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The Differences Between Hand and Hand Plus Vibration Forming on Mechanical Properties of Oil Palm Empty Fruit Bunch Fibreboards

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Abstract: The growth in the production of used palm oil has caused the environmental problem and promotes abundance of oil palm empty fruit bunch (OPEFB) fibre. OPEFB fibre is one of the lignocellulosic materials that could replace other natural cement fibreboard products. The objectives of this research were to analyse the differences of hand and hand plus vibration forming for mechanical properties of empty fruit bunch cement board (EFBCB) and to propose the most suitable forming method in the fabrication process of EFBCB that contributes to optimum mechanical properties of the samples. The study used Ordinary Portland Cement, EFB fibre, water and NaOH in the fabrication of the EFBCB which involved two different methods which were hand forming and hand plus vibration forming method. A total of 12 sample boards with 350mm x 350mm x 12mm size were used with a constant density of 1300 kg/m^3. The ratio used for cement and EFB fibre was 3:1 respectively. Testing of Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Internal Bonding (IB) were conducted in the study. All measurements were carried out according to the BS EN 310:1993 and BS EN 319:1993. Results showed that the mean values when using hand plus two minutes time of vibration were the highest for MOE, MOR and IB which were 4915.67 N/mm^2, 13.08 N/mm^2, and 0.44 N/mm^2 respectively. This showed that the MOE and MOR have complied to the BS EN 634-2:2007 while IB did not comply to the standard. This may highly due to the proportion of the cement component. As the proportion of cement component is higher, the void space decreases. Although IB did not comply to the standard used, it was still accepted due to the nearest value of 0.5N/mm^2 which was the minimum requirement in the standard. Therefore, the second minute of hand forming plus vibration method is being proposed in the fabrication process of EFBCB that contributed to optimum mechanical properties in terms of MOE and MOR of the sample.

Keywords: Empty Fruit Bunch Cement Board, Hand and Hand Plus Vibration Method

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1. Introduction

Oil palm or in its scientific name, Elaeis Guineensis has become one of the most important commodity crops in Malaysia [1]. The oil palm is said to be more effective than other natural source such as rain forest in generating new biomass. New biomass is very useful in the country in order to produce basic necessities such as fuel and also as wood replacement [2]. The oil palm biomass residues especially in oil palm empty fruit bunch (OPEFB) is used as bio-composite industrial raw material or as an alternative substitute material for wood construction [1]. This is to reduce waste and avoid the diminishing of wood supply through deforestation. It has also been globally accepted due to the price, sustainability, biodegradability and the reduction of carbon dioxide emissions [3]. Therefore, oil palm empty fruit bunch (OPEFB) fibre is introduced in wood fibre replacement as it has similar characteristics with other wood or lignocellulosic materials.

In Malaysia, the oil palm industry is considered to be one of the most important tools that has mitigated the growth of both agriculture and the economy. This sector generates lignocellulosic biomass waste which are also known as natural fibre consisting of the oil palm trunk (OPT), the oil palm frond (OPF), the empty fruit bunch (EFB) and the palm-pressed fibre (PPF). Among the waste generated, EFB has contributed 18,022 kilotonnes of wastes which contributed to the second highest amount after OPF [4]. Generally, this research study involved in the making of EFBCB. It was mainly about the differences of hand and hand plus vibration forming on the mechanical properties of EFBCB. In other words, this research primarily focused on laboratory work and investigation that used two different kinds of forming methods in the fabrication process. The objectives of this research study were to analyse the differences of hand and hand plus vibration forming for mechanical properties of EFBCB and to propose the most suitable forming method in the fabrication process of EFBCB that contributes to optimum mechanical properties of the samples

1.1 Oil Palm Empty Fruit Bunch (OPEFB)

Oil Palm Empty Fruit Bunch (OPEFB) has been investigated as to replace other raw materials for construction materials, solid fuel pellets, chemical products, particleboard, fibreboard, blockboard and pulp and paper. In the near future, forecasts indicate that the supply of rubberwood will not fulfil the demand for medium density fibreboard (MDF) production. One of the solutions made to face the problem is by replacing the rubberwood with readily available OPEFB [5]. OPEFB which is one of the fibres that belong to the lignocellulosic family consists of three main components namely hemicellulose (19% - 25%), cellulose (40%-65%) and lignin (19%-21%) [3]. The major barrier to the manufacture of OPEFB fibre cement composites is the incompatibility of chemicals between fibre and cement which inhibits the cement setting as well as hardening. In order to achieve compatibility between the EFB fibre and cement, the EFB fibre must be treated in order to eliminate inhibitory substance before manufacturing EFB fibre cement boards [4]. Chemical treatment using sodium hydroxide, NaOH, calcium chloride, CaCl2 or magnesium chloride, MgCl2, a cement accelerator is the EFB fibre pre-treatment that has been widely used by other researchers [6]. Pre-treatment of the fibre that removes its residual oil has greatly increased the quality of MDF and has prevented delamination [5].

According to Maynet et al. [7], it was found that the particle size in the EFBCB has affected the compaction of EFBCB effects of cement setting through much bigger surface on the board area. The research also showed that the modulus of rupture (MOR), thickness swelling (TS), and modulus of elasticity (MOE) were all affected by the cement EFB fibre ratio. The connection between the fibre and cement composites have determined the strength of EFBCB. The research also stated that the internal bonding (IB) was affected by the proportion of cement component. As the proportion of cement component is higher, the void space decreases. Meanwhile, a research by Peter et al. [8] has stated that the most important step in the cement board manufacturing process is the fibre pre-treatment. This was due to the untreated fibre-cement composite that had the lowest MOR, MOE and IB which also indicated that the fibre and cement were not compatible. This was most likely owing to inhibitory compounds like pectin and waxy chemicals that inhibited the hydroxyl groups from generating interfacial adhesion with the matrix. The result in the research also showed that pre-treating fibre with an eight percent NaOH solution resulted in the greatest increase in MOR, MOE and IB. In general, MOR and MOE increased as NaOH concentration increased which most likely due to the effect of NaOH on cellulose fibril, lignin, degree of polymerization and hemi-cellulosic extraction [9].

In terms of the usage of vibration table machine, a research by Temidayo E, et al. [10] has showed a result of mechanical properties of MOR and MOE from the cement board production that has increased due to the usage of vibration table machine. The vibration machine has aided in the consolidation of the cement composite resulting in improve mechanical qualities. Vibration has consolidated it in two stages, first, it compacted and consolidated the particles and then, it removed entrapped air and weak places hence improved the bond strength and lowered permeability.

2. Materials and Methods

Laboratory work was conducted in order to evaluate the differences of two methods used which were hand and hand plus vibration forming method on the mechanical properties.

2.1 Materials

In this research, Empty Fruit Bunch Fibre (EFB) which was from Oil Palm Fibre (OPF) was obtained from a factory called Ban Dung Palm Oil Industries Sdn Bhd which was located at Jalan Muar, Parit Sulong, Batu Pahat, Johor. Besides, Ordinary Portland Cement was also used in this research. The pre-treatment solution of NaOH with 0.4% concentration and also water was used in order to remove its residual oil which could affect the hydration of cement.

2.2 Methods

There were a few processes that EFB fibres went through in order to become cement boards. A lot of past researchers [4], [5], [11], [12] have used processes such as hammer mill process, screening process, pre-treatment process, and fabrication of EFBCB stage processes. These processes were important as it may influence the results of the mechanical properties at the end of the process. The first process which was hammer mill process was conducted. Hammer mill process need to be done in order to reduce the fibrous fibre to chip particles. This is because the fibrous form of EFB fibre can be hard to be bonded with cement as it has big sizing. The second process was screening process. It was screened with sieve size distribution of R30M for 1 minute, 2 minutes and 3 minutes for each sample equally. The sieving process used the vibration table machine in order to determine the EFB length grading and to isolate dust that could affect the quality of the cement board [3].

The pre-treatment process was conducted right after the screening process. The treatment of EFB fibre was carried out by soaking it in Sodium Hydroxide (NaOH) with 0.4% concentration for 24 hours. To remove any impurities, the fibres were then being washed with tap water to ensure that the presence of NaOH alkali has been completely removed. The treated EFB was then being sun-dried until it was dry enough to be put in the oven for the oven-dried process. It was being oven dried until the moisture content percentage has reached to 5% in order to prevent fungal attacks [4]. Figure 1 shows the hammer mill process, screening process and the pre-treatment process.

The last stage which was the fabrication of EFBCB stage was conducted. In this stage, the mixing process, moulding process, compacting process and curing process were included. The mix design of EFBCB was conducted. The weight of water, fibre and cement were being considered. The ratio used for cement and EFB fibre was 3:1 respectively with sample size of 350mm x 350mm x 12mm and total sample of 12 cement boards. The constant density board of 1300 kg/m^3 was used in the mix design which complied with the minimum density requirement of 1000kg/m^3 in the BS EN 323:1993. In the mixing process, raw materials were placed one by one which began with EFB fibre, followed by water and cement according to the mix design weight of ratio 3:1. It was mixed in the mixer for 5 minutes. Then, material mixture was mixed for another 5 minutes in order to get a complete blended mixture. The blended mixture then was then moved to a wooden mould.

The moulding process involved with hand and hand plus vibration forming method. Hand forming was used in this first step using 10mm x 10mm wire mesh and wooden mould. Hand pressed was applied to form and reduce the thickness of the sample by flattening it with hand. As for hand plus vibration method, a vibration machine table was used. After hand laying process, the wooden mould was left on vibration table for 1, 2 and 3 minutes to uniformly distribute the densities of the cement sample. Compacting process was conducted after the moulding process. Under high pressure, the moulds were compressed until the cement boards were formed with the target thickness of 12mm. The boards were then left in the laboratory and being unclamped after 24 hours. The last process in the fabrication stage was curing process. Under normal temperature conditions of 25 ± 2°C and a relative humidity of 65 ± 2%, the pressed samples were subjected to 28 days of air curing [13], [14]. Figure 2 shows the fabrication process of hand plus vibration forming of EFBCB while table 1 shows the minimum requirement for EFBCB mechanical properties according to the standard used.

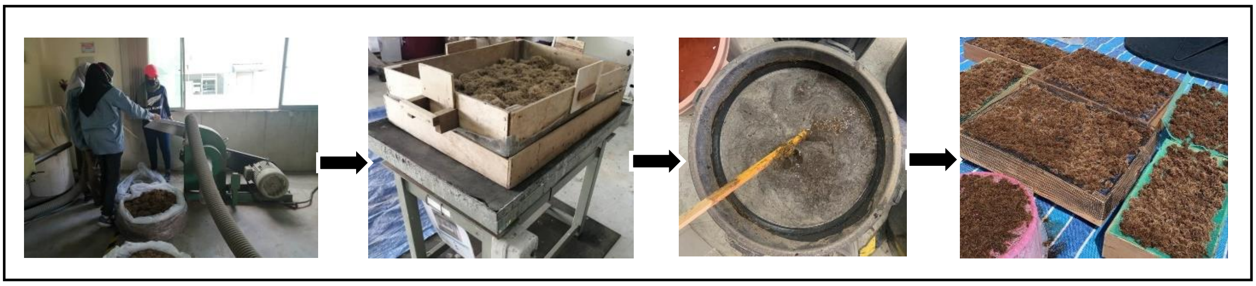

Figure 1: Hammer Mill Process, Screening Process and Pre-treatment Process

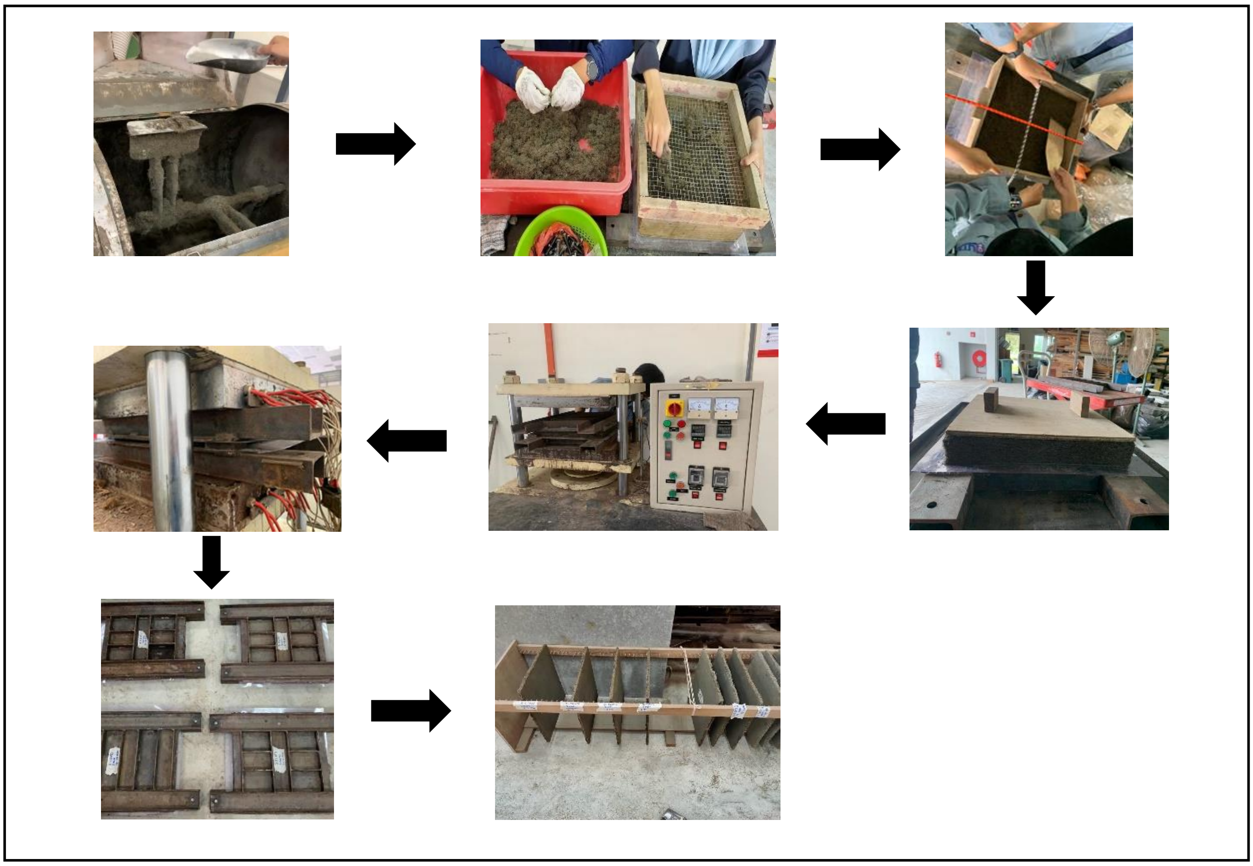

Figure 2: Fabrication Process of Hand Plus Vibration Method of EFBCB

Table 1: Minimum requirement of mechanical properties according to the standard used

Mechanical Properties	Standard Used	Minimum Requirement	Unit
MOE	BS EN 634-2:2007	Class 1: 4500 Class 2: 4000	N/mm^2
MOR	BS EN 634-2:2007	9	N/mm^2
IB	BS EN 634-2:2007	0.5	N/mm^2

2.3 Mix Design Testing

In the mix design of EFBCB, the weight of water, fibre and cement were being considered. The ratio used for cement and EFB fibre was 3:1 respectively. Equation 1 shows the equation for optimum weight of water to be followed.

$$Water\ (g) = 0.4\ of\ Cement\ Weight + 0.3\ of\ EFB\ Oven\ Dried\ Weight\ \ Eq.1$$

2.3.1 Modulus of Rupture (MOR)

To obtain the MOR values, a static bending test was being conducted. The maximum load that could be added to the midpoint of the test specimen of simply supported can be determined by the test [3]. The dimension of the cement board used was 300mm x 50mm for MOR sample boards test. According to the BS EN 310- 1993, MOR can be calculated by using the equation as stated in equation 2.

$$MOR = \frac{3WL}{2bt^2}\ \ Eq.2$$

where,
W = Maximum Load (N)
L = Distance between support center (mm)
t = Thickness of test piece (mm)
b = Width of test piece (mm)

2.3.2 Modulus of Elasticity (MOE)

To obtain the MOE values, the dimension of the cement board that used was also the same as MOR sample board test which was 300mm x 50mm. According to the BS EN 310- 1993, MOE can be calculated by using the equation as stated in equation 3.

$$MOE = \frac{L^2 \Delta w}{4bt^3 \Delta s}\ \ Eq.3$$

where,
Δ = Increment load (N)
ΔS = Increment of deflection at midpoint corresponding to Δw
L = Distance between support center (mm)
b = Width of test piece (mm)
t = Thickness of test piece (mm)

2.3.3 Internal Bonding (IB)

In terms of the Internal Bonding (IB) mechanical properties, the test used The Universal Testing Machine (UTM Instron) and followed the BS EN 319-1993 standard [3], [5], [15]. The dimension of the cement board used for IB test was 50mm x 50mm. The use of IB test was to analyse the strength of the bonding formed between EFB fibre and cement used. The objective of this test was to achieve the maximum load on the sample before it breaks. The stronger the bond between the glue and the strands of fibre, the greater the strength of the board. IB can be calculated manually by using equation 4.

$$IB = \frac{P}{(w \times l)} \quad Eq. 4$$

where,
IB = Internal Bonding (N/mm^2)
P = Peak Load or Maximum Load (N)
w = width (mm)
l = length (mm)

3. Results and Discussion

The data for each type of mechanical properties have been analysed. The graphs for each mechanical property against the duration of vibration time were plotted with mix design ratio of 3:1. Zero minute indicated that the method used for the study was only by hand forming while the vibration time of one, two and three minutes indicated that the method used for the study was by using hand forming plus the vibration method.

3.1 Modulus of Rupture (MOR)

Results showed that the mean values of MOR for hand formed method, hand plus 1-minute vibration, hand plus 2 minutes vibration and hand plus 3 minutes vibration method were 11.77 N/mm^2, 12.52 N/mm^2, 13.08 N/mm^2 and 12.80 N/mm^2 respectively. The results indicate that the hand formed plus two minutes of vibration has the optimum value of mechanical properties in terms of MOR. This was highly due to the vibration method existence that has aided in the consolidation of the cement board composite resulting in improved mechanical properties [10]. Table 2 shows the mean values of the mechanical properties of MOR.

Table 2: Mean values of the MOR mechanical properties

Mechanical Properties	Duration of Vibration	Mean Values	Unit
MOR	0 minute (HF)	11.77	N/mm^2
	1 minute	12.52	N/mm^2
	2 minutes	13.08	N/mm^2
	3 minutes	12.80	N/mm^2

3.2 Modulus of Elasticity (MOE)

As for MOE, the mean values for hand formed method, hand plus 1-minute vibration, hand plus 2 minutes vibration and hand plus 3 minutes vibration method were 4466.33 N/mm^2, 4202.00 N/mm^2, 4915.67 N/mm^2 and 4719.67 N/mm^2 respectively. The result showed that hand plus 2 minute vibration forming method produce an optimum value of MOE. This also can relate with a research by Temidayo et al., [10] that mentioned the vibration table machine has made enormous voids or honeycomb disappeared through the pressure waves generated which arrange the particles and reduce friction between them. Table 3 shows the mean values of the mechanical properties of MOE.

Table 3: Mean values of the MOE mechanical properties

Mechanical Properties	Duration of Vibration	Mean Values	Unit
MOE	0 minute (HF)	4466.33	N/mm^2
	1 minute	4202.00	N/mm^2
	2 minutes	4915.67	N/mm^2
	3 minutes	4719.67	N/mm^2

3.3 Internal Bonding (IB)

Results for IB show the mean values of 0.33 N/mm^2 for hand formed method, 0.36 N/mm^2 for hand plus 1-minute vibration, 0.44 N/mm^2 for hand plus 2 minutes vibration and 0.36 N/mm^2 for hand plus 3 minutes vibration method. The result showed that IB did not comply to the standard used. According to a research by Maynet et al., [7], it has been stated that the IB was affected by the proportion of cement component. As the proportion of cement is higher, the void space decreases. Table 4 shows the mean values of the mechanical properties of IB while figure 3 shows the mechanical properties against vibration time.

Table 4: Mean values of the IB mechanical properties

Mechanical Properties	Duration of Vibration	Mean Values	Unit
IB	0 minute (HF)	0.33	N/mm^2
	1 minute	0.36	N/mm^2
	2 minutes	0.44	N/mm^2
	3 minutes	0.33	N/mm^2

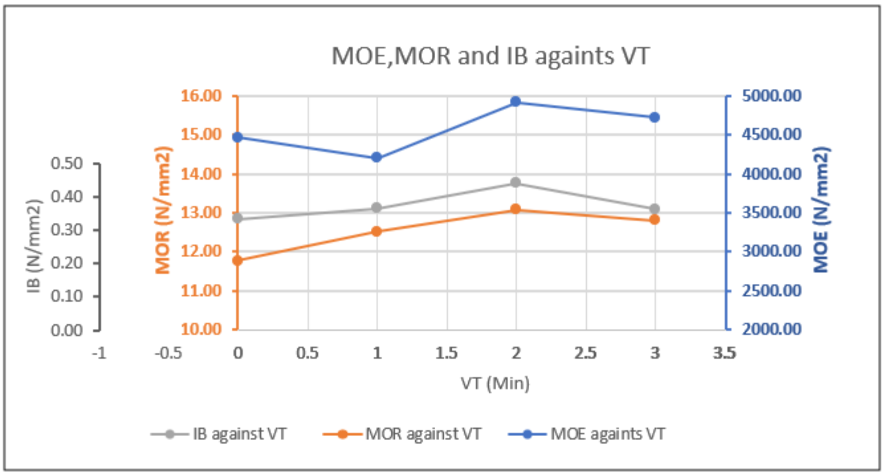

Figure 3: Mechanical Properties against Vibration Time

3.4 Discussions

The first objective which was to analyse the differences between hand and hand plus vibration method in terms of mechanical properties of MOE, MOR and IB have concluded to be achieved and the second objective also was achieved as the most suitable method in the fabrication process that contributed to optimum mechanical properties of the sample board has been proposed.

In objective 1 which was to analyse the differences between hand and hand plus vibration method in terms of mechanical properties of MOE, MOR and IB have been made. The results concluded that the data in mechanical properties showed better values in the method of hand plus vibration method instead of hand forming method only. The differences in results between those two methods were due to the differences in density distribution on the EFBCB.

In terms of MOE result, it was seen that the mean values for both methods have complied to the standard used. According to BS EN 634-2:2007, there were two classes involved in the minimum requirements which is class 1 with 4500 N/mm^2 while class 2 with 4000 N/mm^2. The vibration time of two and three minutes have complied with the minimum requirement of class 1 while the vibration time of 1-minute and with no vibration time were being categorized in class 2 as they generated MOE values of 4202 N/mm^2 and 4466.33 N/mm^2 respectively. The result also indicated that the two minutes duration of vibration was the best in generating the mechanical properties values of MOE.

The value of MOR of 2 minutes of vibration time has shown an optimum value with an average of 13.08 N/mm^2. It has the highest value of MOR compared to hand forming method only and other duration of vibration time. This showed that the EFBCB did require hand forming plus vibration method instead of with hand forming method only to obtain an optimum value of MOR. Based on BS EN 634-2:2007, the minimum requirement is 9 N/mm^2 while the results obtained have shown bigger values. This can be said that all the MOR values throughout this research have complied with the standard used.

The result in IB showed that the hand forming plus vibration method have higher values of internal bonding compared to the hand forming method. Among the three durations of vibration time, the vibration time with two minutes showed the highest value of internal bonding with an average of 0.4403 N/mm^2 while vibration time of one minute and three minutes showed values of 0.3647 N/mm^2 and 0.3633 N/mm^2 respectively. According to BS EN 634-2:2007, the minimum requirement of internal bonding is 0.5 N/mm^2. This showed that the results of this research did not comply to the standard used.

Hand plus vibration method has helped the EFBCB to equally distribute the density as it has used the addition of vibration method using vibration table machine. In other words, the vibration machine has aided in the consolidation of the cement board composite resulting in improved mechanical qualities. Vibration has consolidated the mixture in two stages which was the first one it compacted and consolidated the cement particles and then it removed entrapped air and weak places which improved the bonding strength and hence lowered the permeability. Pressure waves were generated by the vibration machine which rearrange particles and reduce friction between them. As a result, enormous voids or honeycomb has disappeared [10].

The optimum results in the analysis of MOE and MOR have obtained during the two minutes of vibration. This can be said that between three minutes, the second minute vibration has produced an optimum result for both MOE and MOR properties. Although the result of both methods used in IB analysis did not achieve the minimum requirement in BS EN 634-2:2007, the hand plus 2 minutes vibration method used has shown the best values for IB instead of with hand forming method only. The result obtained for IB testing was still accepted due to the nearest value of 0.5 N/mm^2 which was the minimum requirement in BS EN 634-2:2007. Therefore, the second objective of this research which to propose the most suitable forming method in the fabrication process of EFBCB that contributes to optimum mechanical properties of the sample has been achieved. The most suitable method which was being proposed is the hand plus 2 minutes vibration forming method.

3.5 Recommendations

There are some recommendations that can be made in order to get better results especially in terms of internal bonding of the EFBCB as the result did not achieve the minimum requirement value as stated in BS EN 634-2:2007. The recommendations are as followed:

i) The cement used must be the new one instead of the old one. This is because cement is a fine powder that absorbs moisture from the air. When it absorbs moisture, it hydrates, and as a result, the usage of the cement has little or no impact on the strength growth. In other words, cement loses its strength over period of time if it is not stored properly in exposed area which can lead to moisture absorption from the atmosphere. Old cement that is exposed to air moisture gets hardened and form lumps. This can cause the sample to have lower strength in terms of mechanical properties.

ii) The sodium hydroxide, NaOH can be increased from 0.4% to 0.6% or even 0.8% in order to achieve an optimum value of IB. This is because according to a research by Soh et al.

[16], it has revealed that the increasing in the concentration of NaOH has increased the tensile strength of EFB fibres significantly. In other words, alkali treatment has significantly enhanced the tensile strength of EFB fibres and this may due to the alkali treatment that has increases the fibre crystallinity. This has proved that the concentration of the alkali pre-treatment such as NaOH need to be increased in order to increase the tensile strength which also increase the values of IB.

iii) The different length of fibre should be used where the size of the particles affected the potential performance of the mechanical properties on the EFBCB. As stated in the research by Maynet et al. [7], it was found out that long particles rather than microscopic fibre particles make tougher, stronger and more dimensionally stable boards. The composite of the cement board is important as the strength of EFBCB is entirely dependent on the bonding between the fibre and the cement composite as a binder.

4. Conclusion

The results showed that there were differences in terms of the values in the mechanical properties between two different methods used which were hand forming and hand plus vibration forming method. The hand plus vibration forming method with different duration of vibration were being analysed. There were one, two and three minutes of vibration. The hand plus the second minute vibration showed the highest values of each mechanical properties. This may highly due to the equally density distribution throughout the sample board. Another reason for it may due to the consolidation of the EFBCB composite aided by the vibration table machine which resulting in improved mechanical properties [10].

The one-minute vibration may be too low in terms of duration for it to equally distribute the density while the three minutes duration may be too long for the density to be equally distributed. The mechanical properties of MOE and MOR have complied to the standard used. However, the result of IB did not achieve the minimum requirement although the value in hand plus 2 minutes vibration was still accepted as the value was nearest to the minimum requirement of BS EN 634-2:2007. There were some recommendations that need to be done in order to achieve the minimum requirement in terms of mechanical property of IB.

Therefore, the hand forming plus two minutes of vibration method was being proposed in the fabrication process of EFBCB that contributed to optimum mechanical properties in terms of MOE and MOR of the sample.

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