The Influence of Oil Palm Empty Fruit Bunch Fibre Geometry on Mechanical Performance of Cement Bonded Fibre Boards

Zainal Abidin Akasah, Nik Mohd Zaini Nik Soh, Astimar Abdul Aziz, Eeydzah Aminudin, Hayana Dullah

***Abstract*—** The mechanical properties of cement bonded fibreboards theoretically influenced by several factors like density, water cement ratio, fibre to cement ratio and geometry of fibre has been discussed by previous researchers. This experimental research work was conducted to explore the role of EFB Fibre geometry on the mechanical performances of cement boards. The experiment work designed for 1300 Kg/m3 density boards consist of two parts, first is cement boards mixed with different length of EFB; retain 7 mesh (R4M), retain 14 mesh (R14M) and retain 80 mesh (R80M). subsequently, second part is based on the cement boards fabricated from mixed of 6 different percentage lengths of EFB known as SA, SB, SC, SD, SE and SF. The ratio of EFB to cement was 3:1, while water used in the system was 35% with added of 3% Calcium Chloride (CaCl2) as additive. Whereas, water and additive were calculated based on cement weight. The mechanical properties were investigated in this study like modulus of elasticity (MOE), modulus of rupture (MOR) and internal bonding (IB). It was observed that the higher presence of shorter EFB (R80M) in cement boards, the lower mechanical properties were produced. The boards fabricated with heterogeneous fibre length, SE (35% R4M + 45% R14M + 20% R80M) produced the highest mechanical properties with MOE of 4859.5 N/mm2, MOR of 10.06 N/mm2 and IB of 0.36 N/mm2. The properties of MOE and MOR for boards fabricated from SE mixture were satisfy the minimum requirement of British standard.

***Keywords*—** Fibreboards, Empty Fruit Bunch, Modulus of Elasticity, Modulus of Rupture, Internal Bonding, Fibre length.

I. Introduction

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 [1]. In addition, the interest of utilization this cellulosic materials evolve since post War World II due to the shortage of asbestos fibre and in mid-1970s again cellulosic materials getting the attention due to growing awareness of health risk linked to asbestos usage [2]. It is widely reported that research attempts of utilize 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 known as one of the important product that helped to grow up the scenario of agriculture sector and economy. 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 second highest after OPF [14]. The previous research more focus 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], [24]. Furthermore, Onuorah et al. [11] has been done the research on EFB size that retained 4 mesh, they 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 viewpoint, EFB fibre appropriate as wood based materials replacement for cement boards production.

The role of natural fibre/wood in cement composite as reinforcement can increase the workability of composite and fracture development can be reduced significantly. Theoretically, neat cement is brittle and possess higher compressive strength than wood/natural fibre, while wood/natural fibre is slightly higher load in bending [25]. The application of cement boards in building construction mostly required the composite material that must be good in bending, flexural strength and internal bonding. Therefore, integration of natural cellulosic fibre with cement binder able to yield up the properties on composite, to fulfil the requirement of cement bonder fibreboards or particleboards as stated in BS 7916:1998 and BS EN 632-2:2007.

The production of cement-bonded composite (C-BC) evolved in various shapes, e.g. cement bonded wood wool, cement bonded fibreboards and cement bonded particleboards. These C-BCs actually made from different size of particles. Frybort et al. [25] has classified particle as the form of strands, flakes, chips and fibre with the size varying from shapes of particle, fibre to strand. The CB-C produced from different particle size and geometry will have different physical and mechanical properties. The research finding done by Semple and Evans [7] indicated that the manufacturing cement-bonded boards need larger particle size compare to resin bonded panel. In addition, they also clarified the particle with high slenderness ratio (longer and thinner) will produce the

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stronger, stiffer and more dimensionally stable the boards. While Sotannde et al. [28] found that, incorporation heterogeneous particle size will enhance the bending strength properties of CB-C if compared to single particle of larger size. Therefore, particle size of fibre/wood to be incorporated in cement boards production need to be identified to achieve the desired physical and mechanical properties. Perhaps, apart from research attempt for manufacturing Empty Fruit Bunch Cement Boards (EFB-CB), there are very limited and rare to found published research finding about the effect of particle dimension on the EFB-CB properties. Therefore, it is essential to explore and identify the appropriate fibre sizes that contribute to the optimum performance.

The objectives of this study is to identify; (a) The effect of EFB fibre size against mechanical performance of EFB-CB with the classification of fibre size 1) retained 4 mesh, 2) passing 4 mesh and retained 14 mesh and 3) passing 14 mesh and retained 80 mesh (nominal openings 4.76 mm, 1.41 mm and 0.177 mm respectively); (b) The effect of change EFB-CB density with respect to different EFB fibre size (objective a) where EFB-CB fabricated with the density of 1000 Kg/m3, 1100 Kg/m3, 1200 Kg/m3 and 1300 Kg/m3; and (c) The mechanical performance of EFB-CB that fabricate with mixing different percentage EFB fibre size.

II. Materials and methods

A. EFB Fibre Preparation

EFB fibre used for this research supplied by Kulim Plantation, Ladang Tereh Mill located at Kluang Johor. EFB fibre coil were soaked in Sodium Hydroxide (NaOH) with 0.4% concentration based on water weight for 24 hours as recommended by Zawawi, Astimar, and Ridzuan [29]. The coil then washed with tap water to remove any impurities and PH value-measuring device is used to determine the pH value of wash water, to ensure the presence of alkali from NaOH is completely removed. Afterward, the treated EFB fibres were air-dried for 3 days to ensure the percentage moisture content remain as 10%. Originally, EFB fibre from oil palm mill was in coil condition with average length between 50mm to 200mm. EFB fibre then reduced to particle by hammer milled and screened with size distribution about 9.5% retained 4 mesh, 23.8% passing 4 mesh and retained 14 mesh, 51.3% passing 14 mesh and retained 80 mesh and the remainder for the next 15.4% represent dust that passing through 80 mesh (nominal openings of 4.76 mm (4 mesh), 1.41 mm (14 mesh) and 0.177 mm (80 mesh). Table 1 shows the range of fibre length and fibre length distribution. The process of EFB fibre production was done in Timber Fabrication Laboratory, Faculty of Civil and Environmental Engineering, UTHM and Malaysian Palm Oil Boards Laboratory, UKM Research Centre Bang Selangor.

TABLE I

The range of EFB fibre lengths according to meshing size

EFB Fibre Length (mm)		
Retain 4 Mesh (R4M)	**Passing 7 Mesh Retain 14 Mesh (R14M)**	**Passing 14 Mesh Retain 80 Mesh (R80M)**
15.9 mm to 30.85 mm	8.88 mm to 16.55 mm	2.15 mm to 9.67 mm

TABLE II

Design mix for EFB-CB sample with various fibre size and boards density

<table>
<tr><th colspan="7">Part 1 (Based on different fibre size)</th></tr>
<tr><th rowspan="2">Density (Kg/m^3)</th><th colspan="6">Screening Mesh Size</th></tr>
<tr><th colspan="2">Retain 4 Mesh (R4M)</th><th colspan="2">Passing 14 Mesh Retain 14 Mesh (R14M)</th><th colspan="2">Passing 14 Mesh Retain 80 Mesh (R80M)</th></tr>
<tr><td>1000</td><td colspan="2">5</td><td colspan="2">5</td><td colspan="2">5</td></tr>
<tr><td>1100</td><td colspan="2">5</td><td colspan="2">5</td><td colspan="2">5</td></tr>
<tr><td>1200</td><td colspan="2">5</td><td colspan="2">5</td><td colspan="2">5</td></tr>
<tr><td>1300</td><td colspan="2">5</td><td colspan="2">5</td><td colspan="2">5</td></tr>
<tr><th colspan="7">Part 2 (Based on different percentage of size)</th></tr>
<tr><td rowspan="2">1300</td><td>SA</td><td>SB</td><td>SC</td><td>SD</td><td>SE</td><td>SF</td></tr>
<tr><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td colspan="7">Note: SA: 100% R80M; SB: 5% R4M + 15% R14M + R80M; SC: 15% R4M + 25% R14m + 60% R80M; SD: 25% R4M + 35% R14M + 40% R80M; SE: 35% R4M + 45% R14M + 20% R80M; SF: 45% R4M + 55% R14M + 0% R80M</td></tr>
</table>

B. Cement Binder and Chemical Additive

In this study Ordinary Portland Cement Type 1 (OPC-Tasek Brand) and chemical additive Calcium Chloride ($CaCl_2$) was used at 3% based on cement weight as recommended by Onuorah et al. [11]. Whereas, distilled water was used to optimize the hydration rate of cement with the 35% water based on cement weight.

C. EFB-CB Fabrication

Design parameter of EFB-CB as shown in Table 2. Total of 60 samples were prepared for fibre with different EFB fibre size (R4M, R14M and R80) and another 30 samples prepared for different fibre percentage (SA, SB, SC, SD, SE and SF). Oven-dried EFB fibres (5% moisture content) were first mix with solution $CaCl_2$ and distilled water in drum mixer for 2 minutes. Then wet EFB fibre were mix with OPC and the mixing process were continued for another 10 minutes. The mixture then placed in wooden mould with the size of 350 mm x 350 mm on 400 mm x 400 mm reinforced steel plate. The mixture was evenly spread and flattened using a wooden stick to build up the mat, and the wooden mould was removed. Both side (top and bottom) pre-formed mats were covered with polythene sheet. Thereafter, another reinforced steel plate was placed on top of pre-formed mats. The mats were later applied with cold press until meet desired thickness of 12mm. The pressed mats were kept under pressure for 24 hours by bolting the two-reinforced steel plate together. The mats then de-clamped after 24 hours, stacked and conditioned in ambient temperature 28±1 °C with relative humidity of 65±5% for 28 days to allow cement-EFB composite to cure thus increase the strength.

D.EFB-CB Mechanical Properties Testing

There are three mechanical properties testing conducted for EFB-CB; Bending Strength (MOR), Modulus of Elasticity (MOE) and Internal Bonding (IB). These testing were conducted according to BS EN 310:1993 and BS EN 319: 1993 respectively.

III. Results and Discussion

A. Mechanical Performance of EFB-CB Fabricated with Different EFB Fibre Length

Twenty-eight days after being fabricated by procedure as described in section 2.3, the samples EFB-CB were tested for mechanical properties guided by BS EN 310 and BS EN 319 (section 2.4). The results indicated that the mechanical performance significantly influenced by fibre length incorporated in the composite. Besides, the result was also discovering that the increase of board's density would enhance the mechanical performance of EFB-CB. It was observed that the flexural behaviour of EFB-CB made from EFB shortest length (R80M) were very low (1856 to 2976 N/mm^2 in MOE, 2.72 to 6.19 N/mm^2 in MOR and 0.01 to 0.14 N/mm^2 in IB) compared to those EFB-CB fabricated from longer length R14M and R4M as shown in Fig 1. The author attributed this mainly to the several factors. Surface area of shorter fibre larger than longer fibre, thus more binder (OPC) is needed to optimize the cement setting, eventually create stronger bonding between fibre as claimed by earlier research [5,30]. Besides, the embrittlement of composite was associated with the migration of cement hydration product especially calcium hydroxide into the fibre lumen, wall and void consequently mineralization the EFB fibre [30]. It gets worse when short fibres were used since the higher number of exposed surface which allowed a faster penetration of hydration product, thus mineralization of fibre. Furthermore, low energy is required to pull the fibre through the matrix, thus failure fracture of composite occur quickly [31].

The good mechanical performance of EFB-CB made from different EFB length were noted with R14M with the range of MOE (2158 to 4883 N/mm^2), MOR (4.4 to 9.11 N/mm^2) and IB was slightly lower than boards made of R4M (0.13 to 0.18 N/mm^2), and followed by EFB-CB made from R4M with MOE (1519 to 4331 N/mm^2), MOR (2.58 to 8.25 N/mm^2) and IB (0.08 to 0.29 N/mm^2). It clearly shows that the length of the fibres has played significant role to yield up the mechanical properties of composite. As longer EFB fibres were used in making EFB-CB, it provides larger contact area and has resulted in higher friction force between EFB fibre and cement. Therefore, pulled out failure does not occur easily. Earlier research claimed that, the length of fibre in cement-bonded composite is very important since their strength completely depends on the bonding between fibre and binder [32]. Similar finding was obtained by Semple and Evans [7] where the use of high slenderness ratio fibre would enhance mechanical performance of composite.

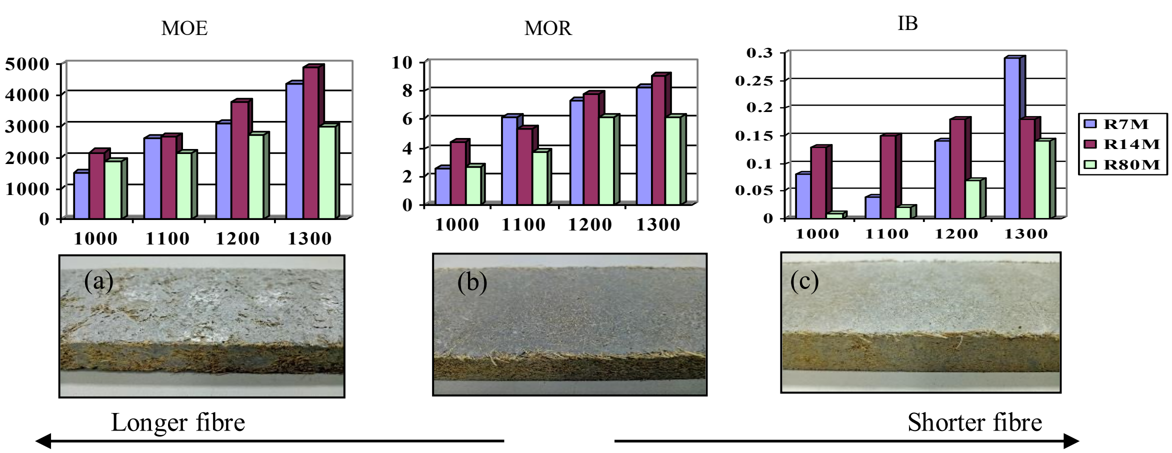

Fig. 1 Mechanical performance and physical observation of EFB-CB fabricated from different length of EFB fibre.

B. The Effect of Mixing Different Percentage of Fibre Length in Fabrication EFB-CB

The research was designed by mixing the EFB fibre with different length percentage to establish the finding on fibre length effect. The idea to mixing the fibre from different length percentage in optimizing the mechanical performance was derived by considering the function short fibre as filler while long fibre as reinforcement. The role of short fibre can be illustrated through the concept of concrete where the strength of concrete could be increased by reducing stress concentration made by coarse aggregate with inclusion of smaller aggregate [25]. Fig 1 shows that typical physical appearance of EFB-CB fabricated from different length of fibre. Fig 1a shows the EFB-CB made solely from R4M. It can be observed that the formation crystallization of cement occurred on board's surface and internal crystallization unevenly distributed. The author attributed the findings with the migration of cement slurry through void between long fibres to mat surface or dense area during pressing process. Fig 1b and 1c represent typical appearance for EFB-CB consists of long and short fibre. The boards surface seen smoother and integration of binder (cement) and EFB fibre evenly distributed. Most likely the presence of short fibre filled up the void and holding cement slurry when pressure applied. Earlier research claimed that the fibre with the length less than 0.3mm acts more as filler in rather than reinforcement in composite [31].

Fig 2 shows the mechanical properties of EFB-CB for SA, SB, SC, SD, SE and SF. As described in 2.1, SA-SF were fabricated with different percentage fibre length. The result of mechanical properties indicated that the optimum performance obtained from EFB-CB made from 35% of R4M + 45% of R14M + 20% of R80M (SE) with MOE (4860 N/mm^2), MOR (10.05 N/mm^2) and IB (0.36 N/mm^2). It proves that the use of the integration various fibre lengths could enhance mechanical performance due to interconnected role of short fibre (filler) and long fibre (reinforcement). This agreed by [28] where cement bonded particle boards made from heterogeneous particle size tend to enhance the bending strength of boards compared to those fabricated from single particle of larger size. Apart of EFB-CB based on SF, the boards contain higher amount of short fibre tend to decrease mechanical performance. Although using small particle could produce more compact matt structure, the better compaction is offset by negative effect of cement setting due to larger surface area-to-volume ratio of the fibre [7]. Therefore, as there is significant correlation between surface and volume ratio of particle, to enhance the cement setting, more binder is needed [29]. In addition, the increment MOE, MOR and IB trend can be observed whenever the amount of R4M and R14M increased, and R80M decreased. The trend shown peak at SE and suddenly drops for SF due to no short fibre (R80M) was added. Therefore, the combination of role short and long fibre believed influenced the overall mechanical performance of EFB-CB.

The results indicated that, two of the three mechanical properties have full fill the minimum requirement stipulated as in BS EN 634-2 (2007). The samples those passing the minimum requirement of standard were MOE and MOR for EFB-CB with R14M at 1300 Kg/m^3 with 4883 N/mm^2 and 9.11 N/mm^2 respectively. While for different percentage of EFB, EFB-CB for SE and SF mix have full fill the requirement with MOE and MOR of 4860 N/mm^2, 10.05 N/mm^2 and 4298 N/mm^2 and 10.05 N/mm^2 respectively.

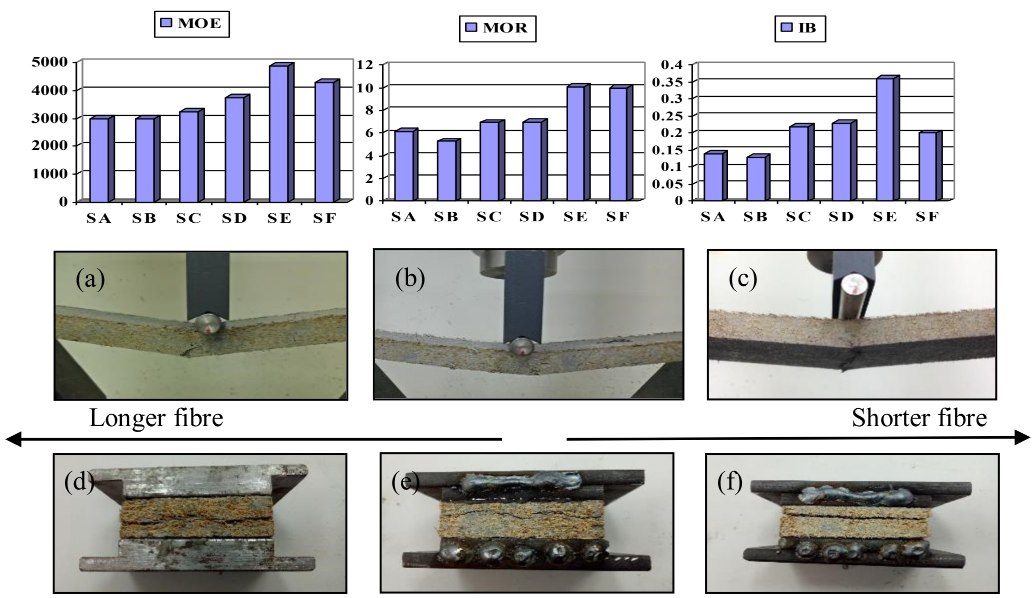

Fig. 2 Mechanical performance and typical flexural strength failure profile for (a) fabricated with long fibre (R4M), (b) fabricated with combine of short and long fibre (R14M, R4M + R14M, R4M + R14M + R80M), (c) fabricated with short fibre (R80M)

C. Failure profile of flexural strength and internal bonding test

Through observation during flexural test were conducting, the failure profile can be clustered by three categories as shown in Fig 2a, 2b and 2c. EFB-CBs made of longer EFB fibre (R4M) have clearly shown the angle of failure bigger and diverge from where the point load acted. This may be due to the facts that the longer fibres in composite have acted to stop fracture propagation. The similar pattern with slightly smaller angle of diverge were observed for those EFB-CB (Fig 2b) made with combination either solely made of R14M or mixed three of them (R4M, R14M, R80M). Therefore, as described earlier, longer EFB provide larger interfacial bonding between cement matrix and fibre thus provide resistance for fracture propagation through higher friction force [25, 34]. However, fracture profile observed from EFB-CB with completely made from short fibre (R80M) shown different characteristic where fracture line observed parallel with the applied load direction as shown in Fig 2c. The main reason for this finding were short fibre inhibit cement setting through larger surface exposure and poor friction forced that permit low pull out forced resulted to the low performance of EFB-CB [5, 30, 34]. Perhaps, if compared the performance of MOE and MOR with the fracture profile for these three clusters EFB-CB, it is clearly there are significant relationships between mechanical performances, distribution of fibre length and flexural failure profile.

Fig 2d, 2e and 2f shows the typical failure profile for internal bending. Through observation, it was found that type of failure generally could be divided into two types. As flexural failure profile, the samples consist of longer fibre or integration of short or long fibre typically shows nonlinear line of fracture failure (Fig 2d and 2e). While, sample made of solely short fibre (Fig 2f) show the failure profile in linear line perpendicular to loading direction. This show that heterogeneous fibre length in composite tends to act as barrier to fracture propagation, thus applied force that transferred to the fibre and binder tend to find the weakest area. A clear distinction found in EFB-CB made solely from short fibre (R80M) where linear line of failure was observed. This may due to short fibre in composite possess large weakest area due to poor in bonding between fibre and cement thus low pull out force capacity as discussed earlier. Furthermore, the trend of IB results were found parallel to failure profile where IBs for short fibre were lower than those samples fabricated either from long fibre or integration of long or short EFB fibre.

IV. Conclusion

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

1. The appropriate EFB fibre lengths that contribute the optimum mechanical performance of EFB-CB can be either 8.88mm to 16.55mm (R14M) or SE (35% R4M + 45% R14M + 20% R80M) or SF (45% R4M + 55% R14M + 0% R80M).
2. EFB-CB fabricated of short EFB fibre (R80M) consistently produced lower mechanical properties due to poor in bonding mechanism between fibre surface and cement matrix thus low friction force consequently low in pull out force.
3. EFB-CB could only full fill the minimum requirement as stipulated in BS 634-2 2007 for those boards fabricated with density of 1300 Kg/m^3.

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