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Development of Oil Palm Empty Fruit Bunch Cement Boards Based on Forming Technique

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Abstract

The utilization of OPEFB, an abundant agricultural waste from the palm oil industry, as a raw material in cement boards contributes to sustainable waste management practices and reduces reliance on traditional wood-based materials. This research project focuses on the development of oil palm empty fruit bunch (OPEFB) cement boards using 2 method which is manual forming and vibration forming but three different techniques which is two-layer forming method, hand-manual forming with a three-layer but one compaction method as a controlled method and also the vibration technique. The study begins by collecting OPEFB fibers from local palm oil mills and processing them to obtain suitable fiber density, 1300kg/m3, dimensions which is 350mm x 350mm x12mm and moisture content with 40%. The fibers are then mixed with cement and water to form a composition mixture. Three techniques are employed to shape the cement boards. In the controlled method which is the hand-manual forming with three layers but one compaction method, the fibre is evenly distributed three times into the mould using sieve and it is compacted once to form the shape, whereas the two-layer forming method is where the fibre is divided into 2 and then it is evenly distributed and first compaction is done and then the remaining fabricated mould will be even distributed again and the second compaction will be done. Conversely, the vibration technique involves using a vibrating table to ensure even distribution of the composition mixture within the molds, resulting in more consistent board properties. The produced cement boards are subjected to a comprehensive set of tests to evaluate their physical and mechanical properties, including density, thickness swelling, Modulus of Rupture, Modulus of Elasticity and also internal bonding. Comparative analyses are conducted to assess the differences in performance between the hand-formed and vibration-formed boards. At the end of this research, according to the data collected from the test, the two-layer forming method has given the best results in both mechanical and physical properties.

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1. Introduction

Cement boards, thin concrete layers composed of cement, glass, aggregate, and fiber reinforcements, find extensive use in construction for reinstalling ceramic, stone, or wooden surfaces in backsplashes, countertops, and flooring (S. P. Raut & RV. Ralegaonkar & S. Mandavgane, 2011). Ranging from 762 mm to 1524 mm, these tile backer boards are secured to wood or steel studs for vertical applications and plywood for horizontal ones. With enhanced impact resistance and strength compared to water-resistant gypsum boards, cement boards serve as a foundation for exterior plaster systems and can be used as finish systems. When tiling, cement board reinforces the subfloor, offering flexibility for both indoor and outdoor applications with wood or steel studs. Despite quick drying times and water resistance, a vapor barrier is recommended for protection against corrosion and mildew on underlying studs (Timothy G. Townsend, 2023, Malak Anshassi, 2023). Installation involves attaching the board with ring-shank nails or drywall screws, leaving 1/8-inch gaps between boards for thermal expansion. For ceilings above bathtubs, a quarter-inch gap is recommended for ventilation (Sadiq & Atoyebi, 2015). After installation, waterproof caulk or tape should be used to seal gaps between boards, and it's crucial to note that cement boards are suitable only in areas intended for tile or plaster applications. Oil palm, a significant oil source in West and Central Africa, Malaysia, Indonesia, and Thailand, produces empty fruit bunches (OPEFB), posing environmental threats (Nattaya & Thapat, 2019). With global EFB output reaching 22.4 million tons in 2014, eco-friendly disposal and utilization strategies are crucial. OPEFB, rich in cellulose, has potential in papermaking, where 5 tons yield 1 ton of pulp (Akpan Sunday Noah, 2014). Malaysia, a major biomass provider, produced 5.2 million tons of EFB in 2002. By exploring EFB fiber morphology, chemical qualities, papermaking potential, and environmental impact, this chapter aims to promote sustainable disposal and value-added product creation from biomass leftovers (Pooja Singh & Othman Sulaiman, 2012). OPEFB, as an alternative to traditional fibers, can contribute to waste-to-riches transformations and environmental improvement in Malaysia and Indonesia.

1.1 Findings of Research on Natural Fibers Reinforcements

Studies of natural threads' qualities have shown that they can be used for a wide range of things. Flax, hemp, jute, cotton, and sisal have all been looked into. Natural fibres are better for the earth because they break down quickly. Researchers found that some natural fibres last a lot longer than other kinds of materials. Natural fibres might make clothes comfier because they can breathe and get rid of wetness. Studies have shown that natural fibres can help control temperature and protect in a variety of situations. The chemical makeup and structure of natural fibres have made them useful in many industrial uses, such as making paper and reinforcing composites. Natural materials have been shown to have a lot of good traits, which means they can be used in many different businesses. Table 2.1 shows the previous research which has been done on natural fibres with different type of natural fibre and different type of method test.

In the realm of textile applications, various natural fibers undergo comprehensive characterization to assess their suitability and performance. Cotton, investigated by Kumar, Anandjiwala, and Rajeshkumr, is analyzed using a high-volume instrument (HVI) and a tensile tester. The findings highlight its softness, breathability, high moisture absorption, and overall comfort when worn. Flax, as studied by R. Baley, exhibits robust mechanical properties, with tensile strength and modulus evaluated according to ASTM D3039 standards. It proves to be strong, durable, absorbent, quick-drying, and resistant to pilling and abrasion.

Hemp fibers, as explored by V. Fiore, L. Fiorillo, and L.A. Utracki, undergo chemical treatments and are assessed for flexural properties using a three-point bending test as per ASTM D790 standards. The results showcase hemp's strength, durability, resistance to mold, bacteria, and UV light, along with good moisture absorption and breathability. Jute, scrutinized by M. B. Hossain, M. F. Fuad, and M. A. Islam, exhibits coarse strength, good insulating and anti-static properties, and affordability, while being biodegradable. Additionally, sisal, studied by F. M. S. Silva, I. B. Sena, and L. M. R. Beraldo, displays stiff and strong characteristics, excellent durability, and abrasion resistance.

Wool fibers, investigated by H. S. Kim, S. J. Lee, and J. H. Park, are characterized for fineness, staple length, and crimp properties using methods like the airflow method and image analysis. Wool emerges as resilient, elastic, warm, insulating, moisture-wicking, and breathable. Bamboo fibers, analyzed by R. H. Wu, X. G. Luo, and F. Wu, are mechanically tested for tensile properties, revealing high breathability, lightweight, softness, and rapid growth as defining features. Lastly, empty fruit bunch (EFB) fibers, examined by M. A. Mannan, M. S. Islam, and M. R. Islam, contribute to concrete reinforcement with low density, proper moisture content, and abundance as notable advantages, as assessed through compressive and flexural strength tests according to ASTM standards.

2. Experimental Work

This research involves five key tests conducted on a total of nine samples, comprising six samples of size 350mm x 350mm x 12mm and three control samples. The tests include the evaluation of Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Impact Resistance (IB), Density, and Thickness Swelling. For MOR and MOE testing, the samples are subjected to bending stress to determine their flexural strength and stiffness, respectively. Impact resistance (IB) is assessed to understand the material's ability to withstand sudden forces. Density testing provides insights into the mass per unit volume of the material, while Thickness Swelling examination gauges the extent to which the material expands under the influence of water. These five tests collectively offer a comprehensive assessment of the mechanical and physical properties of the samples. The study includes 9 samples sized at 350mm x 350mm x 12mm with three different forming technique where 1st is control method, followed by

Table 1 *Design mixture of EFBCB*

Density	13000kg/m3
Volume	1.47 x 10-3 m3
Type of Treatment	Hot Water Treatment (90̊c)
Fibre per sample	424.7g
Cement	1274 g
Water	637g

2.1 Material Preparation

EFB fibers are dried for 2-3 days using methods like sun drying, hot air drying, or rotary dryers to achieve less than 10% moisture. In this research on transforming Empty Fruit Bunch (EFB) fibers into cement board, raw materials were sourced from a company in Kluang, Johor. The manufacturing process involved hammer milling to reduce EFB fiber size, followed by screening to separate fibers based on particle size. Fiber pre-treatment, specifically hot water at a constant temperature, aimed to enhance characteristics. Drying for 24 hours in the sun and then in an oven at 100 degrees Celsius for an additional 24 hours minimized moisture. Various studies emphasized these processes for their significant impact on final mechanical attributes. The complex procedure is outlined in Figure 3.5 (Dullah, 2019).

(a) (b) (c) (d)

Fig. 2 *Preparation of samples (a) Sundry Process, (b) Shredding Process, (c) Hot Water Treatment Process, (d) Oven dry Process*

2.2 Moulding Process

In the fabrication process of EFB cement boards, nine samples sized at 350mm x 350mm x 12mm and with a target density of 1300kg/m3 are produced following guidelines from the Wood Fabrication Laboratory, FKAAB, UTHM, and insights from prior research. The process begins with precise weighing of components, Fiber, cement, and water based on calculated ratios for all samples using a laboratory weighing scale. The mixing phase involves a cement/fiber ratio of 3.5:1, with EFB fibers mixed for 2 minutes before gradually incorporating water and cement, followed by a 10-minute blending period. Molding is done through two methods: Hand Manual Forming, where materials are evenly distributed in a wooden block and manually pressed, and Vibration or Vibro-Compaction, employing a vibration machine for uniform dispersion. The compaction process utilizes a hydraulic press to compress EFB fibers, reducing volume and enhancing density until the desired thickness is achieved. After the cement board is formed, curing of 28 days has been controlled inside the laboratory and later, cutting process has been made according to the size of the cement board need to be tested.



(a) (b) **(c)**



(d) **(e)** **(f)**

Fig. 2 *Moudling Process (a) Fabrication Process, (b) Spreading Fibre , (c) Hand Manual Forming Method, (d) Vibro-Compaction Method (e)Compression (f)Curing*

2.3 Physical Properties

2.3.1 Density

According to British Standards, figuring out how dense cement board is requires following specific guidelines outlined in the relevant standards. Referring to BS EN 323:1993, it states that the minimum density should be 1000kg/m3 or more. The purpose of this test was to check how well it maintains its size. The formula for the test is given in Equation (1) below:

$$\text{Density, p} = \frac{m}{v} \quad (1)$$

where m is mass, and v is volume.

2.3.2 Thickness Swelling

For this task, the primary standard used is BS EN 317:2005, which typically measures the increase in thickness after immersing the material in water with maximum of 1.5%. Due to the specific physical traits of cement board, a thickness swelling (TS) test was conducted. The aim of this test was to assess how much water the sample absorbed after a curing period of 28 days. The thickness swelling values are calculated using the formula provided in Equation (2) below:

$$\text{Thickness Swelling, TS} = \frac{t2-t1}{t1}\ x\ 100\% \tag{2}$$

where t1 is the thickness before being immersed, and t2 is the thickness after being immersed

2.4 Mechanical Properties

2.4.1 Modulus of Rupture

After the curing process, the bending sample was utilized as instructed, and its mechanical properties, including MOR (Modulus of Rupture), were assessed using BS EN 310 (1993) with a minimum range of 9N/mm2. A static bending test was conducted to determine the maximum load applied to the center of the simply supported specimen. The MOR values can be obtained using the equation presented in Equation (3) below:

$$\text{MOR} = \frac{3WL}{2bt^2} \tag{3}$$

where W is the maximum load, L is the distance between the center of support, b is the width of the test piece, and t is the thickness of the test piece.

2.4.2 Modulus of Elasticity

After the curing process, the bending sample was employed as instructed, and its mechanical properties, including MOE (Modulus of Elasticity), were evaluated using BS EN 310 (1993). A static bending test was conducted to determine the maximum load applied to the center of the simply supported specimen. The dimensions of the specimen to be measured are 300 mm x 50 mm x 20 mm. The MOE values can be obtained using the equation provided in Equation (4) below:

$$\text{MOE} = \frac{L^2\,\Delta W}{4bt^3\,\Delta S} \tag{4}$$

where L is the distance between the center of support, ΔW is the increment load, ΔS is the increment of deflection at the midpoint corresponding to ΔW, b is the width of the test piece, and t is the thickness of the test piece.

2.4.3 Internal Bonding

By referring to British Standards Institution BS 1881: Part 116: 1983 the compressive strength was tested with value not less than 0.5N/mm2. The compression test was conducted by using compressive test machine at the Fkaab Laboratory, University Tun Hussein Onn. The IB values can be found using equation (5) below:

$$\text{IB} = \frac{p}{wl} \tag{5}$$

Where p is the peak load or maximum load, w is width od the sample and l is the length of sample

3. Results and Discussion

3.1 Physical Properties

3.1.1 Density

The study's findings illustrate the differential influence of different forming processes on the density of cement boards. It is clear that the cement board treated to a 2-layer forming method has the maximum density, measuring 1021 kg/m3. Meeting the specified standard density of 1000 kg/m3, all three samples using various forming procedures attained the desired density values. Notably, the controlled approach produced the second-highest density at 1005 kg/m3, while the vibration method, although being the least successful of the three, satisfied the stipulated density requirement with a value of 1002 kg/m3.

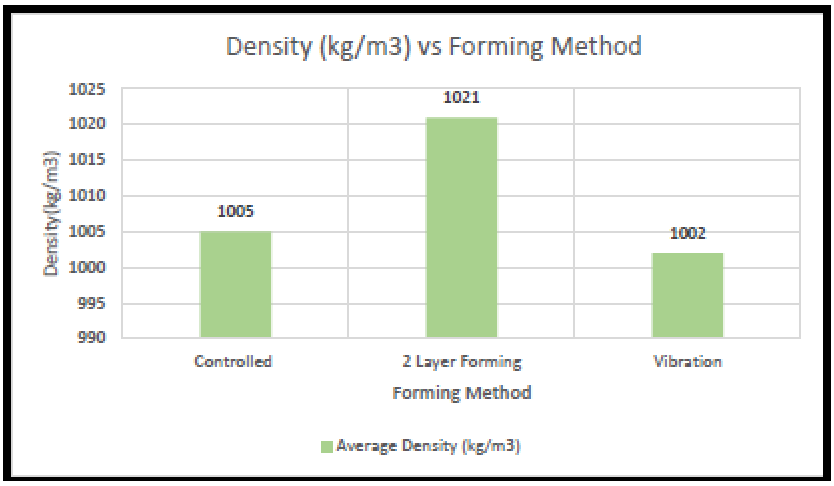

Fig. 3 *Average density of the samples against Forming Method*

3.1.2 Thickness Swelling

Based on the result that has been stated in Table 4.2 and figure 4.2, the average of thickness swelling in percentage of 2 layer forming method shows the least among all the three methods followed by the vibration method with 2.01% and followed by the controlled method 2.56%. Based on the natural fibres, the least the total amount of thickness swelling, the better the fibre to be use as a product. The British Standard requirement to pass the thickness swelling test is to be less than 1.5% hence according to the British standard, 2 layer forming method only has passed this test whereas the controlled method and the vibration method has failed to reach the minimum requirement.

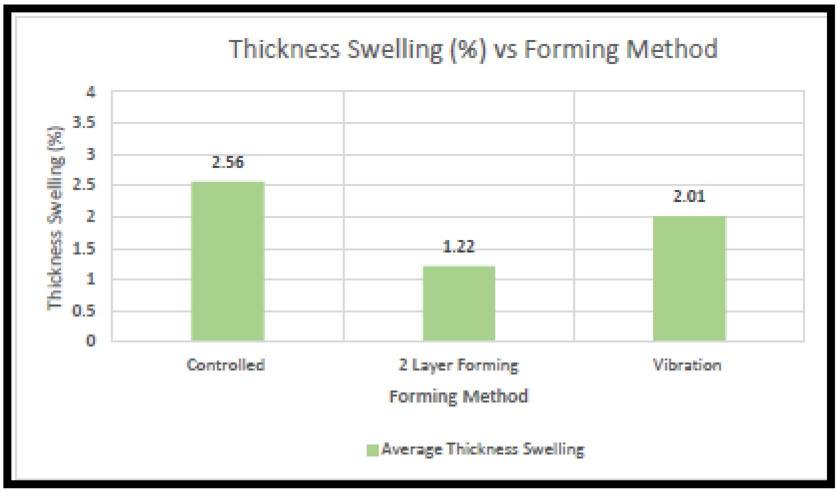

Fig. 4 *Average thickness swelling of the samples against Forming Method*

3.2 Mechanical Properties

3.2.1 Modulus of Elasticity

The study investigated the impact of various forming processes on Modulus of Elasticity (MOE) values (Table 4.4, Figure 4.4). The 2 Layer Forming Method yielded the highest MOE at 4581 N/mm2, indicating a substantial increase in material stiffness. The Controlled Method produced a modest MOE of 4096 N/mm2, falling between the 2 Layer Forming and Vibration Methods. The Vibration Method had the lowest MOE at 2626 N/mm2, suggesting a potential decrease in material stiffness. These findings underscore the significant influence of the forming process on material properties, emphasizing the importance of method selection based on specific material requirements.

British Standard BS EN 310:1993 defines two classes for MOE testing: Class 1, with a minimum requirement of 4500 N/mm2, and Class 2, with a minimum of 4000 N/mm2. Analysis revealed that the 2 Layer Forming Method surpassed Class 1 standards, achieving a notable MOE of 4581 N/mm2, indicating stiffness exceeding the higher criteria. The Controlled Method met Class 2 standards with a MOE of 4096 N/mm2. Both methods aligned with British Standards, demonstrating their efficacy in achieving desired material properties. However, the Vibration Method fell short, with an MOE of 2626 N/mm2, failing to meet the minimum British Standard requirement.

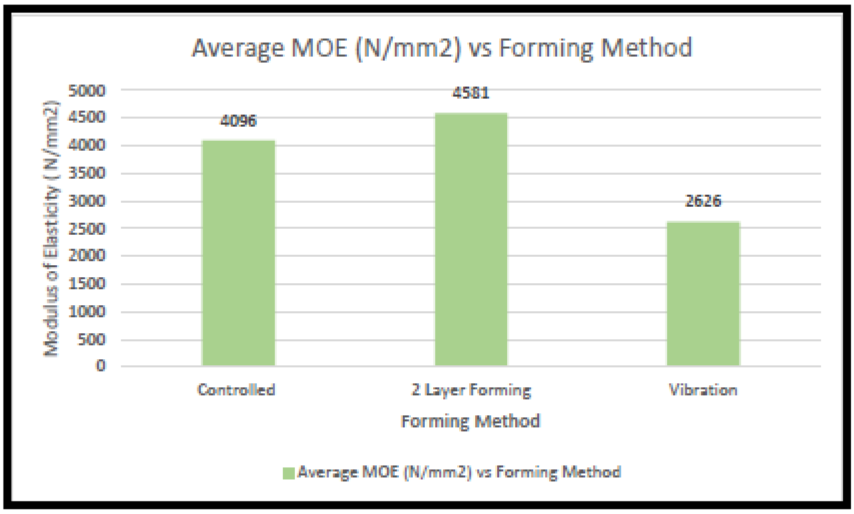

Fig. 8 *Average modulus of elastic of the samples against Forming Method*

3.2.2 Modulus of Rupture

The study reveals significant variations in Modulus of Rupture (MOR) values among different forming processes. The 2-layer forming technique stands out with the highest MOR value at an impressive 6.217 N/mm2, while the controlled forming process demonstrates a substantial but intermediate strength at 3.055 N/mm2. In contrast, the vibration approach yields the lowest MOR value of 2.644 N/mm2, underscoring the distinct impact of forming processes on the structural integrity and strength of cement boards, with the 2-layer forming approach outperforming others.

In compliance with BS EN 319:1993, the MOR strength test requires a minimum value of 9 N/mm2 or above. Unfortunately, the MOR values from the three forming processes fall short of this standard, revealing a significant deficiency in meeting the mandated MOR strength. Additionally, Norul et al.'s 2013 study observes that subjecting a single filament of Empty Fruit Bunch (EFB) fiber to boiling water at 90°C leads to ripping, twisting, and eventual breaking. This suggests that high-temperature hot-water treatments may compromise EFB fiber's mechanical characteristics, leading to fractures with substantial splitting and fibrillation. The presence of cracks or cavities within the cement board further disrupts stress and strain transmission, contributing to the lower MOR values observed. This detailed examination underscores the challenges in meeting BS requirements and maintaining the structural integrity of cement boards across various forming

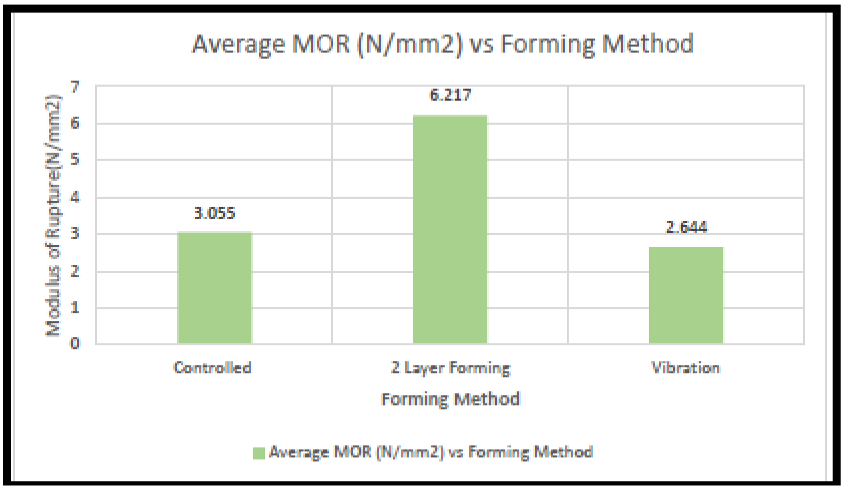

Fig. 9 *Average modulus of rupture of the samples against Forming Method*

3.2.3 Internal Bonding

The study reveals variations in internal bonding strength based on the forming procedure. The 2 Layer Forming Method stands out with the highest internal bonding value at 0.2615 N/mm2, indicating superior ability to handle internal stresses. The Controlled Method follows closely with a notable internal bonding strength of 0.1365 N/mm2. In contrast, the Vibration Method records the lowest internal bonding strength among the techniques at 0.0466 N/mm2, suggesting limited efficacy in enhancing this specific mechanical attribute.

In accordance with the British Standard outlined in Table 4.5, the minimum requirement is a value of 0.5 N/mm2 for internal bonding strength. Unfortunately, all three forming methods fall short of meeting this standard, highlighting a deficiency in achieving the required internal bonding strength. Furthermore, research by M A Mannan in 2020 indicates that the aging of fibers can significantly impact MOR, MOE, and internal bonding readings. Older fibers tend to result in lower internal bonding values, potentially contributing to the observed lower readings in internal bonding strength in this study.

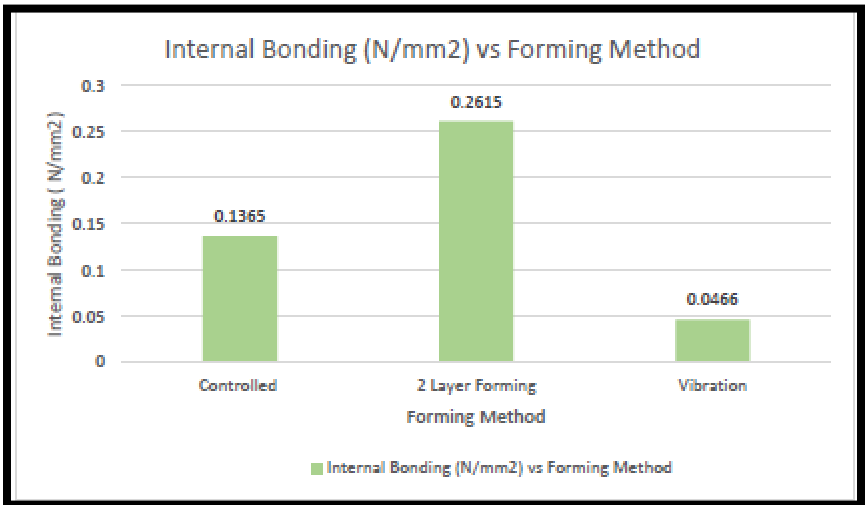

Fig. 9 *Average internal bonding of the samples against Forming Method*

4. Conclusion

Based on the primary objective of this research which is to investigate the potential of Oil Palm Empty Fruit Bunch Fibre as Cement Boards Reinforcement, it is proved as a general view that Oil Palm Empty Fruit Fibre can make cement boards stronger, and it appears to work effectively. In general, it has been demonstrated that employing this fibre from the empty fruit bunch of the oil palm plant can significantly strengthen cement boards. There were various previous studies has proven the capabilities of this Oil Palm Empty Fruit Bunch Fibre as Cement Boards Reinforcement. However, in order for this notion to work well, we must employ a variety of techniques and make particular alterations to strengthen the cement boards as a whole. After experimenting and analysing the data, it appears that the qualities of Oil Palm Empty Fruit Bunch Fibre are beneficial for making cement boards stronger. However, in order to achieve the finest results, steps must carefully consider how the steps has proceed. As moved on to the second objective of this research which is to determine the effect of cement boards forming techniques on physical and mechanical properties, there were three methods which has been carried out in this research which is the controlled method, two layer forming method and also the vibration method. Based on the test that has been carried out, including the physical and mechanical test such as density test and thickness swelling test, the value of the two-layer forming method has given the best results compared to the other two methods. Meanwhile, based on the mechanical test which is MOR, MOE and IB, the results of all the three test gives the highest results on the two layer forming techniques. This proves that the strength of the EFB cement board with 2 layer forming techniques is the highest.

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