Physical and mechanical properties of cement board made from oil palm empty fruit bunch fibre: A review

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Abstract. Oil palm empty fruit bunch (OPEFB) fibre has been introduced to replace current materials mainly such as wood fibre that was not encouraged to be used as a construction sourced due to the sustainability of wood fibres and prevents the high demand of forest resources. In Malaysia, the cultivation and use of the oil palm and its products have increased because of high market demand, and this has resulted in the abundant availability of the empty fruit bunch (EFB). The EFB fibre geometry and particle size in the EFB cement bonded boards have their own mechanical and physical properties. The fibre to cement ratios are also different to boards made out of wood fibres. This experimental research work has been conducted by other researchers. The larger the particle size, the better the compaction of EFB-CB effects of cement setting by much larger surface on the board area. Short particles lead to low values of modulus of elasticity (MOE), caused by inadequate of empty fruit bunch (EFB) particles to cement substances. Nevertheless, short particles avoid large void spaces and irregularities towards cement board. Using different Cement-EBF fibre ratio has direct influence on thickness swelling (TS), modulus of rupture (MOR), and modulus of elasticity (MOE). Strength of EFB-CB depends on the bonding between fibre and cement composites. The pre-treatment fibre was indicated where the EFB fibre composite were dimensionally stable for bonding mechanisms and could be used for both interior and exterior building utilizations based on the tested physical and mechanical properties on cement-boards.

1. Introduction

The oil palm empty fruit bunch (OPEFB) that has been applied to building construction materials. According to Schabowicz et al. [1], the OPEFB has a better reinforced composite strength especially in physical characteristics. The acceptability of the EFB fibre composites is mainly used due to their high applicability properties and high resistance to the insect attack. Hence, the EFB fibre necessary to tested the workability and toughness of the boards to meet the high quality and standards assigned for the natural fibre-cement composites so that, they can compete in building construction worldwide especially in the local markets. Empty fruit bunch fibre is a left over at palm oil mills after the removal of sterilized fruit. It is irregular in shape, weighs about 3.5kg and has thickness around 100mm to 130mm and can vary from 170 to 300 mm long and 250-350 mm wide [2]. Plant fibres which includes Oil Palm Empty Fruit Bunch (OPEFB) consists of unwanted fibre composites. In addition, the chemical composition can vary within a species grown in different soils and different climate condition due to the age of the plant [3]. Recently, research and development on eco-friendly or green construction materials have been attracting the research interest among researchers. The effect of recycling agricultural waste for building...
materials is increasingly popular among researchers and the building construction sector, due to the positive effects towards the environment. Additionally, the use of natural wood products in the manufacture of building materials is no longer sustainable.

2. Utilisation of empty fruit bunch (EFB)

Although EFB is the main waste of oil palm fruit and oil industry, it is usually left rotting at the plantation without any further processing. The fibres can be an important source as a main components for the building construction industries. The selection of natural fibre for building material especially for wall based and roofing has been widely used in many countries. The natural fibres posses the strength to control and delay the tensile cracking matrix.

The usage for these products have high due to the insufficiency of the wood supply [4, 5, 6]. A huge amount of oil palm trees need to be replanted due to the demand of wood industry [7]. The oil palm empty fruit bunch (OPEFB) is biomass materials where it is a lignocellulose biomass that abundant and renewable which has potential in construction industries such as natural fibres. OPEFB has high moisture content. Before this, OPEFB ratherly used by Oil Palm Mills to fuel their boilers [8]. To reduced EFB from being a main waste, the industries turned them into composite boards such as cement boards that can be used in interior and exterior applications in building construction. To managed the EFB fibre cement boards as a wall, roof, etc. rarely used in industry, the measurement of the EFB fibre composite was strongly emphasized on physical and mechanical properties, surface electron morphology (SEM) and thermal properties of boards.

3. Method

The waste material was cleaned and selected according to the specifications needed, then the oil empty fruit bunch (OPEFB) washed usually using tap water and treated the empty fruit bunch (EFB) fibre using hot and cold water in 24 hours to improves the compatibility between EFB fibre and cement such as stickiness and hardening of the mixing materials for concrete mixture through soaking and drying the EFB fibre under sun dried directly and placed the materials in the oven for 24 hours to check the moisture content afterward [9]. There are three types of modification methods are tested on the fibre composite; the first one is to treat the fibre in hot water accordingly to the selected temperatures. The second treatment, EFB fibre were soaked in the cold water for 24 hours, sun-dried and placed in the oven for 24 hours. Lastly, the other treatments, the fibre were soaked in the additives such as Sodium Hydroxide (NaOH) according to the selected percentage of the additives. The three types of the fibre modifications are to obtained and compared which one of the pre-treatments that meet the standards on physical and mechanical properties on the boards fabrication to improve the compatibility between cement and fibres.

4. Raw material properties influencing empty fruit bunch cement board (EFBCB) interface

4.1. Bonding mechanisms

Similar to manufactured resin adheriveness, extinct adherence is resulted from physical and mechanical bonding performances. Several surveys of the deficiency performances of EFB-CB indicates large interfacial bond effectiveness between fibre and cement. Based on Abdul Khalil et al. [10], SEM provides the examination of surface morphology of fibers. Morphology changes occurred after treatments. Untreated EFB fibre clearly contains contamination. Due to the chemical morphology of cement and fibre excessive unwanted composites may leading in a major role in the bonding of these composites. By means SEM, fiber to fiber contacts were founded by Sung et al. [11] who affirmed that the cement composites is strictly bonded to the cellulose fibers.

To prevent the unwanted composite in fibre such as cellulose, lignin and others. That acted as a problem in a bonding mechanism between cement and EFB fibre; the fibre should be treated using pre-treatment. According to Omoniyi [12], the fibre were soaked in a cold and hot water treatment according to the specifications needed [13]. The other pre-treatment, the fibres were soaked in sodium hydroxide solution through different concentration by weight of water for 24 hours at relative humidity.

The morphology analysis is strongly used to analyze the measurement to determine the physical properties of the fibre which is one of the vital factors that need to determine the bonding and the stress
distribution of the structure. According to Coutts [14] and Akash et al. [15], the use of magnifications ranging from 200x to 500x during SEM is appropriate for the observation of the changes to the EFB fiber surface morphology after the pre-treatment.

Table 1 presents the previous study of the effects of raw material composite properties that influenced the empty fruit bunch cement board interface towards the bonding mechanisms throughout fibre treatment. According to the SEM analysis, the fibre composite had an effect on the cement board properties, with excellent performance.

Table 1. EFB fibre composites and treatments performance towards bonding mechanisms.

| Researchers | Type of Fibre       | Treatment        | Performances         |
|-------------|---------------------|------------------|----------------------|
| [11, 21]    | Oil Palm Empty Fruit Bunch | Untreated        | Maximum Stress (MPa) 52 |
|             |                     |                  | Young’s Modulus (MPa) 2407 |
|             |                     |                  | Elongation break 10    |
| [11, 21]    | Oil Palm Empty Fruit Bunch | Water boiling   | Maximum Stress (MPa) 49 |
|             |                     |                  | Young’s Modulus (MPa) 2763 |
|             |                     |                  | Elongation break 7     |
| [11, 21]    | Oil Palm Empty Fruit Bunch | NaOH Soaking    | Maximum Stress (MPa) 64 |
|             |                     |                  | Young’s Modulus (MPa) 2625 |
|             |                     |                  | Elongation break 10    |
| [12]        | Oil Palm Empty Fruit Bunch | Untreated        | Maximum Stress (MPa) 3.6 |
|             |                     |                  | Young’s Modulus (MPa) 5.5 |
|             |                     |                  | Elongation break 0.33  |
| [12]        | Oil Palm Empty Fruit Bunch | Hot water 60°C   | Maximum Stress (MPa) 3.6 |
|             |                     |                  | Young’s Modulus (MPa) 5.5 |
|             |                     |                  | Elongation break 0.55  |
| [12]        | Oil Palm Empty Fruit Bunch | NaOH 8%         | Maximum Stress (MPa) 7.3 |
|             |                     |                  | Young’s Modulus (MPa) 8.9 |
|             |                     |                  | Elongation break 0.40  |

Based on Table 1 above, fibre diameter (330-440µm) with water boiling achieved excellent performance through bonding mechanisms with 2763 MPa of Young’s modulus, 49 MPa maximum stress, and elongation break is 7 MPa less than untreated and Sodium Hydroxide (NaOH) soaking treatment. The researchers completely concurred that the diameter of the fibre affected the properties of the fibres; when the diameter was increased, the strength of the fibre decreased. As the result from other researcher in the Table 1 above, showed that the pre-treatment fibre was indicated where the EFB fibre composite were dimensionally stable for bonding mechanisms and could be used for both interior and exterior building utilizations.

4.2. Compatibility of cement and EFB
The compatibility of EFB fibre on cement has many obstacles. The main factors of the EFB fibres such as the properties of fibres which contained hemi-cellulose, cellulose, lignin, starch, sugar and tannins
which are recognized to hinder normal setting, obstructed the setting time of the cement matrix [16, 17, 18]. Failure in cement and fibre is due to excessives water absorption by the fibres causing in a high water/cement ratio for the applicable mortar mix. The natural fibre cannot be utilized instantaneously on the cement matrix due to the continuance of residual oil that interrupts the binding agent and thus affecting the properties of the empty fruit bunch productions.

The main complication in producing wood-cement composites is the incompatibility between cement and wood due to some soluble chemicals in wood which has stop the hydration of cement which resulting in lower mechanical strength of wood-cement composites. Wood-cement compatibility is affected by several factors that can affected the wood potential in building components [19].

5. Improvement of compatibility

5.1. Determining compatibility

The empty fruit bunch fibres has been used widely in building construction industries. However, due to the fibre-cement incompatibility the cement substances preventing the cement setting and hydration. Hence, the gradation of workability between fibre-cement should be evaluated to analyse whether the fibre is suitable for producing fibre-cement composites. The hydration temperatures of cement depend on the type of cement used, fibre-cement ratios, water content and particle size [20]. The EFB fibre cannot be used solely as an EFB-CB since it has the chemical composition.

The compatibility is usually from the excessive fibre composites such as lignin, cellulose and pectin content in the EFB fibre that prevents the compatibility between cement composites and fibre itself working together. To improve the compatibility of fibre-cement, some of the modifications and surface electron methodology were tested on the fibre.

5.2. Method of compatibility improvement

The compatibility of fibre-cement was certainly used with some of the modifications were applied including pre-treatment of wood, the addition of cement set accelerator. The aqueous extraction is an effective procedure for removing extract soluble harmful compounds before mixing with cement.

Furthermore, the wood surfaces can separate the wood from the cement paste, and increase the resistance to alkali or water attacks to improve the incompatibility between fibre-cement. Several researchers performed a series of experiments in practise to enhance the compatibility of fibre and cement with certain types of treatments such as soaking the EFB fibre in hot water treatment or by adding an accelerator such as magnesium chloride (MgCl) before or during mixing with cement. The most effective method that has been used by the researchers is pre-treatment.

6. Effect of particles geometry and EFB content on mechanical and physical properties

6.1. Failure mechanisms

The role of natural fibre/wood in cement composite on reinforcement can increase the workability of composite and fracture development can be reduced significantly. Theoretically, eat cement is brittle and possess higher compressive strength than fibre/wood is slightly higher load in bending [21]. Normally, the EFB fibre cannot resist the heavy load which leads to the failure of the fibre resulting in the failure of the composite. For the fibre-cement composites was indicated two separate mechanical failures, such as fibre fracture and fibre pull-out or tensile strength indication. However, the researcher strongly agreed that the fibre pull-out was thought to be the primary failure mode indicators. The new findings showed that the mode of failure depends on the length of the fibre and whether the length of the fibre is above or below the composite’s critical fibre length. Usually, the particle size of fibres strongly affected the mechanical properties.

6.2. Particle size/geometry, orientation and cement-fibre ratios

The application of cement boards in building construction mostly highly required the composite material that must be good in mainly to increase mechanical properties (MOE, MOR and IB) of EFB-CB.
Particles was classified as the form of strands, flakes, chips and fibre to strand. The particle geometry has a significant influence on the mechanical properties on the cement board.

The research that has been done by Moslemi and Pjister [22], specified the particles for cement-bonded boards are larger than resin-bonded particles. In addition, they also simplified the uses of particles with high slenderness ratio which has long or small particle flakes. They found that long particles produce the tough and stronger, stiffer, and more dimensionally stable on boards rather than small particles of the fibres. Other consequences suggested that the larger the particles, the stronger the compaction by much larger surface area on the EFB-CB effects of cement settings. However, to avoid void space and irregularities, using small fibre particle much better. The situation is related to the internal bonding specifically.

For the randomly oriented short fibre composites, prediction of mechanical properties of EFB-CB, it is more challenging as of the fibre dispersal, orientation and complications for the load distributions along the fibre matrix interface.

According to the research that conducted by Sreekala and Thomas [23] and Papadopoulos and Ntalos [24], the Mechanical of Rupture (MOR) increases as the cement-wood ratio is lowered. Based on the study, the appropriated cement to fibre-ratio that contributed optimum physical and mechanical properties can easily observed based on the testing. Founded on the Thickness Swelling (TS) testing result with fibre/cement ratio 2:1, the presence of void is low when the cement board contained more fibre. The MOR for EFB-CB of ratios 2:1 and 3:1 cement/fibre ratios displayed MOR values significantly higher than other due to the spring back effect and higher fibre quantities. MOE increased with cement/fibre ratios independent of the cement components value. For internal bonding (IB) testing of cement boards acting as an adhesive and increased the strength of the cement board with ratio 7:1. The higher the proportion of cement component, the lower the void space.

6.3. Mechanical and physical performance

Basically, there are three mechanical properties testing conducted for EFB-CB; Bonding strength (MOR), Modulus of Elasticity (MOE), and Internal Bonding (IB). These testing were conducted according to selected standards [25-28].

According to Rahman et al. [29], the performance of mechanical and physical on EFB-CB was influenced by fibre particles size where their study was using different size (R7M, R14M and R80M). The result obtained towards flexural behaviour of EFB-CB which are made with fibre size R80M were very low compared to R14M and R7M, but IB value was slightly higher than R14M. It clearly classified that the length of EFB fibre has influenced the mechanical properties of EFB fibre composites. Besides that, the EFB-CB, composite is very important, in view of the fact that the strength of EFB-CB is completely depends on the bonding between fibre and cement composite as a binder.

Thickness Swelling (TS) has known as physical properties on an EFB-CB which is resulted in dimensional stability aspect which is strongly correlated with the cement-wood ratios. In general, when the cement content is higher, the TS of EFB-CB is lower [30]. Increasing the cement coating on the particles can have a positive impact on the physical properties of the thickness swelling. Besides, EFB-fibre pre-treatment may have positive impact on TS results. By using hot water treatment, by way of soaking EFB fibre into the hot water. The method of using hot water can improve bonding ability with cement and reduce TS.

In addition, TS also depends on particle geometry. Thickness Swelling affected with the increasing thickness of the particles and the decreasing length of the particles (small and large particle size). The thickness particles have great heterogeneity and more irregular open board surfaces that can lead to excessive water absorption of the cement board.

7. Conclusion

The following conclusions have been drawn based on the comprehensive literature review as presented by several researchers:

- EFB-CB influenced by the particle geometry (size of particles). The larger the particle size of the composites, the better compaction of EFB-CB cement implications hardening setting by much
larger surface on the board area. Short particles caused low values of MOE, caused by inadequate particle to cement contact, but avoid large void space and irregularities towards cement board.

- The amount of particle in using different cement-fibre ratio has a direct influence on TS, MOR, and MOE. Strength of EFB-CB fully depends on the bonding between fibre and cement composites.

- The appropriated cement to fibre ratio that contributed to the optimum physical and mechanical properties can easily be observed based on the testing. In concluding, it is recommended to use the different length of fibre where the size of particles influenced the potential and performance of mechanical and physical properties on the cement boards. Consequently, composite is very important, in view of the fact that the strength of EFB-CB is completely depends on the bonding between fibre and cement composite as a binder.

- The pre-treatment fibre was indicated where the EFB fibre composite were dimensionally stable for bonding mechanisms and could be used for both interior and exterior building utilizations based on the tested physical and mechanical properties on cement-boards.

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