RECENT TREND IN CIVIL ENGINEERING AND BUILT ENVIRONMENT
e-ISSN: 2773-5303

RTCEBE

Vol. 6 No. 1 (2025) 53-63
https://publisher.uthm.edu.my/periodicals/index.php/rtcebe

Study of Dimensional Stability of Oil Palm Empty Fruit Bunch Cement Boards Based on Different Temperatures in Hot Water Treatment

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DOI: https://doi.org/10.30880/rtcebe.2025.06.01.006

Article Info

Received: 8 January 2024
Accepted: 15 April 2024
Available online: 6 May 2025

Keywords

Empty Fruit Bunch (EFB), Empty Fruit Bunch Cement Board (EFBCB), Hot Water Treatment, Dimensional Stability

Abstract

Malaysia's prominent status as a major oil palm producer results in the generation of substantial quantities of empty fruit bunches, leading to significant agricultural waste. In this context, Oil Palm Empty Fruit Bunches (OPEFB) emerge as a promising natural fibre reinforcement for cementitious materials. OPEFB exhibits superior physical properties, positioning it as an excellent alternative to wood for reinforcing cement boards. This substitution holds the potential to mitigate the demand for forest resources, thereby promoting sustainability. However, the hydrophilic nature of EFB fibres directly influences the dimensional stability of cement boards, with higher fibre hydrophilicity correlating to decreased dimensional stability. This study aims to investigate the impact of different hot water treatment temperatures on the dimensional stability of EFB fibres and evaluate their consequent effects on the physical and mechanical performance of EFB fibre cement boards. The hot water treatment temperatures employed in this research are 80°C, 90°C, and 100°C, with a treatment duration of 3 hours. The target density for the produced cement boards is set at 1300 kg/m^3, utilizing a cement-to-fibre ratio of 3.5:1. A total of nine samples will be fabricated, comprising three samples for each treatment temperature. Based on comprehensive physical property tests, the findings reveal that increasing the treatment temperature negatively impacts the bonding between EFB fibres and the cement matrix. Consequently, the physical properties of the resulting EFBCB exhibit a decline. Moreover, there exists a direct proportional relationship between the treatment temperature and the mechanical properties of EFBCB, with higher temperatures resulting in reduced strength. Ultimately, this study demonstrates that as the treatment temperature increases, the dimensional stability of EFBCB becomes increasingly compromised.

1. Introduction

According to Sanagi, (2018), each year the number of abundant palm oil residues increases. Malaysia produced 99.85 million tonnes of fresh fruit bunches (FFB) in 2011 compared to 97.38 million tonnes the year before. Therefore, over 23.8% of the tonnes of fresh fruit bunch (FFB) are produced from empty fruit bunches (EFB). Palm oil production increases continuously each year just to fulfil global market demand. 17.7 million tonnes of palm oil are produced in Malaysia and there is 4,500,000 ha of land used in Malaysia for palm plantation (Nor *et al*., 2021). Malaysia and Indonesia dominate vegetable oil worldwide which is counting 35 million tonnes of crude palm oil (CPO) in the year 2010 (Dashti *et al*., 2021).

Empty fruit bunch (EFB) is one of the natural fibres that can be utilized. A type of biomass produced during the process of producing palm oil is known as an empty fruit bunch (EFB). The by-product of palm oil milling will be collected and sundried and will undergo several processes before being mixed with cement to produce a cement board. The plantation of oil palm is the biggest agriculture business (Derman *et al*., 2018).

Cement boards are synonyms in the construction industry. A cement board is a simple-to-produce building material. This building material has been utilized in the construction industry since the beginning of the century (Tomasz *et al*., 2020). A cement board is a combination of fibre and cement which is made with a certain ratio. There are many uses of cement board in the construction industry such as tile backing board, exterior wall cladding, floor, and roof tiles etc. This building material has a good durable and moisture resistant that able to prevent cracking to occur. Besides, resisting mould, water and fire also is one of the superiorities of cement board also making it a choice in the industry (Younesian *et al*., 2019).

Empty fruit bunch cement board is one of the efforts toward green building and achieving sustainability in construction. By using empty fruit bunches in cement board, we will be able to reduce dependency on wood fibre which can indirectly reduce forest exploration. According to Maynet *et al.,* (2021), the main material in cement fibre board which is wood fibre has been replaced with oil empty fruit bunch (OPEFB) fibre. The replacement happened to reduce and minimize the demand for forest resources which is not good for the sustainability of wood. Since cultivation and use of oil palm are in high demand in Malaysia, this will thus cause abundant availability of the empty fruit bunch (EFB). According to Onuorah *et al*., (2015), similar chemical constituent and morphological properties which makes oil palm empty fruit bunch (OPEB) fibre and tropical hardwood sawmill residue are suitable substitutes.

1.1 Relevant previous studies

Plant-based natural fibres are good for sustainability in construction material usage. It is because the source is renewable resources. These resources are low-cost renewable materials which can be abundant and readily available in most countries. Not all fibres that are available are suitable to be a reinforcement agent. . Previous studies found that cementitious materials are highly suitable to pair together with plant fibre. Since natural fibres have a lot of benefits in terms of strength, cost and sustainability, natural fibre is a great choice to use in construction material (Onuaguluchi & Banthia, 2016).

Previous study shows that hot water treatment on natural fibre is able to improve dimensional stability. The study shows that hot water treatment is capable to extract hemicellulose from the natural fibre. The higher the temperature of hot water treatment, the better the dimensional stability of cement board (Hosseinaei *et al.,* 2012). Fibre's physical properties are primarily influenced by the amount of available OH groups in hemicellulose. Hemicellulose is a substance that are attracted to water and this will cause the dimensional stability of the cement board will decrease. To prevent these substances from disrupting dimensional stability, hot water treatment is capable to reduce and minimize the presence of hemicellulose in the fibre. The longer the fibre is treated with hot water, the better the fibre in terms of thickness swelling and water absorption (Ozdemir *et al*., 2014).

Dimensional stability is a quality of materials that may affect other properties including mechanical, electrical, and physical performance. There are several factors that influence dimensional stability of cement board such as density, fibre loading, shrinkage properties, thickness swelling and total moisture content (Taib & Julkapli, 2019). Treatment towards fibre will give a significance result towards dimensional stability of cement board. Previous study found that treated fibre in cement board have a better strength compared to untreated fibre. This is because, throughout the treatment of boiling water, the hydrophilic substances is able to issue which it will improve the dimensional stability. The finding of the study was boiling water are better in tesile strength test, cross sectional area and axial strain compared to untreated fibre (Momoh *et al*., 2020).

Previous study shows that increasing the pressing temperature of EFBCB can increase the dimensional stability of the cement board. To know the effect of pressing temperature on the dimensional stability of the cement board, previous researchers produce two different density samples which are medium density and low density. Both densities show improvement in Thickness Swelling (TS) due to the increase in pressing temperature on the cement board. The value of the compress of the sample shows a higher value of MOE and compressive strength compared to the original coconut wood (Srivaro *et al*., 2022).

2 Materials and Methods

2.1 Materials Preparation

Empty fruit bunch is an organic composite from the results of the production process of palm oil. This empty fruit bunch is a waste product from the factory and is no longer used. This waste were used for reinforcement in cement boards. EFB will go through several processes before it is ready to mix with the cement mixture. Empty fruit bunches that have been obtained from the factory need to be sun-dried to make sure that there a no moisture left in the EFB fibre. The EFB fibre were laid on the canvas and arranged uniformly to make sure all the EFB fibre is sundried equally. The EFB fibre was shreded and hammer mill to obtain required size of fibre for fabrication. After the shredding and hammer mill process, EFB fibre was sieve to make sure there are only fibre is retained not the dust. Separating the dust from the fibre is important to make sure that the fibre is in optimum condition as reinforcement in EFBCB. After that, the hot water treatment was conducted on the EFB fibre. This study was focus on several temperatures which are hot water for 80^{o}C, 90^{o}C, and 100^{o}C for 3 hours. By doing so, were be able to observe which temperatures are preferable in terms of stability of dimension. Sundried is needed after the EFB fibre was done treated. The EFB fibre needs to spread out on the canvas until it is fully dried. The EFB fibre should be arranged uniformly to optimize the sun-dry process. After the 3 hours of hot water treatment, the EFB fibre was oven-dried at a temperature of 100°C for 24 hours to ensure the EFB fibre was fully dried.

Table 1 Design Mixture of EFBCB

Ratio	3.5:1 (Cement:Fibre)
Size Dimension of Sample	350 x 350 x12 (mm)
Dry weight	1911 (g)
Density	1300 (kg/m^3)
Total weight of dry EFB fibre	728 (g)
Weight of cement	1490 (g)
Weight of water	12134 (g

2.2 EFB Cement Board Fabrication

Fabrication of EFBCB needs to be done according to the required study. Wood Fabrication Laboratory, FKAAB, UTHM be a place to do fabrication and reference guidelines. This study were produced 9 samples for hot water treatment with different temperatures where 3 samples for 80^{o}C, 3 samples for 90^{o}C and 3 samples for 100^{o}C. The weight of EFB fibre, cement and water was determined. With the ratio of cement toward fibre was 3.5:1, the targeted density of the EFBCB was 1300 kg/m^3. Each material will be weighed on the weight scale. Material that has been weighted were proceed with the mixing process. This process was using a drum mixer to mix the EFB fibre and cement. Before the mixing process is carried out, the EFB fibre was wet for 2 minutes in the drum mixer. After wetting the EFB fibre for 2 minutes, the cement were added gradually. This mixing will continue for 8 minutes to make sure EFB fibre and cement was mixed well in the drum mixer. Next, the mixture were poured into a wooden mould. A 350 x 350 mm wooden mould used in this study. Material that has been mixed be poured in this 350 x 350 mm wooden mould to form an EFBCB. The mould was placed on a 400 x 600 mm reinforced steel plate with both sides (top and bottom) of pre-samples covered with a polythene sheet. The mixture of EFBCB poured into the wooden mould and were spread through wire mesh and flattened evenly in the mould. After the pre-compressing stage, the mixture is compressed by placing a plywood plate on top of it. On top of the preformed samples, a reinforced steel plate was placed over the wooden mould. The sample that has been clamped put in the press machine and compressed until the cement board reaches 12mm thickness (the allowable thickness for fabrication is ± 1). The reinforced steel mould needs to be de-clamped and were proceed with curing process for 28 days.

2.3 Mechanical Properties Testing

The sample that has been cut were went through several mechanical properties tests. The test consists of the Modulus of Elasticity (MOE), Modulus of Rupture (MOR) and Internal Bonding (IB) test. All the tests were follow the criteria of BS EN 324- 1:1993 and BS EN 31-1993. The minimum criteria for mechanical properties (MOE ≥ 4000N/mm^2, MOR ≥ 9N/mm^2, IB ≥ 0.5N/mm^2). The size of sample required for MOE and MOR testing was 300 mm x 50 mm. The size of sample required for IB testing was 50 mm x 50 mm.

2.4 Physical Properties Testing

Physical Properties Testing were include of Thickness Monitoring (TM), Density, Thickness Swelling (TS) and Water Absorption (WA) test. The sample that has been cut was underwent through physical characteristics test for EFBCB. The cement board were tested and following the standard from BS EN 324-1:1993, BS EN 323-1993 and BS EN 317:1993 for the test which was done. The size required was 50 mm x 50 mm

3. Results and Discussion

3.1 Effect of hot water treatment on Density of cement board

Figure 2 below shows the average graph density of sample for 80^{o}C, 90^{o}C and 100^{o}C. Based on the graph above, observation can be done by the trend of the density of EFBCB. The maximum density that can be reach was sample for EFBCB of 80oC of hot water treatment for 3 hours. 80^{o}C sample of EFBCB record the highest density with reading 1313 kg/m^3 compared to the other type of sample. The minimum density recorded for this test was on sample 100^{o}C of hot water treatment. The value for the lowest density recorded was 1297 kg/m^3.

Based on the test have been done, the higher the temperature treatment of fibre, the harder the sample to reach the optimum density of the cement board. The finding of this study is align with previous research. Based on finding of previous researcher, fibre with hot water treatment in high temperature good in mechanical properties but not in physical properties of EFBCB (Izani *et al.*, 2013). Conclusion for this test is EFBCB fibre treatment of boiling water for temperature of 80^{o}C for 3 hours is the best method in order to get the optimum density of EFBCB. According to BS 634-2:2007 this cement board is achieved the standard by exceeding 1000 kg/m^3.

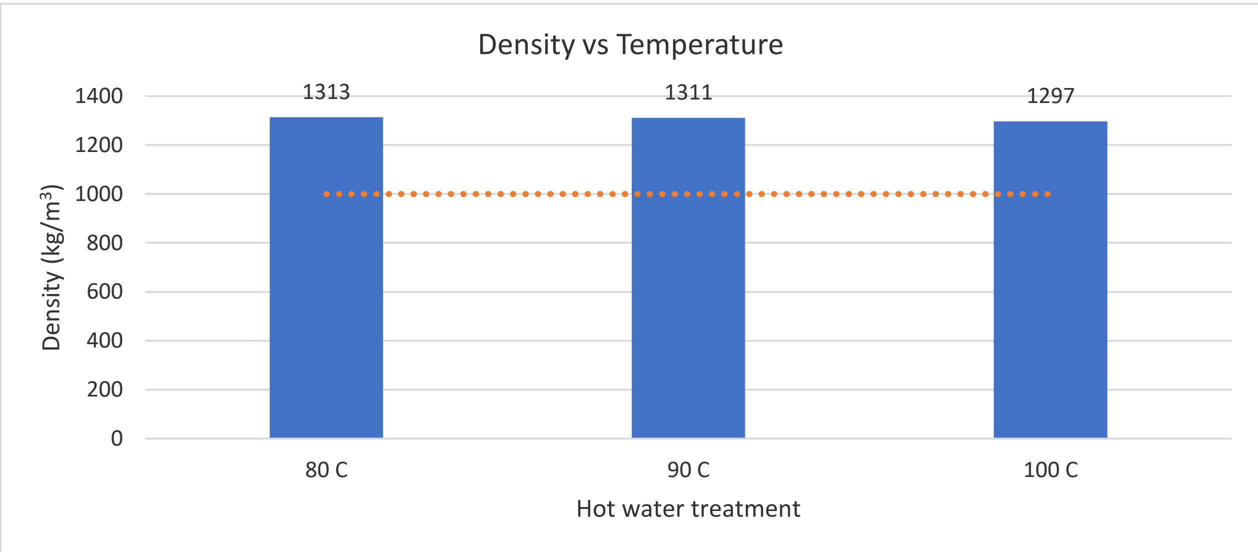

Figure 2: Density for sample 80^{o}C, 90^{o}C and 100^{o}C

3.2 Effect of hot water treatment on Thickness Monitoring (TM)

Based on the graph below observation can be made by referring to the graph. Based on the graph above, the sample for 80°C of hot water treatment had the best average thickness throughout the curing day. Throughout the curing day, sample of EFBCB at 80°C shows the most stable reading compared to the other sample. As the increases of curing day, the sample start to increase the reading of thickness start from day 2 and reach the maximum thickness on the day 26th day before the thickness drop on the last day of curing process. The sample for 80°C recorded the lowest value of thickness throughout the curing day which was average at only 13.14 mm. The lower the thickness, the better the dimensional stability.

The worst reading of thickness monitoring throughout the curing day based on the graph was EFBCB at 100°C of hot water treatment. This happened because of having hot water for 100°C for 3 hours damaged the fibre which will affect the bonding between the fibre and cement composite. Data of the EFBCB at 100°C of water treatment recorded unstable readings that go up and down throughout the curing process. The average thickness for EFBCB at 100°C of water treatment was 13.60 mm. Since the fibre not in the optimum condition, so the spring back effect will easily occurred in the EFBCB. This addition of the thickness happened called as spring back (SpB) development in the cement board itself due to the natural behavior of the empty fruit bunch fibre (Mohd *et al.*, 2022). This test was done by following the standard of BS EN 324-1:1993.

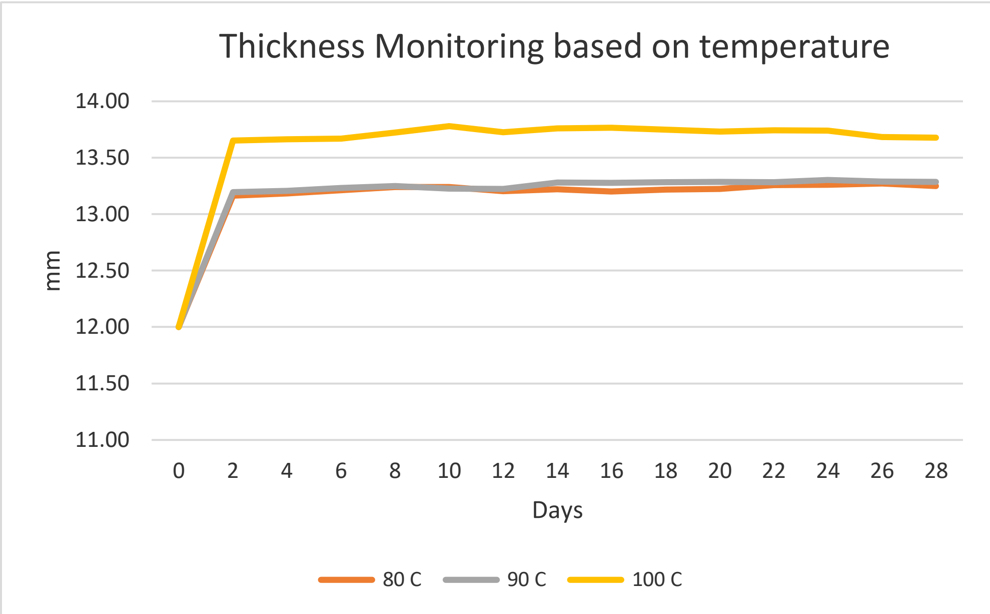

Figure 3: Thickness Monitoring (TM) for sample 80°C, 90°C and 100°C

3.3 Effect of hot water treatment on Thickness Swelling (TS)

Based on the graph below, observation of the Thickness Swelling (TS) can be made by referring to the graph. The trend of the cement board in Thickness Swelling (TS) was increased as the temperature of hot water treatment increased. The lowest thickness swelling occurred was on sample of EFBCB with 80°C of hot water treatment for 3 hours. The value for sample with 80°C was only 1.85 %. The highest Thickness Swelling (TS) occurred was on sample of EFBCB with 100°C of hot water treatment. The percentage of the thickness swelling for EFBCB sample for 100°C was 3.24 %.

This evidence shows that sample of EFBCB with 80°C of hot water treatment for 3 hours is the most stable in term of dimensional stability. Thickness Swelling (TS) directly proportional with the temperature of hot water is because the fibre start to damage as the fibre imposed too long on high temperature. Because of that, the water easily absorbed by the sample due to weak bonding between fibre and cement composite. According to Dewi *et al.,* (2023), high temperature of treatment towards fibre cause the fibre to damage. Based on BS 634-2:2007, all of the sample of Empty Fruit Bunch Cement Board (EFBCB) were not achieve the standard which was only 1.5 % of thickness swelling is allowed.

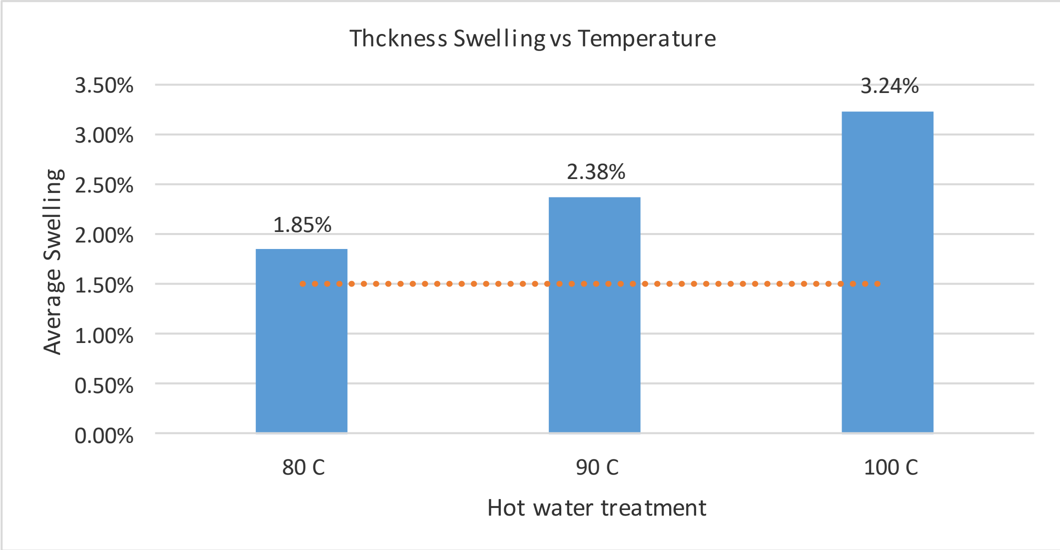

Figure 4: Thickness Swelling (TS) for sample 80ºC, 90ºC and 100ºC

3.4 Effect of hot water treatment on Water Absorption (WA)

Water Absorption (WA) test was conducted according to BS 5669-1979 standard. Each sample was cut into dimension of 50 mm x 50 mm x 12 mm. Based on the graph below, observation can be done by seeing the pattern of the graph. Based on the figure 5, the pattern of the graph for Water Absorption for sample of hot water treatment for 3 hours was increase. The highest value of the Water Absorption (WA) recorded on the sample for sample of 100ºC hot water treatment for 3 hours. Sample type of EFFBCB with 100ºC of hot water treatment for 3hours recorded 32.56 % rate of water absorption. The lowest value of Water Absorption (WA) recorded on the type of sample with 80ºC of hot water treatment for 3hours

The lower the rate of water absorption, the better the dimensional stability of Empty Fruit Bunch Cement Board (EFBCB). Based on the pattern of the graph, the lower the hot water treatment imposed on the fibre, the better the dimensional stability of the EFBCB. This is because of the structure of the fibre start to damage and brittle as the heat damage the structure of the fibre. This finding is align with previous research which have the same finding. Early research found that as the temperature of fibre treatment applied too high, the fibre will become more brittle and will affect the performance of the fibre. The consequence of that, the water will easily penetrate through the EFBCB due to the capillary effect and the lack of bonding between the fibre and cement composite as the fibre damaged (Zalinawati *et al.,* 2020).

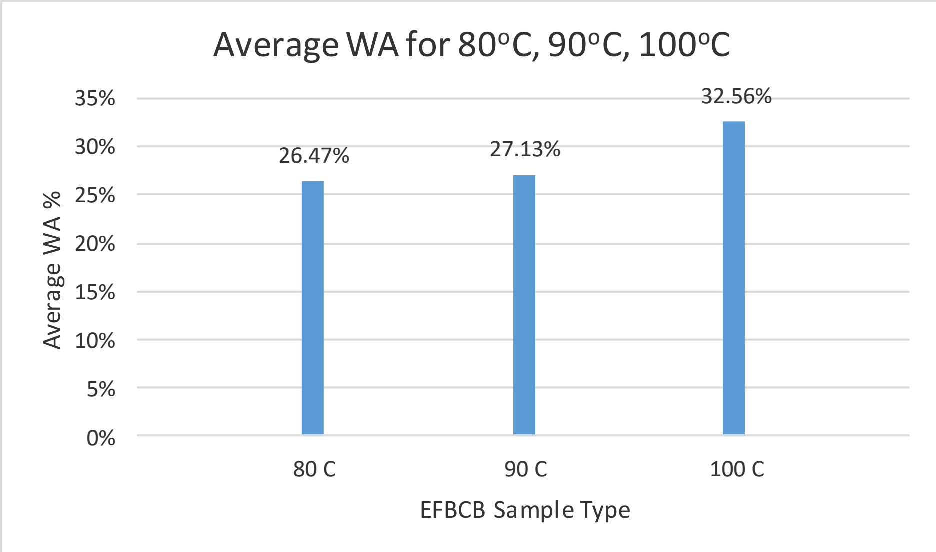

Figure 5: Water Absorption for sample 80°C, 90°C and 100°C

3.5 Effect of hot water treatment on Modulus of Elasticity (MOE)

Below are the average graph of Modulus of Elasticity (MOE) that have been recorded after the test was done toward the sample of EFBCB with different temperature for 3 hours. As the graph display, the lowest reading and finding of Modulus of Elasticity (MOE) recorded by type of sample EFBCB with hot water treatment with 100°C for 3 hours. Hot water treatment with 80°C for 3 hours recorded the highest value of MOE compared to other type of EFBCB. Sample of EFBCB with hot water treatment with 90°C for 3 hours recorded the second highest value in MOE which was 3909 N/mm^2 .The lowest reading and finding of Modulus of Elasticity (MOE) recorded by type of sample EFBCB with hot water treatment with 100°C for 3 hours.

The higher the temperature which is imposed on the fibre, the brittle the fibre are going to be. The reason of the value of Modulus of Elasticity (MOE) drop and decrease gradually as the temperature of hot water treatment increase are because of the structure of the fibre itself start to damage and brittle. Which mean that the elasticity of the sample will decrease gradually if the temperature imposed increase. Past researcher found that treatment with too high temperature will make the MOE drop. This is because the bonding between fibre lignocellulosic and cement are not bonding well as the temperature damaging the fibre (Aladenika *et al.,* 2016). According to the BS 634-2:2007, only EFBCB sample with 80oC of hot water achieve the minimum requirement to achieve class 2. EFBCB sample with 90°C and 100°C not reach the minimum standard as the situation of weak bonding between fibre lignocellulosic and cement.

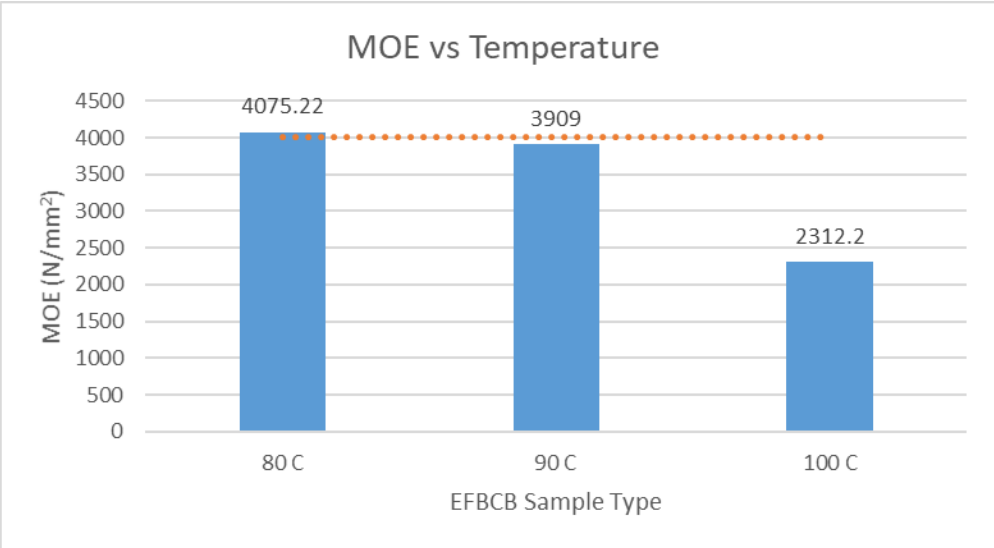

Figure 6: MOE for sample 80°C, 90°C and 100°C

3.6 Effect of hot water treatment on Modulus of Rupture (MOR)

Above are the average graph of Modulus of Rupture (MOR) that have been recorded after the test was done toward the sample of EFBCB with different temperature for 3 hours. As can the graph above, sample of EFBCB with hot water treatment with 80°C for 3 hours recorded the highest value of MOR with 6.61 N/mm^2 compared to other type of EFBCB. Sample of EFBCB with hot water treatment with 90°C for 3 hours recorded the second highest value in MOE which was 6.39 N/mm^2 .The lowest reading and finding of Modulus of Elasticity (MOE) recorded by type of sample EFBCB with hot water treatment with 100°C for 3 hours with value of 3.89 N/mm^2.

According to Abid *et al*., (2019), the weak bonding between cement and fibre happened because of the the fibre was damage due to too the high temperature imposed on the fibre. The fiber's structure is beginning to deteriorate and become more brittle, which is why the Modulus of Rupture (MOR) value gradually decreases as the temperature of the hot water treatment increases. The fibre will become more brittle as the higher the temperature that is applied to it. It indicates that if the forced temperature rises, the sample's strength will steadily diminish. Referring to BS 634- 2:2007, none of the sample was achieve 9 N/mm^2 which is the minimum requirement for MOR.

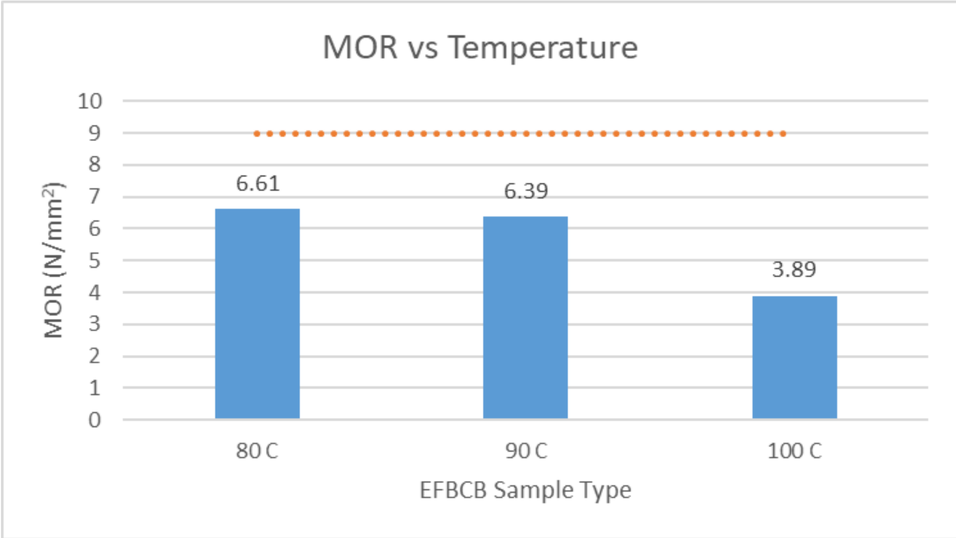

Figure 7: MOR for sample 80°C, 90°C and 100°C

3.7 Effect of hot water treatment on Internal Bonding (IB)

Figure 8 below display the average value of Internal Bonding (IB) for each type of EFBCB sample of hot water treatment for 3 hours. Based on the Figure 4.33, observation can be made with Sample with the lowest IB for this test was recorded on sample 100°C which only 0.5 N/mm^2. The second highest load that can be resist was EFBCB sample with 90°C hot water treatment for 3 hours. The highest value of Internal Bonding (IB) that can resist was sample with 80°C hot water treatment for 3 hours. EFBCB sample for 80°C recorded with 1.39 N/mm^2 load and make it the sturdiest sample that can support weight compared to the other type of sample.

Based on the pattern and finding Internal Bonding (IB) test that have been done, the conclusion that can be made was the ability of sample to resist load will decrease. The reason of this situation happened was because of the fibre in the sample lost the ability to resist load as the temperature imposed increase. Fibre imposed to high temperature for a long time will damage the structure of fibre and will affect the strength of the fibre. This finding was align with finding from previous research. Based on previous researcher, fibre will reach at an optimum strength by reduce the hydrophilic of nature in the fibre. One of the way to reduce the hydrophilic was using hot water treatment. However, the fibre will start to brittle when the fibre was imposed with at certain temperature (Momoh *et al.*, 2020). Based BS 634-2:2007, all type of EFBCB sample reach the minimum load which was 0.5 N/mm^2 .

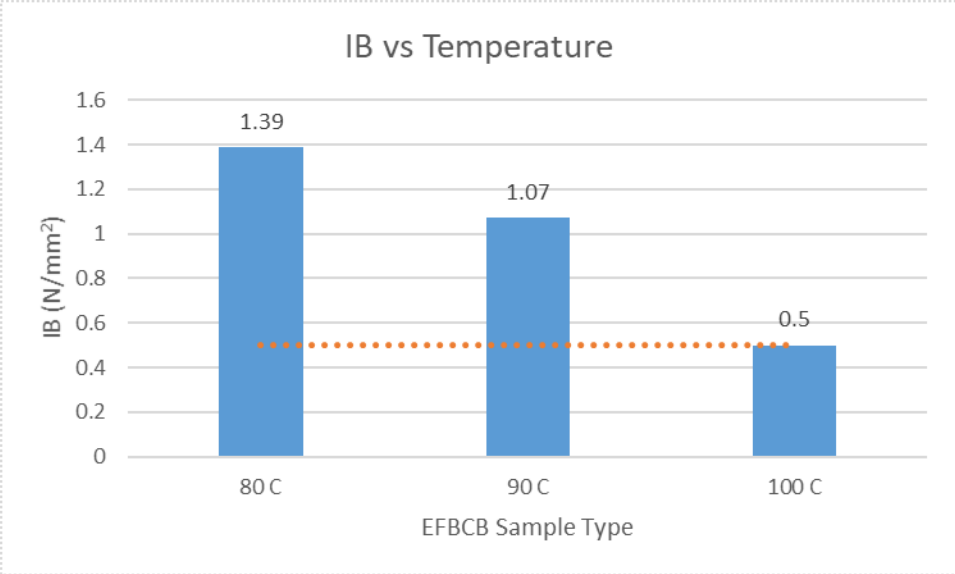

Figure 8: IB for sample 80°C, 90°C and 100°C

4. Conclusion

Based on the finding that recorded from the study, conclusion can be made by stating that high temperature with a long duration is not a good way to treat the EFB fibre. This is because the EFB fibre was not bonded well together with the cement in the EFBCB. The reason of the bonded was weak because of the EFB fibre itself start to damage due to the temperature that imposed on the EFB fibre for a long period. This was the reason which make the structure of the EFB fibre start to brittle. As the bonding between the EFB fibre low, it will affect the dimensional stability of the cement board. As can be observed based on the test that have been done, all test shows that the dimensional stability of EFBCB drop as the temperature of the treatment increase. All of the test shows that the higher the temperature of hot water treatment, the lower the workability of EFBCB based on physical properties. This situation is closely related to temperature received by the EFB fibre during the treatment. It is because the temperature was intrude the structure and damage the EFB fibre. All of the test on mechanical properties conducted shows the same trending which was the higher the temperature of the treatment, the lower the mechanical properties of the cement board. As the temperature of the hot water treatment goes high, the fibre will start to brittle due to the heat that damaged the structure of fibre. Due to that, the strength and bonding of EFBCB start to drop as the temperature raise

Acknowledgement

I would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) for give me a chance to succeed this research. Special thanks and gratitude to all those who contributed, both directly and indirectly, to the successful completion of this research.

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