentration of the chemicals to observe the optimum percentage for application of EFB fibre since there are very limited and rare to found published research finding about the effect of EFB fibre as a main material for the cement bonded board product.

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