Physical and Mechanical Properties of Empty Fruit Bunch Fibre-Cement Bonded Fibreboard for Sustainable Retrofit Building

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Abstract: Cement bonded fibreboards have been extensively used mainly in the construction of buildings in numerous countries. Most commonly used materials to fabricate the cement boards are wood. Therefore, due to the depletion of wood resources, the potential of Oil Palm Empty Fruit Bunch Fibre (OPEFB) as wood replacement for cement boards production is explored in this study as one of the materials for sustainable retrofit building. The main obstacle for Empty Fruit Bunch (EFB) fibre cement composite manufacturing is the chemical incompatibility between fibre and cement, which inhibits cement setting and hardening. In this study, EFB fibre was then treated with 0.4%, 1% and 4% of NaOH for EFB-CB fabrication and chemical accelerator which is calcium chloride ($CaCl_2$) was used at 0.1%, 0.2%, 0.3% and 4% based on cement weight. Physical and mechanical properties were observed in this study. The result indicated that the best percentage of NaOH is 1% as pre-treatment for the fibres, meanwhile minimum percentage of 0.3% and 0.4% $CaCl_2$ should be consider as cement accelerator in board production. Other than that, the minimum requirements for physical and mechanical properties were met by EFB fibre treated with 4% NaOH with or without cement accelerators.

Key words: Cement bonded fibreboards, empty fruit bunch, alkaline treatment, cement accelerator, physical properties, mechanical properties.

1. Introduction

Construction industry presently has been accused as a main factor that is causing of environmental problems. Although, many researches have been conducted to explore the best methods of introducing sustainable approach, their main concern mostly toward greener for commercial building, new building and sometime retrofitting building [1]. The use of natural wood/fibre in cement boards manufacturing has been explored since 1930's. The root history of utilization natural wood/fibre in composite of building materials basically started by incorporation of wheat or rice straw with mud to produce composite muds-brick [2]. It is widely reported that research attempts of utilizing natural fibre/wood as cement boards reinforcement; wood particle/wood wool [3]–[7], oil palm frond [8], rice straw [9], recycle newsprint paper [10], oil palm fibre [11] and bagasse [12].

Oil palm industry in Malaysia is known as one of the most significant resources that has alleviated the development of agriculture as well as the economy sector. Lignocellulosic biomass waste produced through this sector consist of oil palm trunk (OPT), oil palm frond (OPF), empty fruit bunch (EFB) and palm pressed fibre (PPF) [13]. Among the waste produced, EFB contributed the waste amount 18,022 ktonnes which is the second highest after OPF [14]. Previous research focused more on the use of EFB as building materials, in the form of Medium Density Boards (MDF) and Insulator Boards (IB) [15]–[22] and EFB in concrete [23]. Furthermore, Onuorah *et al.* [11] have previously conducted research on EFB cement board, to which they have found that the mean value for MOR (3.08-16.82 Mpa), MOE (2515-5291 Mpa), IB (0.28-0.75 Mpa) and TS (1.36-4.23%). From the mechanical and physical properties viewpoints, EFB fibre is appropriate as a form of wood-based material replacement for cement boards production.

EFB fibre consist of three components; lignin, hemicellulose and cellulose and solubility such as sugar [24]. The main obstacle for EFB fibre cement composite manufacturing is the incompatibility of chemicals between fibre and cement, in which inhibits the cement setting as well as hardening. According to Bin *et al.* [25], inhibitory substance mainly includes some sugar, part of hemicellulose and other fibre degradation products. Therefore, before manufacturing of EFB fibre-cement boards (EFB-CB), EFB fibre must be treated to remove inhibitory substance in order to the reach compatibility between EFB fibre and cement.

Several methods can be used in order to increase the compatibility between cement and natural fibre. The most effective method that has been used by researchers so far is the natural fibre pre-treatment and cement accelerator. The EFB fibre pre-treatment that has been frequently used by other researchers is chemical treatment using sodium hydroxide (NaOH) and calcium chloride ($CaCl_2$) as a cement accelerator.

The overall objective of this study is to investigate the effect of EFB fibre alkali treatment (NaOH) in different concentrations to the mechanical and physical performance. Since utilization of EFB fibre as cement boards reinforcement is new attempts and very hard to find reported in elsewhere, the effect of EFB-CB density also be explored.

2. Materials and Methods

2.1. EFB Fibre Preparation

In this research, Oil Palm Fibre (OPF) has been used in which was comprised of empty fruit bunches (EFB), from a factory namely, Global Seed Sdn. Bhd. This factory is located at Simpang Renggam industrial area, Johor. The fibres were shredded, screw pressed and compacted into bundles. EFB fibre was then treated with 0.4%, 1% and 4% of NaOH [24] for EFB-CB fabrication.

2.2. Cement Binder and Chemical Additive

In this study Ordinary Portland Cement Type 1 (OPC-Tasek Brand) and chemical additive calcium chloride ($CaCl_2$) as recommended by Dullah *et al.* [24] was used at 0.1%, 0.2%, 0.3% and 4% based on cement weight. Whereas, distilled water was used to optimize the hydration rate of cement with the 40% water based on cement weight.

2.3. EFB-CB Fabrication

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/m3. The mix design of cement board panels with different percentage of sodium hydroxide (NaOH) treatment and calcium chloride $CaCl_2$ consist of 5 samples for each mix with 100 samples in total. The fabrication of Empty Fruit Bunch Cement Board (EFB-CB) as recommended by previous researchers [11], [26]–[30]. Cement and water in certain ratios were used as the binder to form EFB-CB which was later pressed with a cold-press machine.

To accelerate the hydration time of the mixture, the pressed mats were placed in an oven for a 24-hour period. Controlled by a digital precision thermoregulatory-indicator, the temperature was kept constant at 60°C [8]. The pressed samples are then demolded after 24 hours and subjected to 28 days of air curing under standard climate conditions of 25 ± 2°C and a relative humidity of 65 ± 2% [11], [26], [28]. Air curing is the process of maintaining satisfactory moisture content and a reasonable temperature range.

2.4. EFB-CB Physical and Mechanical Properties Testing

A sample test was performed to obtain the properties of specific cement board samples. There were four properties testing conducted for EFB-CB; Thickness Swelling (TS), Bending Strength (MOR), Modulus of Elasticity (MOE) and Internal Bonding (IB). These testing were conducted according to BS EN 317:1993 [31], BS EN 310:1993 [32] and BS EN 319: 1993 [33] respectively. As guided by the Malaysian Standard specification (MS 934 1984) and British Standard (BS EN 326), the samples of EFB-cement bonded fibreboards were cut as shown in Fig. 1.

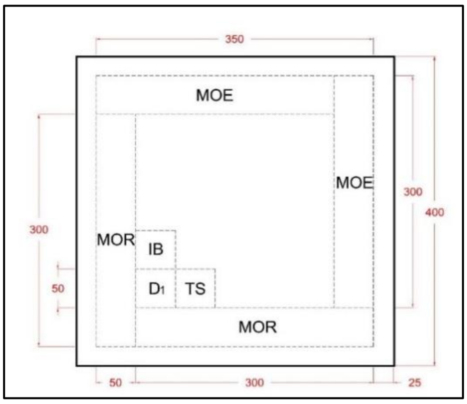

Fig. 1. Cutting dimension of EFB-CB samples.

3. Results and Discussion

3.1. EFB-CB Physical Performance Based on Different Percentage of NaOH Treatment and Cement Accelerator

According to the different percentages of Sodium Hydroxide (NaOH) pre-treatment and cement accelerators, the physical properties of EFB-CB were interpreted and discussed in terms of Thickness Swelling (TS) performance. The thickness of swelling was determined by measuring the increase of thickness in the test piece after complete immersion in water. This test was carried out as specified by the British Standard BS EN 317:1993 [31].

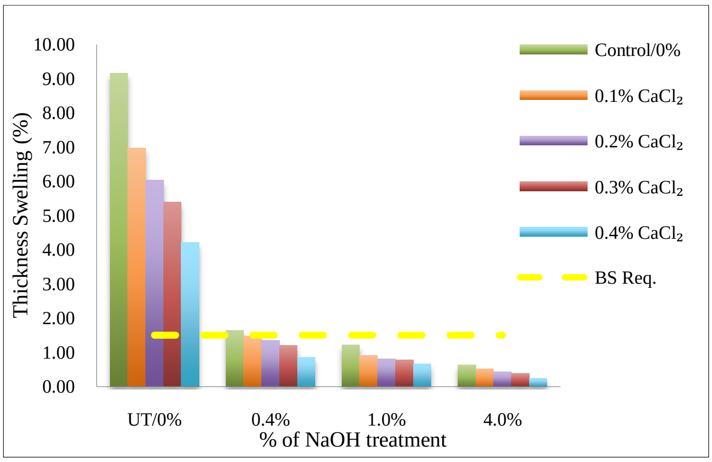

Fig. 2. TS of EFB-CB for different percentages of NaOH treatment and $CaCl_2$ accelerator.

Fig. 2 shows the EFB-CB specimen which contains EFB fibre treated with different concentrations of NaOH and cement accelerators ($CaCl_2$). The figure has shown that the TS (%) for untreated fibre did not comply with the BS requirements. However, the thickness swelling of EFB-CB has rapidly dropped in percentage when EFB fibre was treated with 4% NaOH was used. The percentage of thickness swelling of EFB-CB treated with 1% NaOH without the use of any cement accelerators met the BS requirements. Fibres that are treated with 1% NaOH and 4% NaOH without any accelerator has achieved the thickness swelling values of 1.22% and 0.63% respectively. As recommended by the BS, these values are below the maximum thickness swelling value. The use of treated fibre for cement boards was supported by Bin *et al.* [25] who suggested the use of NaOH as a treatment method to improve the compatibility of fibre with cement mixtures.

Clearly, the increase of percentage of cement accelerator could affect the physical properties of EFB-CB. However, a particular concern that did not comply with the British Standard requirements is the additional cement accelerator for untreated fibre in EFB-CB. Nevertheless, the results of TS reveal that the 0.4% of NaOH treatment is not enough and the TS slightly above the maximum TS of 1.5% as required by British Standard.

The highest thickness swelling value (1.22%) was found experienced by the control specimen (0% accelerator) containing fibre treated with 1% NaOH which complies to the British Standards. The thickness swelling for both 1% and 4% NaOH was below than 1.5% of the TS which complies favourably with the specifications outlined in the British Standards.

3.2. EFB-CB Mechanical Properties Based on Different Percentage of NaOH Treatment and Cement Accelerators

In terms of Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Internal Bonding (IB), the mechanical properties of EFB-CB based on different percentages of Sodium Hydroxide (NaOH) treatment and the use of cement accelerators on EFB-CB were interpreted and discussed.

3.2.1. Modulus of Rupture (MOR)

As demonstrated in Fig. 3, the MOR value increases rapidly with the increment of NaOH concentration during the EFB fibre treatment. Evidently, 4% of NaOH concentration for fibre treatment could meet the requirements by British Standard without any additional cement accelerator. Nevertheless, 1% of NaOH could meet the BS requirements with the addition of 0.3% $CaCl_2$ and 0.4% $CaCl_2$. Conversely, the use of untreated EFB fibre and 0.4% NaOH treatment have proven to be inefficient since the value of MOR could not meet the minimum BS requirements. In line with a study by Harsono *et al.* [34], untreated oil palm fibre was not able to meet the standard requirements of particle boards. The failure of MOR may be due to the incompatibility of EFB fibre with the cement mixtures as a result of carbohydrate content in oil palm fibre.

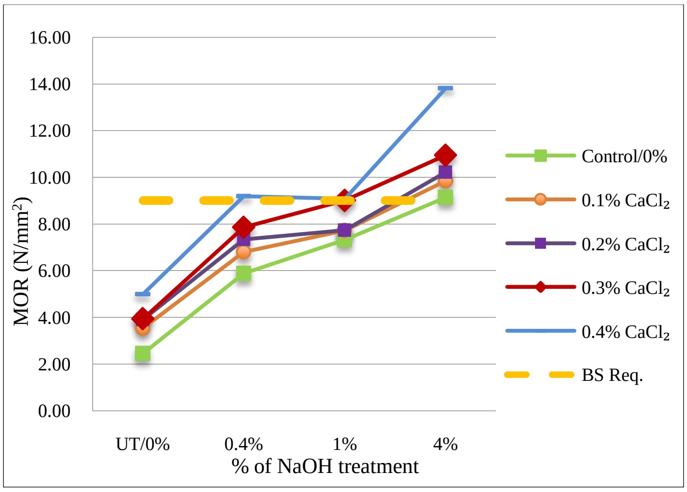

Fig. 3. MOR of EFB-CB for different percentages NaOH treatment and $CaCl_2$ accelerator.

MOR values for untreated fibre increased from 2.45 N/mm^2 to 5 N/mm^2 when 0% to 0.4% of cement accelerators were incorporated into the specimen respectively. The bending strength increased with the increment of cement accelerator content in the board samples. Nevertheless, MOR values for all specimens with untreated fibre obviously did not meet the minimum British Standard requirements. Thus, the use of untreated fibre in EFB-CB is not recommended even with the addition of cement accelerators. Untreated EFB fibre is incompatible with cement due to the inhibitory substances in oil palm fibre Ibrahim *et al*. [35]. On the other hand, $CaCl_2$ are considered better than MgCl2 as it has showed higher MOR value at all concentrations.

It was observed that the EFB fibre with high proportions of NaOH treatment (4%) in the mixture achieved higher MOR compared to other percentage of NaOH. The MOR value for 4% of NaOH met the requirements of BS with or without cement accelerators. It can be concluded that 4% of NaOH for the pre-treatment of EFB fibres without any accelerators is sufficient to meet the requirements.

3.2.2. Modulus of Elasticity (MOE)

Fig. 4 shows a graph of MOE vs EFB fibre treated with different percentages of NaOH. The values continued to increase starting from untreated fibre to fibre treated with 4% NaOH where the highest MOE is 8078 N/mm^2. Untreated fibre without accelerators has the lowest recorded MOE value which is 955 N/mm^2. As predicted, the sodium hydroxide treatment with the highest concentration tends to achieve the highest MOE value for both accelerators provided compared to untreated fibre. Furthermore, the result from the MOE test has fulfilled the BS requirement of 0.4% NaOH with additional cement accelerators starting with 0.2% of $CaCl_2$.

Similar to the results of MOR, the MOE results for untreated fibre could not fulfill the BS requirements. Untreated fibre contradicts with cement mixture due to the content of oil in oil palm fibre consequently reducing the strength of EFB-CB. Alternatively, EFB fibre treated with 0.4% NaOH promptly improved the MOE performance with the addition of 0.2% $CaCl_2$. The MOE significantly increased to 3157 N/mm^2 when the EFB fibre was treated with 0.4% NaOH. In line with the findings by Ibrahim *et al.* [36], 0.4% of NaOH treatment was found to enhance the EFB fibre properties of the MDF product. The addition of cement accelerators will most likely increase the compatibility of EFB fibres with the cement mixture.

All EFB-CB specimens treated with 1% and 4% of NaOH complied with the British standard specifications [37] which fulfill the requirements for OPC bonded particle boards for use in dry, humid and external conditions (class 1 and class 2). For EFB fibre treated with 1% NaOH, the MOE value slightly increased from the control sample (without accelerator) to 0.4% accelerator which is 5141 N/mm^2. Moreover, the use of $CaCl_2$ resulted in a higher MOE than no cement accelerator added. This finding was similar to the MOR results where $CaCl_2$ was found to be more effective in increasing the MOE values. Furthermore, 1% of NaOH would be sufficient to treat EFB fibre and enhances the compatibility with cement mixtures. Meanwhile, 4% of NaOH fibre treatment enhances the MOE properties with or without the use of cement accelerators. Ultimately, both 1% NaOH and 4% NaOH fibre treatment met the minimum BS requirements.

3.2.3. Internal Bonding (IB)

Fig. 5 show graphs displaying internal bonding values (IB) vs NaOH treatment with $CaCl_2$ as a cement accelerator. For the case of EFB-CB with untreated fibre, the lowest value of IB is 0.0016 N/mm^2 for untreated fibre. 0.4% of $CaCl_2$ obtained the highest value at 0.098 N/mm^2, followed by 0.3% $CaCl_2$ at 0.0077 N/mm^2. Nevertheless, the highest value of untreated fibre did not fulfill the BS requirements. In contrast, EFB fibre treated with 0.4% of NaOH significantly increased the IB value up to 0.357 N/mm^2 with the addition of cement accelerators but has remained below the minimum BS requirement. The value of IB were increased and has fulfilled the BS requirement when EFB fibre treated with 1% NaOH with the addition of 0.3% and 0.4% of $CaCl_2$ cement accelerators.

Similar to the mechanical performance of MOR, specimens with untreated fibre and fibre treated with 0.4% NaOH has nonetheless met the standard requirement. The IB values for untreated fibre and fibre treated with 0.4% NaOH were 0.098 N/mm² and 0.357 N/mm² respectively with the addition of 0.4% $CaCl_2$. The IB values for fibre treated with 1% NaOH were significantly higher than untreated fibre. Similar with the MOR result, 1% of NaOH treatment increased the IB performance up to 0.516 N/mm² with the addition of 0.4% $CaCl_2$ thus fulfilling the minimum BS requirement. Similarly, the addition of 0.3% $CaCl_2$ also complied with the minimum requirements for cement-bonded boards. Conversely, the value of IB for EFB fibre treated with 4% NaOH met the BS requirements without the use of accelerator. It is clear that the IB values slightly increased from 0.526 N/mm2 to 0.852 N/mm² with the addition of cement accelerators.

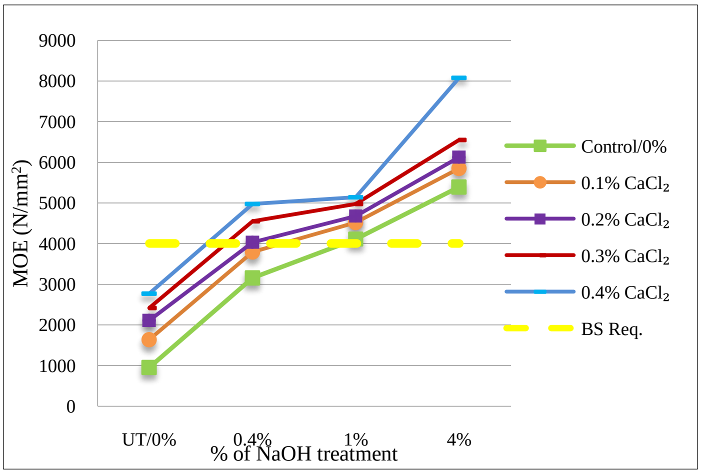

Fig. 4. MOE of EFB-CB for different concentrations of NaOH treatment and $CaCl_2$ accelerator.

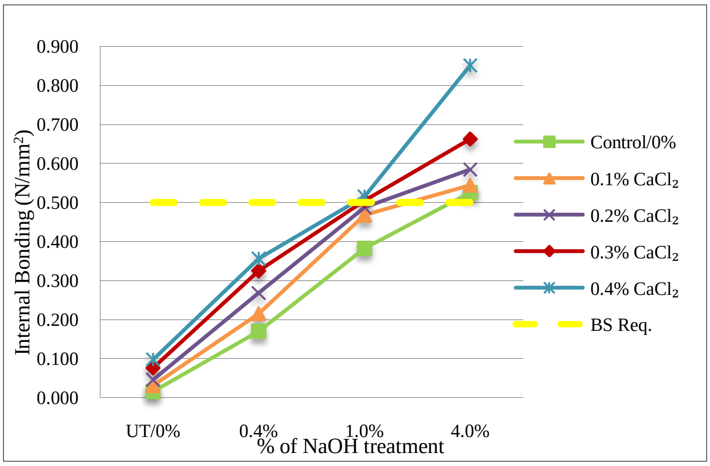

Fig. 5. IB of EFB-CB for different concentrations of NaOH treatment and $MgCl_2$ accelerator.

4. Conclusion

Based on the experimental work the following conclusions have been drawn;

1. Fibres that have not undergone the pre-treatment were found to be unsuitable to be incorporated in cement bonded fibreboard as the results of the specific board fails to achieve the minimum requirement of MOE, MOR, IB and TS. Hence, does not fulfil the standard requirement of such a board.
2. The best percentage of NaOH is 1% as a pre-treatment for the fibres, meanwhile the minimum percentage of 0.3% and 0.4% $CaCl_2$ should be consider as a cement accelerator in board production.
3. The minimum property requirements of the British Standard [37] for physical and mechanical properties were met or exceeded by EFB fibres that were treated with 4% NaOH with or without cement accelerators.

4. The utilization of EFB fibre as a replacement material for wood fibre in cement bonded fibreboards are highly capable as a process for sustainable retrofit building.

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Ms. Hayana was involved in many associations and assigned as a program director for university programs. In 2017, Ms. Hayana and her team participated in National Innovation and Invention Competition through Exhibition, which they were awarded gold medal for the innovation product which is "Unsanded Empty Fruit Bunch Cement Board (EFB-CB).

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